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QUALITY AND RELIABILITY OF IFC/BIM MODELS FOR PUBLIC EDUCATIONAL FACILITIES CONSTRUCTION PROJECTS VIA CLASH DETECTION

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Abstract. This study investigates the reliability of monodiscipline IFC/BIM models in public construction projects of educational facilities through advanced clash detection and quantitative analysis. Data were collected from BIM models of two kindergartens and a school in Vilnius, Lithuania, representing different design disciplines. A mixed-methods approach was employed to analyse the number, types, and geometric characteristics of detected clashes. The research introduces innovative metrics, such as the Relative Quality Coefficient (RQC), Relative Uncertainty Coefficient (RUC), and Modified Relative Quality Coefficient (MRQC), to assess model quality and reliability quantitatively. The findings reveal a direct relationship between model complexity, clash detection precision, and the number of identified clashes, underscoring the importance of enhanced quality control measures in IFC/BIM models for public procurement. The study concludes that the implementation of these novel metrics can enhance the reliability of IFC/BIM models, thereby optimizing the design and construction process.

Keywords: IFC/BIM monodiscipline models, quality and reliability, building information modelling, clash detection, educational facilities, industry foundation classes, public construction projects.

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1. Introduction

Developments in informatics and computer technologies, alongside advancements in Building Information Modelling (BIM), are pivotal in the architecture, engineering, and construction (AEC) industry. BIM, a transformative tool within the industry, supports various processes across construction projects. It facilitates the creation of digital building models that are utilized throughout the entire project lifecycle (Patacas et al., 2020). Given the complexity of buildings, which encompasses architectural, structural, and various systems such as plumbing, electrical, and HVAC (heating, ventilation, air conditioning), BIM-based design, offering digital models instead of traditional 2D documentation, offers significant benefits. A primary expectation of adopting BIM in construction projects is the reduction of design errors and flaws (compare, e.g., Barnes & Davies, 2014; Eastman et al., 2011; Kasznia et al., 2018). This, in turn, is expected to reduce construction phase failures caused by design deficiencies. One of the processes greatly enhanced by BIM technology is clash detection (CD), also known as collision detection. This process aims to identify and rectify design errors, or at the very least, minimize their occurrence. These errors are recognized as potential sources of project failures, complications, delays, and cost overruns during the construction phase (compare, e.g., Wong et al., 2018; Czmoch & Pękala, 2014; Johansson et al., 2014).

The objective of this study is to present research findings on the reliability of monodiscipline BIM models in an open format of Industry Foundation Classes (IFC). The investigated IFC/BIM models are given as components of federated models developed for public construction projects of educational facilities. This study aims to establish quality and reliability metrics for monodiscipline IFC/BIM models through advanced clash detection and quantitative clash analysis. These metrics are designed to evaluate model quality and reliability effectively. Additionally, the research examines the interrelationships between BIM model disciplines, complexity, and reliability, using case studies from public construction projects in educational facilities. By introducing innovative methodologies, this study provides a new framework for assessing reliability across different disciplines, going beyond traditional approaches that focus solely on individual models or components. Through a multi-project analysis, this research this research extends beyond conventional case studies, proposing a comprehensive approach that enhances BIM practices and supports improved quality control in public procurement.

The paper comprises a literature review aimed at identifying research gaps, a concise discussion of background information to formulate research questions, an explanation of the applied methods and proposed approach, along with a brief presentation and discussion of the utilized data. Additionally, it includes an analytical section presenting the obtained results, a discussion of these results, and finally, concluding remarks.

The main highlights of the study are listed below:

- Highlight (1) – analysis of quality and reliability of IFC/BIM models for public projects of educational facilities.
- Highlight (2) – clash detection analyses for mono-discipline IFC/BIM models as components of federated models.
- Highlight (3) – quantitative analysis of clashes within IFC/BIM models and introduction of quality and reliability metrics.

2. Literature review

BIM is extensively discussed in the current literature, with its principles, fundamental applications, and expected benefits reviewed in works by authors such as Barnes and Davies (2014), Eastman et al. (2011), Kasznia et al. (2018), Kjartansdóttir et al. (2017) and Tomana (2016), among others. Some studies discuss the challenges, barriers, and risks of technology implementation (Azhar, 2011) and speculate on the future of BIM (Azhar et al., 2012). A specific area of focus within the literature is the process of clash detection (CD). Clash detection refers to the process of identifying and analysing clashes (also known as collisions), which can be defined as conflicts among various building elements or components within a digital model. Clashes occur when different elements, like structural, architectural, or mechanical, electrical, and plumbing (MEP) systems, occupy the same space or have conflicting locations and geometries that could cause adverse construction issues. It is widely accepted that CD is beneficial for minimizing design errors and improving the quality of BIM models in construction projects. The following subsections provide a structured review of the literature with a focus on the BIM-related and CD-related issues which are relevant for the study.

2.1. BIM and design quality considerations

The adoption of BIM technologies into design has led to the considerations and research into various aspects of quality and reliability in construction projects. In a study by Donato et al. (2017), a method is described for evaluating BIM processes and models through a BIM Quality Assurance (BIM-QA) approach supported by BIM Quality Control (BIM-QC) mechanisms. This method, validated through applications on several Italian healthcare projects, incorporates customized checklists and queries within a database management system to assess data quality and guide design solutions. Further examination of BIM's impact on design quality is discussed in Sadek et al. (2019), where a conceptual model highlights the role of BIM in enhancing information sharing and collaborative decision-making in construction projects. By evaluating the influences of BIM on functionality, form, aesthetics, and construction quality, the study emphasizes BIM's role in improving design standards. Another study by Choi et al. (2020) addresses the need for qualitative enhancements in BIM-based projects. The authors propose a set of BIM quality control requirements, organized by physical and logical data quality categories, to support more efficient quality management in architectural design. A rule-based checking system was developed as part of this study to ensure that quality standards are met through an automated process. In their research, Kovacs and Micsik (2021) present a BIM Quality Control Ecosystem that leverages Requirement Linked Data for automated compliance checking. By examining different types of project requirements, the study outlines a holistic quality management framework that emphasizes interoperability, automation, and data governance. Lastly, Jiao and Cao (2023) explore the potential of BIM to enhance project design management in China's construction sector. Their work presents a framework for integrating design and construction workflows within the BIM environment, advocating for a streamlined process that enables downstream participants to contribute during the design phase. All these examples clearly demonstrate that there is a need to further improve data quality aspects of BIM models which, among others, also concern clash detection issues.

2.2. Importance and adoption of clash detection in BIM

Numerous studies highlight the significance of the CD process in BIM-based construction projects. Some authors, such as Wong et al. (2018) and Czmoch and Pękala (2014), underscore the potential for reducing design errors and emphasize clash detection as a key advantage in the implementation of BIM within construction projects. According to research presented in Farnsworth et al. (2015), the use of BIM-based clash detection is recognized as advantageous for surveyed construction companies. The potential of automatic CD and its benefits for building projects is mentioned in the study of Koo and O'Connor (2022). Additionally, a research report by Johansson et al. (2014) investigates BIM's role in preventing design errors, highlighting the significant importance of the CD process. An intriguing aspect of the CD process is its national-level adoption in construction industries, such as advancements in specialized BIM tools for the Italian market (Trebbi et al., 2020). Reports from the Republic of Kazakhstan (Akhmetzhanova et al., 2022), Vietnam (Nguyen et al., 2020), and India (Raut & Valunkjar, 2017) also highlight discussions on adopting CD processes.

Some publications explore specific issues related to CD and its applications within BIM. For example, Tommelein and Gholami (2012) study focuses on the causes of clashes. Another work (Hjelseth, 2016) introduces a framework aimed at classifying model checking concepts. A taxonomy addressing design coordination issues, accompanied by an ontology defining relationships between physical, process, and model-based design aspects, is presented in Mehrbod et al. (2019a). Additionally, research by Akponeware and Adamu (2017) investigates coordination problems, root causes of clashes, and discusses concepts related to clash detection and avoidance. In another work, van den Helm et al. (2019) explore collision detection methods based on IFC/BIM models and IFC engine solutions.

2.3. Advancements in studies on clash detection

Research on the CD process covers a range of applications, including the examination of collisions between particular elements in digital models. The study by Chidambaram (2020) addresses challenges related to the modelling of reinforcement in structural building elements. Another work by Luo et al. (2022) presents an analysis of BIM's use in establishing an evaluation framework for underground pipeline clash detection. his framework includes clash type definition and analysis, clash-rule development, BIM clash detection, rule evaluation, irrelevant clash filtration, and coordination. Further research by Han et al. (2012) explores BIM-based clash detection between building facility pipes and ducts, highlighting the advantages of virtualizing construction to enhance engineering and design quality and efficiency. Leite et al. (2009) addresses coordination problems in mechanical, electrical, and plumbing (MEP) systems design, comparing clashes identified through manual coordination based on 2D drawings, automatic clash detection using a BIM model, and on-site clash detection for a specific project. The consequences of clashes within electrical installations, along with their detection, analysis, and resolution, are discussed in Daszczyński et al. (2022). Additionally, the application of clash detection in mid-rise building construction is examined in another noteworthy paper by Savitri and Pramudya (2020). The available literature shows that researchers focus on different structures/building elements and aspects of CD.

Attention is also focused on investigating the connections between design errors, the CD process, and costs in construction projects. In Ham et al. (2018), results from an analysis aimed at quantifying costs associated with design errors in high-rise construction projects are reported. Another work by Chahrour et al. (2021) emphasizes the potential cost savings achievable through the implementation of BIM-based clash detection, with a specific focus on achieving a favourable cost-benefit balance. The previously mentioned study by Daszczyński et al. (2022) specifically focuses on cost analysis related to clash detection in electrical installations, including discussions of possible financial benefits associated with the use of the BIM approach. Accordingly, the cost aspect of CD represents one of main motivations why to advance the CD process.

A notable trend in research on the CD process and its capabilities is the use of case studies for in-depth analysis. In Kermanshahi et al. (2020), research based on the Malaysian Police headquarters building examines the impact of BIM and CD during the design phase, revealing that constructability issues can be identified early, positively affecting design quality, project cost, and time. Another study by Sampaio et al. (2022) presents clash detection as a preliminary step to 4D BIM analysis, assessing software tools in a case study based on a digital model that includes architecture, structure, and water supply systems. A different approach, as presented in Abd and Khamees (2017), demonstrates the use of case studies to analyse BIM's efficacy in addressing conflicts between existing buildings and construction documents, showcasing its capability for redocumentation and developing as-built digital models. The investigation presented in Eldeep et al. (2022) explores the utilization of BIM as a tool for lean construction management. Through a comprehensive case study, the research illustrates that BIM possesses the capability to identify errors, omissions, and clashes in advance of the construction phase, thereby contributing to waste reduction and enhancing the efficiency of construction processes. Thus, the CD process has a potential to deliver positive contribution throughout the entire lifespan of a facility.

Another area of research focuses on efforts to improve the CD process. One work undertakes an exhaustive examination of clash detection, adopting a holistic perspective, and assesses the efficacy of a network-based method in refining the process (Hu et al., 2019). Another investigation by Seo et al. (2012) strives to pinpoint obstructions and interferences within the clash detection process, subjecting them to dedicated analyses. Addressing the challenge of advancing clash detection in terms of codifying clashes for enhanced categorization and efficiency, Malsane et al. (2022) assert that their approach contributes to more effective clash management. Concurrently, a separate contribution (Hasannejad et al., 2023) tackles a comparable issue, focusing on the automatic classification of clashes. Their research culminates in the development of a plugin for BIM tools, which automates clash grouping to ascertain priority and relevance. A different study by Coraglia et al. (2017) proposes a tool that supports the clash detection process. The authors introduce the logical-operative dimension and integrate a BIM model into a game engine environment to mitigate adverse impacts, reduce time, and minimize costs associated with construction activities. Furthermore, multiple works (Hu & Castro-Lacouture, 2018, 2019, 2022) emphasize the application of Bayesian statistics, as well as various artificial intelligence and machine learning methods and tools, in intelligent clash detection and prediction of clash relevance. Their studies aim to leverage historical data to enhance clash management, e.g., in the context of clash context information analysis. An additional study by Lin and Huang (2019) presents advancements in a methodology designed to facilitate the automatic screening of clashes deemed irrelevant to the building and its construction. The proposed approach synergistically integrates rule-based reasoning and supervised machine learning techniques. This innovative combination aims to effectively identify clashes that pose no harm to the building or its construction, thereby enhancing the efficiency of clash detection processes. An impactful study conducted by Jowett et al. (2018) explores the application of CD as a tool for the analysis, quantification, and assessment of design and build, as well as BIM-based construction projects for potential value realization. One finding of this investigation suggests that facilitating BIM, alongside necessary changes in the construction project process, can enhance the value of design and build projects. Another noteworthy contribution by Pärn et al. (2018) presents a compelling approach to the quantitative analysis of design clashes, incorporating probabilistic modelling. The authors utilized density functions and cumulative distribution functions to analyse collisions between BIM models of mechanical, electrical and plumbing systems (MEP) and structural BIM models as components of a federated BIM model for a building. The research results deepen the understanding of clash occurrence, with the developed probability distributions reported to be useful for forecasting clashes in future projects. In other work (Khosakitchalert et al., 2009), the authors focused on the accuracy issue of compound element quantities extracted from BIM models. They proposed a method using clash detection to improve the accuracy of quantities, verified through application in four case studies. According to the authors, key benefits of the method include the delivery of accurate quantities and time savings in BIM model editing. In summary, we state that current trends in the field of clash management are intensively concerned with improving clash detection process.

2.4. Clash detection and design coordination

The coordination of BIM models, which involves integrating and harmonizing diverse models generated by different disciplines, is another important aspect. The CD process plays a pivotal role in facilitating this coordination, serving as an integral component of the overall workflow. The general role of coordination is discussed in many comprehensive works such as Baldwin (2019), Eastman et al. (2011) and Kasznia et al. (2018). One study by Kim and Grobler (2009) explores the application of ontological consistency checking in the design process to identify potential conflicts, enhance coordination, and improve communication. The study also provides guidelines for modelling an ontological representation and automating the identification of issues and conflicts in the BIM-based design process. In another investigation (Mehrbod et al., 2019b) the goal was to gain a deeper understanding of the challenges associated with interacting with BIM. Through a long-term study of a design coordination process using advanced BIM tools, the authors developed a taxonomy representing the relationships between goals, artifacts, interactions, and transitions in BIM-based design coordination processes. In such a way, it's possible to adopt BIM-based design coordination and modelling strategies more effectively.

In a subsequent study (Mehrbod et al., 2020), the objective was to characterize the BIM building design coordination process, identify bottlenecks in the current workflow, and provide design considerations to address these challenges. Another paper by Paik et al. (2022) presents the results from an empirical case study, where an analysis was conducted to assess the priority of design coordination issues. Using the entropy weight method to evaluate the comparative importance of design issues, the study found that issues between design segments are more critical than the mere frequency of issues. Research on utilizing ontological consistency checking in the design process for identifying potential conflicts and improving coordination and communication is also reported in Kim and Grobler (2009). The research provides guidelines for modelling an ontological representation and automatically identifying problems and conflicts in the BIM-based design process.

The related topic, namely the role of BIM coordinators as professionals responsible, among others, for the CD process, is also discussed in the literature. The study by Jacobsson and Merschbrock (2018) delves into the core responsibilities of BIM coordinators through an integrative literature review. The identified core responsibilities, as revealed by the research, encompass tasks such as clash detection, managing information and communication flows, overseeing design changes, supporting new working procedures, and contributing to technical development. In a different study (Gustavsson, 2018), the exploration of new professional roles, specifically that of the BIM coordinator, is presented within the context of liminality. The findings indicate that professionals in new roles engage in multiliminal work, recognizing tensions that present challenges for these roles to effectively serve as catalysts for change.

2.5. Summary and identification of research gap

A comprehensive literature review reveals that CD is a widely discussed topic with several key conclusions. The CD process is crucial for preventing design errors, enhancing interdisciplinary coordination, and ensuring model reliability. By managing conflicts early in the design or construction phases, it allows for resolution before physical construction begins. Its focus on identifying design errors, improving coordination, and ensuring BIM model reliability minimizes failure risks and supports a more efficient, error-free construction process. Ultimately, the CD process is pivotal in enhancing the accuracy and efficiency of BIM-based designs, playing an integral role in improving project outcomes.

The pertinent literature encompasses numerous research threads, perspectives, and viewpoints on the CD process. However, in terms of studies on the advancements of the CD in the context of BIM models quality and reliability, there remains a significant research gap:

- in the field of clash detection and collision analysis within mono-discipline BIM models, as parts of federated BIM models, aiming to eliminate errors before the models are combined;
- in the lack of analysis of detected clashes within mono-discipline BIM models and their relevance to model quality and reliability;
- in the lack of comprehensive studies covering more than one project and more than one type of building.

In light of the identified research gaps, it is evident that existing studies primarily focus on collisions between architectural and/or structural components and MEP components within BIM models. Most of these studies rely on case studies from single projects. Additionally, some research has approached the clash detection process as a means of assessing BIM model quality and reliability. However, there remains a need to introduce quantitative metrics to better capture and reflect these essential issues. The objectives of this study (as presented in the Introduction section) correspond with the identified research gap.

3. Background

In construction, Building Information Modelling (BIM) involves generating and managing digital representations of buildings' physical and functional attributes of buildings, facilities, structures, and infrastructure (e.g., Eastman et al., 2011; Kasznia et al., 2018; Tomana, 2016). BIM, unlike conventional 2D documentation, has a significant impact on the construction projects. Incorporating BIM methodologies from the project's inception results in models with greater reliability than traditional drawings and documents (e.g., Czmoch & Pękala, 2014). BIM emphasizes collaboration among diverse stakeholders, including architects, structural engineers, and mechanical, electrical, and plumbing (MEP) engineers, each responsible for their specific models. This collaborative synergy is indispensable for fostering seamless collaboration and data sharing. Integrating different disciplines within the BIM framework fosters a comprehensive understanding of complex project environment, but effective BIM management is essential to capitalize on its advantages. Specifically, in public construction projects, the application of BIM is expected to foster greater public accountability. Furthermore, it is expected to result in more reliable project outcomes.

3.1. BIM standards and requirements in public projects

Public projects often require BIM models in the open IFC format, as specified in ISO 16739-1:2018 (International Organization for Standardization, 2018). IFC stands out as an open and neutral data format developed by the buildingSMART® organization. It facilitates interoperability between BIM software, ensuring information exchange. In the context of public procurement, where multiple stakeholders with varying software preferences are involved, the open nature of IFC becomes pivotal. The key aspects of IFC are its openness, neutrality, and non-proprietary file format. IFC facilitates comprehensive data exchange among design team members by transcending mere geometric information, encompassing attributes, properties, and relationships of BIM model elements. Central to this process are federated models, which amalgamate discipline-specific models to foster collaboration among architects, engineers, contractors, and other stakeholders. Construction projects involve contributions from various disciplines, including architectural, structural, and MEP (Mechanical, Electrical, and Plumbing). IFC's capability to represent data consistently across these domains ensures interoperability, which is essential for effective collaboration. Throughout the procurement lifecycle, IFC facilitates data exchange from early design to construction and facility management, with architects creating IFC models and engineers refining them with structural and systems data. Serving as the linchpin in federated models, IFC provides a standardized schema accommodating diverse data types and disciplines, ensuring seamless integration and enabling a holistic project perspective. On the other hand, ensures interoperability, which is essential for effective collaboration, while facility managers receive information for ongoing maintenance and operations.

Recently, European countries have made significant progress in setting BIM standards and requirements for public contracts. Organizations such as the European Construction Sector Observatory, European Committee for Standardization, and the European BIM Task Group play pivotal roles in facilitating harmonization and convergence of BIM standards across borders – compare, e.g., European Construction Sector Observatory (2019) and EUBIM Task Group (2017). Recognizing the potential of BIM to enhance efficiency, collaboration, and sustainability in construction projects, frameworks to promote its adoption are being developed at country levels; however, the progress varies across countries. Significantly, there is a prevailing trend towards the mandatory implementation of BIM in public projects, aimed at ensuring uniformity, interoperability, and data exchange.

Notably, on December 8, 2021, the Government of the Republic of Lithuania enacted a resolution (Lietuvos

Respublikos Vyriausybė, 2021) mandating BIM adoption for public projects. This mandate, effective from February 28, 2022, applies to design services, construction, reconstruction, and installation projects that meet specific cost and subject matter criteria. Further elaboration on the subject matter of public procurement is provided in Table 1.

To present broader context of the research, the specifics regarding the estimated costs of the subject matter for public procurement, as determined according to the provisions of Lietuvos Respublikos Vyriausybė (2021), are outlined in Table 2. Analysis of the data presented in the table reveals a noticeable trend towards reducing minimum estimated costs, thereby mandating the adoption of BIM over time. highlights the goal of promoting widespread BIM adoption in Lithuania's public projects.

In the context of legal regulations governing the application of BIM in public procurement in Lithuania, another legal instrument issued by the Ministry of Environmental Protection (Lietuvos Respublikos aplinkos ministras, 2022) deserves attention. This directive includes a standardized template outlining information requirements relevant to BIM implementation, particularly when design services are involved. Procuring entities are responsible for defining and providing these requirements alongside the procurement documentation. The aforementioned directive outlines the structure of this template and specifies the types of required information. It is important to note that the scope and specifics of the required information are subject to evaluation by the respective procuring entity.

Despite regulations mandating the use of BIM in public procurement in Lithuania, there are currently no obligatory minimum standards for BIM models regarding delivery format, cooperation protocols, coordination guidelines, or similar criteria. Similarly, no regulations currently define minimum requirements for Level of Detail (LOD), Level of Geometry (LOG), or Level of Information (LOI). (It is worth mentioning that LOD defines the overall precision and completeness of model components, LOG refers to the geometric complexity and accuracy of model elements, and LOI provides relevant metadata or specifications for each model element, such as material properties or maintenance requirements). Such standards remain unregulated in Lithuania, with specific project requirements established by procuring entities on a case-by-case basis.

However, it is customary for procuring entities to develop documents known as Employer's Information Requirements (EIR) and include them as part of the mandatory set of documents for public procurement projects utilizing BIM. These documents outline essential requirements for the BIM process, supplementing the legal requirements stipulated by Lithuanian law. The EIR documents cover a broad spectrum of topics, including general project information, modelling regulations, levels of model development, information classification systems, software specifications, BIM data exchange and communication infrastructure, structure of expected model files, quality control and discrepancy detection, model transfer to the client, and project stage completion. Another common practice is that mono-discipline BIM models for specific projects are requested and delivered in the IFC format. These models, when combined, form a federated IFC/BIM model for the construction project, serving as both a technical description of the building, facility, or structure to be built and a source of information for project stakeholders.

Table 1. Subject matter of public procurement where BIM is required according to Lithuanian law regulations

Subject matter	Description
Design services	▪ for new construction or reconstruction projects of structures classified under special categories
	▪ for installation or rearrangement of movable items, including various technological accessories such as electrical overhead lines, cable lines, underground cable ducts, support structures, gas pipelines, and communication lines
	▪ for block (quarter) renewal (modernization) projects
Construction or reconstruction works	▪ of new construction or reconstruction of structures classified under special categories
Installation or rearrangement works	▪ of movable items, including various technological accessories such as electrical overhead lines, cable lines, underground cable ducts, support structures, gas pipelines, and communication lines
Renewal works in urbanized areas	▪ for block (quarter) renewal (modernization) works implemented as part of block renewal projects in urbanized areas

Table 2. Estimated cost versus date of mandatory BIM implementation in Lithuania

Effective from	Estimated cost		
	Buildings	Civil engineering structures	Movable items*
2022.02.28	5 mln. EUR	10 mln. EUR	10 mln. EUR
2024.01.01	3 mln. EUR	5 mln. EUR	5 mln. EUR
2026.01.01	1.5 mln. EUR	3 mln. EUR	3 mln. EUR

Note: * as explained in the Table 1.

3.2. Clash detection in model coordination and conflict check for IFC/BIM models' reliability

The reliability of IFC/BIM models is critical for project success and efficiency, serving as the digital backbone throughout design, construction, and facility management phases. Reliable IFC/BIM models improve project management, reduce errors during construction, enhance accuracy in cost estimation, and optimize resource utilization. In ongoing building operation and maintenance, dependable IFC/BIM models provide valuable insights, streamline processes, and promote long-term sustainability. Additionally, reliable IFC/BIM models minimize potential costly errors, delays, and disputes, ensuring compliance with strict regulatory standards in public projects. BIM models offer a robust platform for compliance assessments, ensuring the project meets requirements.

Based on the analysis of procurement practices in Lithuania and considering the requirements of procuring entities, there are common principles of the Model Coordination and Conflict Check (MC&CC) process applied to BIM models. The process is synthetically characterized in Table 3.

The general objective of the MC&CC process is to reduce the number of design errors and conflicts within the model, thereby minimizing the need for corrections during the construction phase and subsequent phases of the project life cycle. This process is essential for coordinating the IFC/BIM model as a whole, particularly when several monodiscipline IFC/BIM models representing different branches and parts of the project are combined into a federated IFC/BIM model. Specifically, Table 3 highlights that collision checking and the CD process are integral components of the MC&CC process.

Table 4 illustrates the typical sequence of steps required for the CD process to coordinate a federated IFC/BIM model comprising multiple monodiscipline IFC/BIM models. The numbers in Table 4 denote successive steps of the CD process, where each step involves checking a specific monodiscipline model against itself and other monodiscipline models. In the literature (e.g., Andersson et al., 2016; Chidambaram, 2020; Rowlinson et al., 2010), similar tables are often referred to as clash matrices. The matrix supports decision-making during the model coordination process, providing a hierarchy of monodiscipline models (typically based on the discipline's flexibility and ease of model changes) and rules dictating how models should adapt to others when clashes are detected.

The matrix presented in Table 4 reflects the requirements for ordering and sequencing the CD process. The successive steps allow for a systematic identification, analysis, and resolution of conflicts, ensuring a structured approach to model integration. This structured clash detection approach is essential for enhancing the overall quality and reliability of both monodiscipline IFC/BIM models and the federated model as a whole. Furthermore, this approach facilitates clearer communication across disciplines, creating a predictable workflow that enhances interdisciplinary collaboration.

3.3. Research questions

In light of the preceding discussion, the use of clash detection and quantitative clash analysis to assess the reliability of IFC/BIM models describing designed and commissioned buildings was introduced. Specifically, emphasis was placed on analysing monodisciplinary models as components of federated models. Subsequently, the following research questions were formulated:

Table 3. Common principles of the model coordination and conflict check in public procurement practices in Lithuania

Type of verification	Description / Objective	Responsible project team members
Visual inspection	Check for unsuitable model elements and ensure that BIM is being followed according to the project team's defined objectives.	BIM coordinator, team members responsible for monodiscipline IFC/BIM models
Collision checking (Clash Detection)	Check for collisions between elements within monodiscipline IFC/BIM models and between elements of different monodiscipline IFC/BIM models to identify collisions and manage the necessary correction process.	BIM coordinator, team members responsible for monodiscipline IFC/BIM models
Integrity inspection	Verify that the model meets integrity requirements by checking for any missing, duplicated, or redundant elements or information, as specified in the detailed requirements (e.g., in the Employer's Information Requirement, EIR).	BIM Coordinator

Table 4. Common principles of the model coordination and conflict check in public procurement practices in Lithuania

Monodiscipline IFC/BIM models (project parts)		ARCH	STR	HVAC	IWSS	EL
Architectural model	ARCH	1	3	5	10	12
Structural model	STR		2	6	8	13
Heating, ventilation and air-conditioning model	HVAC			4	9	14
Internal water supply and sewage model	IWSS				7	15
electrical installations model	EL					11

- What is the reliability of monodiscipline IFC/BIM models regarding clash detection and the quantitative clash analysis?
- What kind of reliability measures can be proposed for monodiscipline IFC/BIM models concerning clash detection and quantity analyses of clashes?
- Do specific aspects of IFC/BIM model complexity, such as the number of components, affect their reliability?
- Do the disciplines represented in IFC/BIM models influence their reliability?

4. Methodology – data and methods applied

4.1. Data

The research analysed several IFC/BIM models created for public contracts in Lithuania. Specifically, these models were crafted to serve as comprehensive descriptions and information sources for construction projects focused on the construction of public educational facilities. The analysed models included two kindergartens and a school in Vilnius, the capital city of Lithuania. Several factors justify the selection of educational buildings for this study. These types of facilities require diverse spaces, including classrooms, corridors, restrooms, sports areas, and administrative offices. Educational buildings must meet safety, accessibility, and structural standards to ensure inclusivity for children and staff. These buildings are expected to last for many decades and often need to be adaptable to future educational needs. Public educational facilities involve multiple disciplines, such as architecture, structural engineering, and mechanical, electrical, and plumbing (MEP) systems. This cross-disciplinary interaction is a core element in federated BIM modeling, making educational buildings suitable examples for studying coordination, clash detection, and model reliability. Finally, educational projects are publicly funded, which creates a strong incentive for design and construction efficiency, providing value for money, and ensuring transparency. In summary, using educational facilities in the study allows for an in-depth exploration of how models can support the complex, multi-stakeholder, and accountability-rich environment typical of public construction projects.

The models selected for the research were sourced from the Lithuanian central public procurement platform, available at https://cvpp.eviesiejipirkimai.lt/. These models were intended to facilitate the procurement of construction works after building permits were obtained (it is worth noting that while the requirement to utilize BIM in public procurement was only mandated in 2020, Vilnius City Municipality and its associated organizations had begun utilizing BIM as early as 2018. As a result, there is significant prior experience in integrating BIM for public procurement and construction project management). All examined models were developed for new constructions, excluding projects involving reconstruction or renovation efforts.

Table 5 presents essential details regarding these buildings.

BIM models for the selected three buildings were developed by different design teams, each using different BIM software tools. Since each project was unique, the size and complexity of the buildings varied. However, a common aspect among all projects was that the BIM models were delivered in the IFC format as sets of files. These sets included several monodiscipline IFC/BIM models, which together constituted federated models.

EIR requirements regarding LOD and LOI were specified consistently across all three projects and their respective models (important notes: Higher LOD allows for better identification of potential clashes, as it captures finer elements that may collide in a real-world scenario. Without an appropriate LOD, small but critical clashes may be missed, affecting project accuracy. During the CD process, LOI-related requirements and information help prioritize clashes based on importance or relevance, distinguishing between critical clashes and minor, non-impactful conflicts). The aforementioned EIR documents did not include LOG requirements (however, it is worth noting that in the CD process, LOG ensures that the actual shape, size, and position of each component are accurately represented, which is essential for detecting spatial conflicts. Insufficient geometry detail can lead to inaccurate clash results, as the model may not fully represent actual dimensions).

The LOD requirements were as follows for specific parts of each project:

- site plan, outdoor engineering systems – LOD 200;
- architecture, structures – LOD 350;
- internal MEP systems, electrotechnics – LOD 300.

Minimum LOI were as follows:

- identification parameters: name, type, make, material, colour, finish, energy class, wattage;
- classifier information: functional system type, technical system type, element/component type;

Table 5. Basic characteristics of buildings which models were analysed

Characteristics	Kindergarten No. 1	Kindergarten No. 2	School
Gross floor area [m^2]	3 340	3 454	11 782
Volume [m^3]	15 830	14 950	70 902
Number of floors	3	3	4
Height [m]	8.8	10.45	17.00
Energy class	A++	A	A++

- product description from the technical specification or reference to the drawing or technical specification number;
- dimensions of the system: height, length, width, thickness, weight, etc.;
- fire part: fire resistance rating, flammability class, environmental aggressiveness class, sound class.

Figures 1–3 depict screenshots of the models, including architectural, structural, and MEP models. These three models were the subjects of analysis and research. However, since the required scope of BIM-based design varied across different projects and models – both in terms of the number of required monodiscipline models and their variety – the analysis focused on disciplines present in all three cases, namely: architecture (ARCH), structure (STR), and internal installations such as heating (HEAT), ventilation (VENT), water and sewage (IWS&S), electrical (IEL), and electronic communication (IEC).

Figure 1 presents screenshots of the models developed for Kindergarten No. 1, later referred to as KGT01. The total number of monodiscipline models in this case was 15. LOD requirements varied depending on the discipline, ranging between 200 and 350.

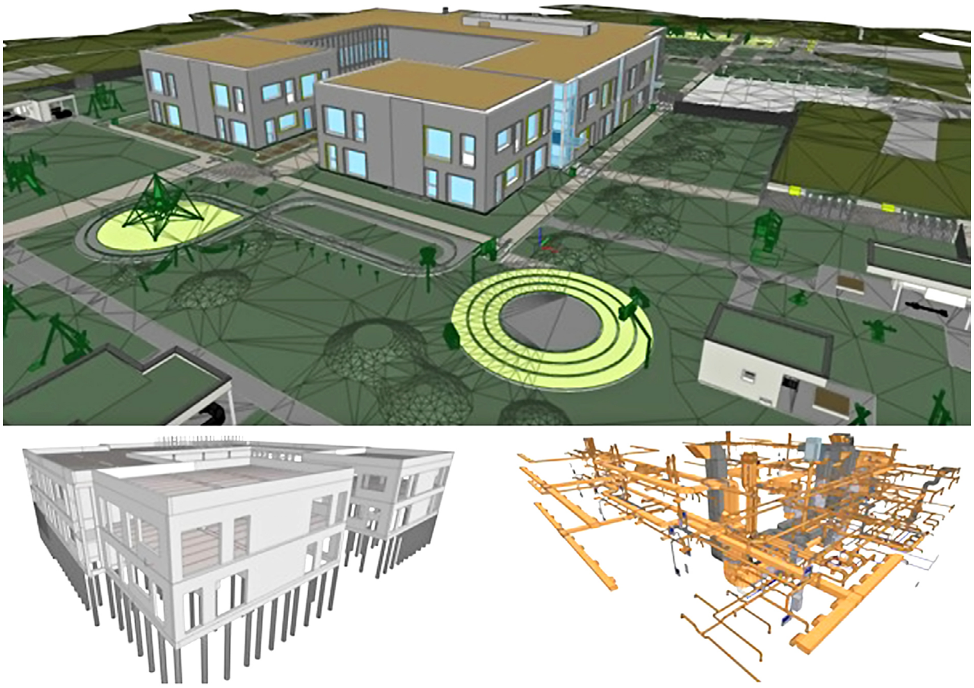

Figure 1. Screenshots of IFC/BIM models developed for Kindergarten No. 1

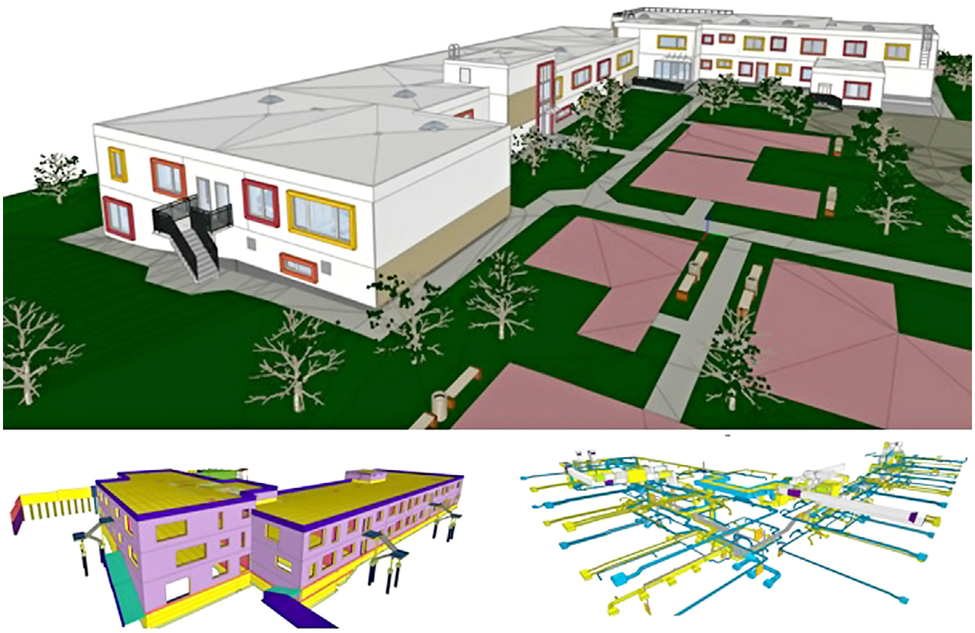

Figure 2. Screenshots of IFC/BIM models developed for Kindergarten No. 2

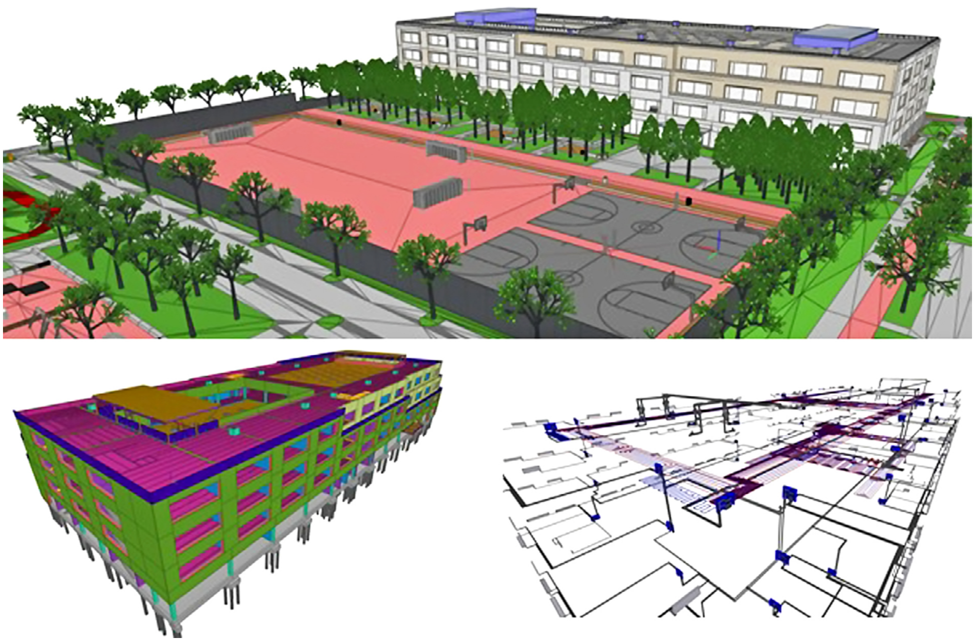

Figure 3. Screenshots of IFC/BIM models developed for school

Figure 2 displays screenshots of the models developed for Kindergarten No. 2, later referred to as KGT02. The total number of monodiscipline models in this case was 11.

Figure 3 depicts screenshots of the models developed for school, referred to as SCHL. The overall number of monodiscipline models in this case was 17, LOD requirements varying between 200 and 350 depending on the discipline.

These three models served as the data source for the methods described in the next subsection.

4.2. Methods

The study used a multifaceted approach to analyse IFC/BIM monodisciplinary models, including:

- fact finding with the use of geometric algorithms and an "all against all" clash detection method across models;
- evidential reasoning for data analysis, which prioritized collision significance based on geometric factors and model complexity;
- descriptive statistical methods to gain quantitative insights into collision patterns.

The research approach adopted involved gathering information on the number and geometric characteristics of collisions, as well as employing evidential reasoning and elements of statistical methods to interpret the data. Based on the literature review, no similar studies have been presented previously.

For the purpose of gathering information, the BIMvision software and the clash detection process were utilized. The clash detection process, facilitated by the BIMvision software and based on IFC/BIM models, utilizes geometric algorithms. This process is illustrated in a simplified scheme in Figure 4 along with an exemplary collision.

As illustrated in the scheme, the initial step involves enclosing all components of an IFC/BIM model in bounding boxes, which are defined as the smallest possible rectangular prisms encompassing these components. Subsequently, determining whether two bounding boxes intersect. In the context of complex models comprising numerous components, assessing the intersection of all possible pairs of bounding boxes becomes inefficient. This inefficiency arises from the quadratic increase in operations with the number of model components, significantly compromising the approach's efficacy. To mitigate the volume of operations, a preliminary grouping of components can be conducted relative to a selected plane, which is a straightforward procedure. Thereafter, the analysis is performed independently within these groups. Iterative preselection based on planes reduces groups and component sizes, significantly speeding up the identification of intersecting bounding boxes. The concluding phase involves ascertaining whether the model components enclosed by the intersecting bounding boxes indeed share common volume, along with the computation of the actual surface area and volume of component intersections. Notably, the BIMvision software incorporates sophisticated algorithms tailored for volume and surface area calculations, as well as for the visualization and presentation of detected clashes.

The fact-finding focused on identifying collisions within the IFC/BIM monodiscipline models. The primary approach involved running the clash detection process in "all against all" mode, where all components of a monodiscipline model were checked against one another using three ε parameter values. The ε parameter sets the minimum overlap value for model components before testing begins. For this study, ε values of 10 mm, 5 mm, and 1 mm were applied in separate runs across all models to understand the number of collisions detected and test accuracy

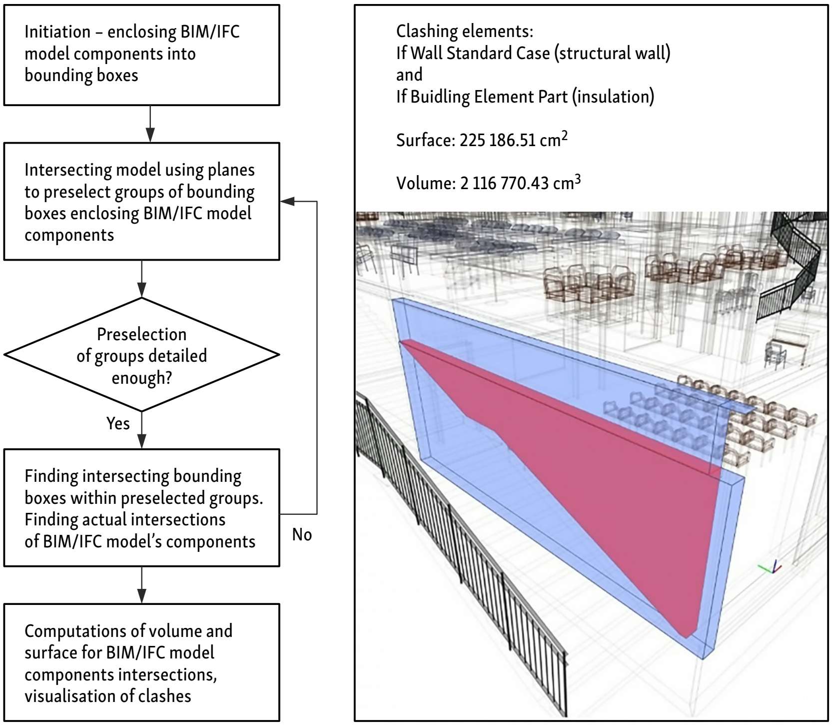

Figure 4. Scheme of a CD process facilitated by the software used in the course of research

(the ε value of 10 mm is the default setting in the BIMvision software, while 1 mm is the lowest possible value that can be applied. A 5 mm intermediate ε value was chosen to compare the default and lowest settings. This selection of parameters was intended to illustrate how test accuracy affects clash detection results).

The collected data were analysed using a mixed-methods approach, through evidential reasoning, statistical methods and qualitative analysis.

Evidential reasoning provided a systematic and rigorous method to analyse collisions within monodiscipline IFC/BIM models, providing key insights into model reliability. Specifically, in this study, evidential reasoning aimed to assess model reliability by evaluating the complexity of models against the number of detected collisions and their geometric measures. By integrating evidence related to collision counts, their volume, occurrence across different monodiscipline models, and model complexity, factors influencing model reliability were identified and practical applications proposed. The integration of clash detection test results across different monodiscipline IFC/BIM models provided multiple sources of evidence and perspectives on collision occurrences across various disciplines.

Descriptive statistical methods, such as averages, standard deviations, and quartiles, were employed to support the evidential reasoning process quantitatively.

5. Results

Tables 6–8 present the results of the CD processes for monodiscipline IFC/BIM models across disciplines such as architecture (ARCH), structure (STRU), heating (HEAT), ventilation (VENT), water and sewage (IWS&S), electrical (IEL), and electronic communication (IEC).

The results are presented for the three buildings studied: Kindergarten No. 1 (KGT01), Kindergarten No. 2 (KGT02), and the school (SCHL). As expected, lowering the ε value (which increases the precision of the clash detection process) results in a higher number of identified collisions. It is also evident that the number of collisions correlates with the number of elements in the model. Greater complexity increases the likelihood of collisions between elements. However, most models (except IEC for KGT01, KGT02, and SCHL, and IEL for KGT02) show numerous collisions even at an ε value of 10 mm. In analysing the results, it is evident that as the ε value decreases (indicating greater precision in clash detection), the number of identified collisions increases across all disciplines and models. Another straightforward observation is that models with higher complexity, measured by the number of elements, tend to exhibit more collisions, regardless of the ε parameter used. Notably, while some models showed fewer collisions at higher ε values (e.g., IEC for KGT01, KGT02, and SCHL; IEL for KGT02), most models across all buildings showed a significant number of collisions even at ε = 10 mm.

These observations underscore the complexity and challenges inherent in clash detection within monodiscipline IFC/BIM models, underscoring the importance of robust methodologies to manage and resolve clashes during design and construction phases.

Further analysis was conducted on collisions identified from tests run with ε = 1 mm. Although this precision level may not always be practical, it provides a detailed and comprehensive understanding of all detected collisions.

Table 6. Collision tests results for KGT01 models

Monodisicipline model	LOD	IFC file size [MB]	Number of elements (complexity)	Number of collisions CL		
				ε = 10 mm	ε = 5 mm	ε = 1 mm
ARCH	350	22.8	4632	589	973	1044
STR	350	37.4	1761	144	164	216
HEAT	300	66.9	3732	1238	1421	3606
VENT	300	64.9	4664	432	738	841
IWS&S	300	168.0	16081	5065	6828	22152
IEL	300	8.2	2586	173	177	180
IEC	300	1.3	291	0	0	0

Table 7. Collision tests results for KGT02 models

Monodisicipline model	LOD	IFC file size [MB]	Number of elements (complexity)	Number of collisions CL		
				ε = 10 mm	ε = 5 mm	ε = 1 mm
ARCH	350	90.8	3477	236	492	624
STR	350	15.0	4059	457	535	703
HEAT	300	299.0	2183	843	1013	1284
VENT	300	468.0	5835	156	185	343
IWS&S	300	363.0	7385	119	251	619
IEL	300	284.0	1415	0	0	0
IEC	300	3.5	490	0	0	0

Table 8. Collision tests results for SCHL models

Monodisicipline model	LOD	IFC file size [MB]	Number of elements (complexity)	Number of collisions CL		
				ε = 10 mm	ε = 5 mm	ε = 1 mm
ARCH	350	90.8	12106	1087	1091	2284
STR	350	15.0	10565	4505	5516	6073
HEAT	300	299.0	24968	9587	10636	13752
VENT	300	468.0	9873	520	565	589
IWS&S	300	363.0	14075	3045	3954	12924
IEL	300	284.0	9426	6	45	4042
IEC	300	3.5	1303	0	0	0

An important finding during the analysis of geometric measures of clashes (as presented in Tables 6–8) was that a significant number of clashes had a zero volume. This occurred due to errors in the IFC/BIM models, where one or both of the colliding elements were not closed solids. While the exact causes of these errors remain unknown, they impeded the calculation of collision volumes.

Tables 9–11 present results obtained for each monodiscipline model in the subsequent step. The tables show the number of collisions with volumes where v = 0 and v > 0 in separate columns. Using the ratio of collisions to model elements, coefficients representing model quality and uncertainty were introduced. The values of Relative Quality Coefficient (*RQC*), Relative Uncertainty Coefficient (*RUC*), and Modified Relative Quality Coefficient (*MRQC*) were obtained with the use of following formulas:

$$RQC = \frac{CL}{EL}; \tag{1}$$

$$RUC = \frac{ZCL}{EL}; \tag{2}$$

$$MRQC = \frac{NzCL}{EL}, \tag{3}$$

where: *CL* – overall number of identified clashes, *ZCL* – number of identified clashes for which volume equals 0, *NzCL* – number of identified clashes for which volume is greater than 0, *EL* – number of elements within a monodiscipline model (complexity).

These coefficients provide insights into the quality of each model based on collision data, as well as the level of uncertainty due to collisions with zero volume. Ideally, the *RQC*, *RUC*, and *MRQC* values should be as low as possible, indicating higher model quality and reliability.

Based on the data from Tables 6–11, it can be observed that for many models, the number of identified collisions is counted in thousands. The collision identification process in the utilized software was relatively short, with the required time not exceeding one minute. However, calculating geometric measures, especially collision volumes, was computationally intensive for complex models, taking up to several minutes. For one of the models – SCHL, IEL – despite repeated attempts, calculations for ε = 1 mm were not completed.

Table 9. Quality and uncertainty coefficients for KGT01 models

Monodisicipline model	RQC	Number of collisions		RUC	MRQC
		ZCL (v = 0)	*NzCL* (v > 0)		
ARCH	0.23	193	851	0.04	0.18
STR	0.12	120	96	0.07	0.05
HEAT	0.97	3343	263	0.90	0.07
VENT	0.18	154	687	0.03	0.15
IWS&S	1.38	8814	13338	0.55	0.83
IEL	0.07	113	67	0.04	0.03
IEC	0.00	0	0	0.00	0.00

Table 10. Quality and uncertainty coefficients for KGT02 models

Monodisicipline model	RQC	Number of collisions		RUC	MRQC
		ZCL (v = 0)	*NzCL* (v > 0)		
ARCH	0.18	525	99	0.15	0.03
STR	0.17	169	534	0.04	0.13
HEAT	0.59	1052	232	0.48	0.11
VENT	0.06	324	19	0.06	0.00
IWS&S	0.08	432	187	0.06	0.03
IEL	0.00	0	0	0.00	0.00
IEC	0.00	0	0	0.00	0.00

Table 11. Quality and uncertainty coefficients for SCHL models

Monodisicipline model	RQC	Number of collisions		RUC	MRQC
		ZCL (v = 0)	*NzCL* (v > 0)		
ARCH	0.19	553	1731	0.05	0.14
STR	0.57	396	5677	0.04	0.54
HEAT	0.55	1627	12125	0.07	0.49
VENT	0.06	31	558	0.00	0.06
IWS&S	0.92	6321	6603	0.45	0.47
IEL*	0.43	na	na	na	na
IEC	0	0	0	0	0

Note: * na – not available.

Based on the obtained results, a chart depicting the relationships between the model's discipline and *RQC* values was developed, as shown in Figure 5.

The analysis of the results enabled the ranking of model reliability based on *RQC* values and disciplines. The models were ranked as follows on a four-point Likert scale:

- the most reliable: electronic communication models (IEC);
- reliable: ventilation (VENT) and architectural (ARCH) models;
- moderately reliable: electrical (IEL) and structural (STRU) models;
- the least reliable: heating (HEAT) and water and sewage (IWS&S) models.

Tables 12–14 present descriptive statistics computed for collisions whose volumes, as geometrical measures, were greater than 0. The tables include the values of average, standard deviation, median, as well as first and third quartiles. Additionally, minimum and maximum values are provided (for clarity the volumes of collisions in the Tables 12–14 are presented as dm^3, and not cm^3).

The minimum values were so small that in some cases, despite volumes greater than 0 being indicated, 0 was shown in the tables. In most cases, the average values are higher than the third quartiles (Q3) or slightly lower but still close to that value. Generally, the largest collisions in terms of volumetric measures are above Q3, and the differences between Q3 and minimum values are relatively small. The vast majority of the overall volume is concentrated in a small number of collisions. This allows us to conclude that the majority of collisions detected with small volumes constitute "collision noise", resulting from imperfections in the modelling process, deficiencies in modelling tools, modelling errors (e.g., inaccuracies in trimming elements), or potential errors in exporting models from the native format to the IFC format. However, unequivocal identification of the causes of this state is not possible.

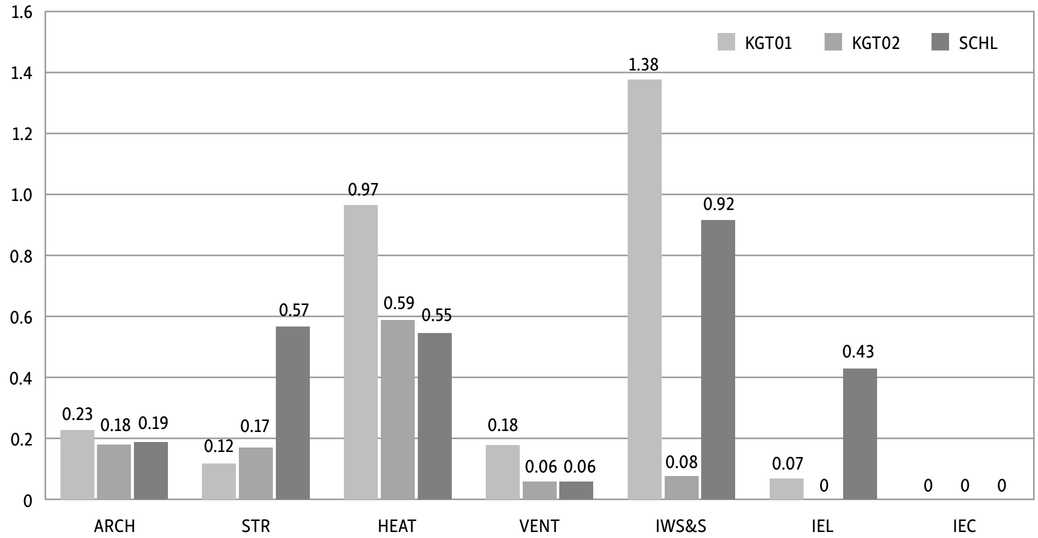

Figure 5. Relationship between the branch of monodiscipline model and *RQC* value

Table 12. Descriptive statistics of identified collisions for KGT01

Model	avg	std. dev.	min	Q1	med	Q3	max
ARCH	30.590	230.688	0.002	0.027	0.221	3.656	3892.461
STR	11.241	40.368	0.002	0.023	0.293	3.339	317.700
HEAT	0.069	0.191	0.001	0.002	0.007	0.024	1.508
VENT	128.233	500.243	0.001	0.042	0.480	24.956	7201.082
IWS&S	0.189	1.628	0.000	0.001	0.006	0.031	74.699
IEL	0.068	0.088	0.001	0.044	0.054	0.054	0.581
IEC	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 13. Descriptive statistics of identified collisions for KGT02

Model	avg	std. dev.	min	Q1	med	Q3	max
ARCH	121.3036	415.7853	0.0003	1.6135	5.5439	27.7494	2235.468
STR	6.9616	27.1403	0.0003	0.0088	0.1280	1.4576	249.596
HEAT	0.1501	0.2311	0.0000	0.0124	0.0627	0.1939	1.229
VENT	48.7051	117.5471	0.0006	0.0424	0.1156	0.8306	325.000
IWS&S	0.0789	0.8031	0.0000	0.0001	0.0006	0.0169	10.961
IEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IEC	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 14. Descriptive statistics of identified collisions for SCHL

Model	avg	std. dev.	min	Q1	med	Q3	max
ARCH	3.004	15.630	0.000	0.010	0.156	0.975	281.900
STR	5.646	18.604	0.000	0.017	0.180	7.500	400.000
HEAT	0.313	3.166	0.000	0.004	0.015	0.072	186.985
VENT	287.302	564.839	0.000	8.400	55.383	297.316	3628.985
IWS&S	0.620	4.943	0.000	0.001	0.006	0.131	116.182
IEL*	na	na	na	na	na	na	na
IEC	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: * na – not available.

6. Discussion

Collisions in IFC/BIM models, especially concerning geometric measures such as volumes, are key indicators of potential design clashes. When assessing collisions, distinguishing between important and negligible collisions based on their volumes is essential. Larger collision volumes typically indicate significant clashes that could impact construction or operation, necessitating attention and resolution. Smaller collision volumes often represent minor interferences that may not significantly impact the project. Therefore, understanding and analysing collision volumes enable project teams to prioritize and address critical clashes efficiently, ensuring smoother project execution and minimizing delays or errors.

The analysis of collision data within the monodiscipline IFC/BIM models yielded several important findings. Firstly, the number of identified collisions increased with greater clash detection precision and higher model complexity, as expected. Surprisingly, the majority of models exhibited numerous collisions even with a relatively large tolerance level (ε = 10 mm), suggesting issues with model accuracy or the clash detection process. Further investigation focused on collisions detected with ε = 1 mm, offering detailed insights despite practical limitations. It was observed that a significant proportion of clashes had a volume of 0, likely due to errors in the BIM models, such as elements not being closed solids. Subsequent analysis introduced coefficients to assess model quality and uncertainty, revealing varying levels of reliability across different disciplines. Descriptive statistics were computed for collisions with non-zero volumes, highlighting the concentration of collision volume in a small number of clashes.

The Relative Quality Coefficient (*RQC*), Relative Uncertainty Coefficient (*RUC*), and Modified Relative Quality Coefficient (*MRQC*) were introduced to evaluate the reliability and quality of monodiscipline IFC/BIM models. These coefficients serve as quantitative indicators of model performance, with lower values indicating higher reliability and lower uncertainty. These coefficients enabled the ranking of models based on relative quality and uncertainty. The introduction of these measures offers insights into the overall reliability of BIM models across different disciplines, aiding in decision-making processes and quality assurance efforts. Additionally, these measures support standardizing assessment methodologies and enhancing BIM project quality. The utilization of these coefficients represents a step forward in enhancing the transparency and accountability of BIM model evaluation processes. Moreover, by demonstrating the value of integrating both qualitative and quantitative methods, this research contributes to advancing BIM practices, encouraging more reliable models and improving decision-making in public procurement.

From the perspective of practical implications, adoption of originally proposed coefficients (*RQC*, *RUC*, *MRQC*) create a promising prerequisite for the introduction of monodisciplinary as well as federated IFC/BIM models post audits. Such post-audits may help to: (1) identify the model designers/suppliers that significantly disrupt/lower model's reliability whatever the reason (e.g., technical or technological ignorance), (2) identify critical building elements that are the most problematic from the point of view of possible clashes occurrence, (3) monitor, whether the reliability of models is improving over time, and (4) based on the quantitative data retrieved, decide on the need for independent error checking for specific models or elements. All of this sets the stage for the creation of a knowledge base that, when shared within the organisation or across the market, will further minimize model errors. In the line with Daszczyński et al. (2022), this approach can deliver financial benefits for project owners. Furthermore, when the reliability investigation is followed with prioritization and relevance of clashes, a favourable cost-benefit balance, as emphasized by Chahrour et al. (2021), is particularly desirable for public projects.

Based on the results obtained, it is evident that the quality of IFC/BIM models for public procurement needs to be carefully evaluated and improved. The identified collisions and discrepancies in geometric measures highlight shortcomings in the modelling process, causing uncertainties and reliability concerns. Therefore, there is a clear need for stricter quality control measures and standards to ensure that IFC/BIM models meet the expected quality criteria for public procurement projects. This may involve implementing rigorous validation processes, improving modelling techniques, and training stakeholders involved in model development. Ultimately, enhancing the quality of IFC/BIM models will contribute to better project outcomes, reduced risks, and enhanced decision-making in public procurement.

Incorporating the newly proposed metrics (*RQC*, *RUC*, *MRQC*) into project documentation, such as the EIR, can provide public clients with a more transparent and measurable approach to assessing model quality and reliability. By specifying these metrics in the subject matter description, public clients can ensure that suppliers are held to consistent standards of model accuracy and clash management. This not only facilitates accountability among design teams but also enables public clients to make more informed decisions about model quality, minimizing the risk of costly construction issues and rework. Additionally, these metrics allow for easier monitoring of model reliability over time, providing valuable insights into areas needing improvement and fostering a proactive approach to model quality in public procurement processes.

7. Conclusions

The study demonstrated that clash detection in monodiscipline IFC/BIM models for public educational facilities effectively highlights areas for improving model reliability. The research provided insights and introduced innovative metrics – Relative Quality Coefficient (*RQC*), Relative Uncertainty Coefficient (*RUC*), and Modified Relative Quality Coefficient (*MRQC*) – to assess IFC/BIM model quality.

These metrics provide a quantitative foundation for assessing model performance, offering a new perspective on BIM-based clash detection by associating detected clashes with model complexity and specific disciplines.

Key findings include:

1. Clash Detection and Model Reliability: Higher precision in clash detection correlates with increased collision counts, highlighting the influence of model complexity and parameter settings on reliability. This reinforces the importance of rigorous quality control in BIM, particularly during the integration of models for large-scale public projects.
2. Applicability of New Metrics: The *RQC*, *RUC*, and *MRQC* coefficients offer a structured approach to evaluating BIM model quality. Lower metric values indicate higher reliability, enabling comparative analysis across projects and models.
3. Implications for Practice: The proposed metrics can be integrated into public procurement documentation, such as EIRs, to improve transparency and standardize quality assessments. Over time, these tools can support better design practices and build a knowledge base to minimize errors and enhance project outcomes.

These findings have implications for enhancing model accuracy and reliability, particularly in complex multi-disciplinary projects. Future work would involve validating these metrics across more building types and expanding their application to federated BIM model assessments.

Notations

Variables and functions

RQC – Relative Quality Coefficient;
RUC – Relative Uncertainty Coefficient;
MRQC – Modified Relative Quality Coefficient;
EL – number of elements within a monodiscipline model (complexity);
CL – overall number of identified clashes;
ZCL – number of identified clashes for which volume equals 0;
NzCL – number of identified clashes for which volume is greater than 0;
ε – clash detection process parameter which denotes the minimum overlap value for model components;
v – volume of a collision.

For descriptive statistics computed for collisions whose volumes, as geometrical measures, were greater than 0:

avg – average value;
st. dev. – standard deviation value;
min – minimum value;
max – maximum value;
med – median value;
Q_1 – first quartile value;
Q_3 – third quartile value.

Abbreviations

BIM – building information model / building information modelling;
AEC – architecture, engineering, and construction;
HVAC – heating, ventilation, air conditioning;
IFC – industry foundation classes;
CD – clash detection / collision detection;
MEP – mechanical, electrical, and plumbing;
LOD – Level of Detail;
LOG – Level of Geometry;
LOI – Level of Information;
EIR – Employer's Information Requirements;
MC&CC – Model Coordination and Conflict Check;
ARCH – architecture;
STR – structure;
HEAT – heating internal installations;
VENT – ventilation internal installations;
IWS&S – water and sewage internal installations;
IEL – electrical internal installations;
IEC – electronic communication internal installations;
KGT01 – IFC/BIM model for Kindergarten No. 1 building;
KGT02 – IFC/BIM model for Kindergarten No. 2 building;
SCHL – IFC/BIM model school building.

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Author contributions

MJ, LU, and RK developed the concept of the study. MJ, TH, RK, and MV conducted the literature review. RK was responsible for selecting and acquiring the BIM/IFC models used in the research. MJ, LU, TH, and HŁ developed the methodology. HŁ acquired the software and provided IT support during the research. RK and MV conducted the collision analyses and provided the results. MJ, RK, and HŁ introduced and proposed the reliability and quality metrics. MJ, MV, TH and LU were responsible for interpreting the results and conducting statistical analyses. MJ, LU, RK, TH, HŁ, and MV discussed the research findings and prepared the conclusions. MJ and RK wrote the manuscript. MJ and LU supervised the research.

Disclosure statement

All of the authors declare that they do not have any competing financial, professional, or personal interests from other parties.

References

Abd, A. M., & Khamees, A. S. (2017). As built case studies for BIM as conflicts detection and documentation tool. *Cogent Engineering*, *4*(1), Article 1411865. https://doi.org/10.1080/23311916.2017.1411865

Akhmetzhanova, B., Nadeem, A., Hossain, M. A., & Kim, J. R. (2022). Clash detection using building information modeling (BIM) technology in the Republic of Kazakhstan. *Buildings*, *12*(2), Article 102. https://doi.org/10.3390/buildings12020102

Akponeware, A. O., & Adamu, Z. A. (2017) Clash detection or clash avoidance? An investigation into coordination problems in 3D BIM. *Buildings*, *7*(3), Article 75. https://doi.org/10.3390/buildings7030075

Andersson, L., Farrell, K., Moshkovich, O., & Cranbourne S. (2016) *Implementing virtual design and construction using BIM*. *Current and future practices* (1st ed.). Routledge. https://doi.org/10.4324/9781315657073

Azhar, S. (2011). Building information modelling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering*, *11*(3), 241–252. https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127

Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building information modeling (BIM): now and beyond. *The Australasian Journal of Construction Economics and Building*, *12*(4), 15–28. https://doi.org/10.5130/AJCEB.v12i4.3032

Baldwin, M. (2019). *The BIM-manager*: *A practical guide for BIM project management*. Beuth Verlag GmbH.

Barnes, P., & Davies, N. (2014). *BIM in principle and in practice*. London: ICE Publishing. https://doi.org/10.1680/bimpp.58637

Chahrour, R., Hafeez, M. A., Ahmad, A. M., Sulieman, H. I., Dawood, H., Rodriguez-Trejo, S., Kassem, M., Naji, K.K., & Dawood, N. (2021). Cost-benefit analysis of BIM-enabled design clash detection and resolution. *Construction Management and Economics*, *39*(1), 55–72. https://doi.org/10.1080/01446193.2020.1802768

Chidambaram, S. (2020). The application of clash-detection processes in building information modelling for rebars. *Proceedings of the Institution of Civil Engineers-Smart Infrastructure and Construction*, *172*(2), 53–69. https://doi.org/10.1680/jsmic.20.00005

Choi, J., Sejin, L., & Inhan, K. (2020). Development of quality control requirements for improving the quality of architectural design based on BIM. *Applied Sciences*, *10*(20), Article 7074. https://doi.org/10.3390/app10207074

Coraglia, U. M., Simeone, D., Cursi, S. Fioravanti, A., Wurzer, G., & D'Alessandro, D. (2017). A simulation model for logical and operative clash detection. In *35th International Conference on Education and Research in Computer Aided Architectural Design in Europe* (*eCAADe 2017*) (pp. 519–526), Rome, Italy. https://doi.org/10.52842/conf.ecaade.2017.2.519

Czmoch, I., & Pękala, A. (2014). Traditional design versus BIM based design. *Procedia Engineering*, *91*, 210–215. https://doi.org/10.1016/j.proeng.2014.12.048

Daszczyński, T., Ostapowski, M., & Szerner, A. (2022). Clash cost analysis in electrical installations based on BIM technologies. *Energies*, *15*(5), Article 1679. https://doi.org/10.3390/en15051679

Donato, V., Lo Turco, M., & Bocconcino, M. M. (2017). BIM-QA/QC in the architectural design process. *Architectural Engineering and Design Management*, *14*(3), 239–254. https://doi.org/10.1080/17452007.2017.1370995

Eastman, C. M., Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook*: *A guide to building information modeling for owners*, *managers*, *designers*, *engineers*, *and contractors*. John Wiley & Sons.

Eldeep A. M., Farag M. A. M., & Abd El-hafez, L. M. (2022). Using BIM as a lean management tool in construction processes – A case study. *Ain Shams Engineering Journal*, *13*(2), Article 101556. https://doi.org/10.1016/j.asej.2021.07.009

EUBIM Task Group. (2017). *Handbook for the introduction of building information modelling by the European public sector*. *Strategic action for construction sector performance*: *driving value*, *innovation and growth*.

European Construction Sector Observatory. (2019). *Building information modelling in the EU construction sector*. European Commision.

Farnsworth, C. B., Beveridge, S., Miller, K. R., & Christofferson, J. P. (2015). Application, advantages, and methods associated with using BIM in commercial construction. *International Journal of Construction Education and Research*, *11*(3), 218–236. https://doi.org/10.1080/15578771.2013.865683

Gustavsson, T. K. (2018). Liminal roles in construction project practice: exploring change through the roles of partnering manager, building logistic specialist and BIM coordinator. *Construction Management and Economics*, *36*(11), 599–610. https://doi.org/10.1080/01446193.2018.1464197

Ham, N., Moon, S., Kim, J. H., & Kim, J. J. (2018). Economic analysis of design errors in BIM-based high-rise construction projects: Case study of Haeundae L project. *Journal of Construction Engineering and Management*, *144*(6), Article 05018006. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001498

Han, N., Yue, Z. F., & Lu, Y. F. (2012). Collision detection of building facility pipes and ducts based on BIM technology. *Advanced Materials Research*, *346*, 312–317. https://doi.org/10.4028/www.scientific.net/AMR.346.312

Hasannejad, A., Sardrud, J. M., & Shirzadi Javid, A. A. (2023). BIM-based clash detection improvement automatically. *International Journal of Construction Management*, *23*(14), 2431–2437. https://doi.org/10.1080/15623599.2022.2063014

Hjelseth, E. (2016). Classification of BIM-based model checking concepts. *ITcon*, *21*, 354–370.

Hu, Y., & Castro-Lacouture, D. (2018). Clash relevance prediction in BIM-Based design coordination using Bayesian statistics. In *Construction Research Congress 2018* (pp. 649–658). ASCE. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000810

Hu, Y., & Castro-Lacouture, D. (2019). Clash relevance prediction based on machine learning. *Journal of Computing in Civil Engineering*, *33*(2), Article 04018060. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000810

Hu, Y., & Castro-Lacouture, D. (2022). Intelligent clash detection in building information modeling. In W. Lu, & C. J. Anumba (Eds.), *Research companion to building information modeling* (pp. 230–247). Edward Elgar Publishing. https://doi.org/10.4337/9781839105524.00021

Hu, Y., Castro-Lacouture, D., & Eastman, C. M. (2019). Holistic clash detection improvement using a component dependent network in BIM projects. *Automation in Construction*, *105*, Article 102832. https://doi.org/10.1016/j.autcon.2019.102832

International Organization for Standardization. (2018). *Industry Foundation Classes* (*IFC*) *for data sharing in the construction and facility management industries* (ISO Standard No. 16739-1:2018).

Jacobsson, M., & Merschbrock, C. (2018). BIM coordinators: a review. *Engineering*, *Construction and Architectural Management*, *25*(8), 989–1008. https://doi.org/10.1108/ECAM-03-2017-0050

Jiao, Y., & Cao, P. (2023) Research on optimization of project design management process based on BIM. *Buildings*, *13*(9), Article 2139. https://doi.org/10.3390/buildings13092139

Johansson, P., Linderoth, H., & Granath, K. (2014). The role of BIM in preventing design errors. *In 30th Annual Association of Researchers in Construction Management Conference* (*ARCOM*) (pp. 703–712). Portsmouth, UK.

Jowett, B. R., Al Hattab, M., & Kassem, M. (2018). Demystifying collaboration in BIM-based projects under design-build procurement: Clash detection as a use value. In B. Kumar (Ed.), *Contemporary strategies and approaches in 3-D information modeling* (pp. 158–190). IGI Global. https://doi.org/10.4018/978-1-5225-5625-1.ch007

Kasznia, D., Magiera, J., & Wierzowiecki, P. (2018). *BIM w praktyce*: *standardy*, *wdrożenie*, *case study*. Wydawnictwo Naukowe PWN.

Kermanshahi, E. K., Tahir, M. B. M., Lim, N. H. A. S., Balasbaneh, A. T., & Roshanghalb, S. (2020). Implementation of building information modeling for construction clash detection process in the design stage: a case study of Malaysian police headquarter building. *IOP Conference Series*: *Earth and Environmental Science*, *476*(1), Article 012009. https://doi.org/10.1088/1755-1315/476/1/012009

Khosakitchalert, C., Yabuki, N., & Fukuda, T. (2019). Improving the accuracy of BIM-based quantity takeoff for compound elements. *Automation in Construction*, *106*, Article 102891. https://doi.org/10.1016/j.autcon.2019.102891

Kim, H., & Grobler, F. (2009). Design coordination in building information modeling (BIM) using ontological consistency checking. In *Computing in Civil Engineering* (*2009*) (pp. 410–420). ASCE. https://doi.org/10.1061/41052(346)41

Kjartansdóttir, I. B., Mordue, S., Nowak, P., Philp, D., & Snæbjörnsson, J. T. (2017). *Building information modelling-BIM*. Civil Engineering Faculty of Warsaw University of Technology.

Koo, H. J., & O'Connor, J. T. (2022). A strategy for building design quality improvement through BIM capability analysis. *Journal of Construction Engineering and Management*, *148*(8), Article 04022066. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002318

Kovacs, A. T., & Micsik, A. (2021). BIM quality control based on requirement linked data. *International Journal of Architectural Computing*, *19*(3), 431–448. https://doi.org/10.1177/14780771211012175

Leite, F., Akinci, B., & Garrett Jr, J. (2009). Identification of data items needed for automatic clash detection in MEP design coordination. *In Construction Research Congress 2009*: *Building a Sustainable Future* (pp. 416–425). ASCE. https://doi.org/10.1061/41020(339)43

Lietuvos Respublikos Vyriausybė. (2021). *Lietuvos Respublikos Vyriausybės nutarimas dėl statinio informacinio modeliavimo metodų taikymo atvejų nustatymo*, *2021 m*. *gruodžio 8 d*. *Nr*. *1061* [Resolution of the Government of the Republic of Lithuania on the determination of cases of application of static information modeling methods, 2021 December 8 No. 1061].Vilnius (in Lithuanian).

Lietuvos Respublikos aplinkos ministras. (2022). *Įsakymas dėl užsakovo informacijos reikalavimų patvirtinimo*, *2022 m*. *vasario 24 d*. *Nr*. *D1-57* [Minister of the Environment of the Republic of Lithuania, Declaration on the approval of customer information requirements, 2022 February 24 No. D1-57]. Vilnius (in Lithuanian).

Lin, W. Y., & Huang, Y. H. (2019). Filtering of irrelevant clashes detected by BIM software using a hybrid method of rule-based reasoning and supervised machine learning. *Applied Sciences*, *9*(24), Article 5324. https://doi.org/10.3390/app9245324

Luo, S., Yao, J., Wang, S., Wang, Y., & Lu, G. (2022). A sustainable BIM-based multidisciplinary framework for underground pipeline clash detection and analysis. *Journal of Cleaner Production*, *374*, Article 133900. https://doi.org/10.1016/j.jclepro.2022.133900

Malsane, S., Merin, M. J., Gokul, G. J., Nithin Dev, P., & Babu, S. T. (2022). Management of high-volume clashes during clash detection. In P. Srivastava, S. S. Thakur, G. I. Oros, A. A. AlJarrah, & V. Laohakosol (Eds.), *Lecture notes in networks and systems*: *Vol*. *214*. *Mathematical*, *computational intelligence and engineering approaches for tourism*, *agriculture and healthcare* (pp. 285–295). Springer, Singapore. https://doi.org/10.1007/978-981-16-3807-7_23

Mehrbod, S., Staub-French, S., Mahyar, N., & Tory, M. (2019a). Beyond the clash: Investigating BIM-based building design coordination issue representation and resolution. *ITcon*, *24*, 33–57.

Mehrbod S., Staub-French S., Mahya N., & Tory M. (2019b). Characterizing interactions with BIM tools and artifacts in building design coordination meetings. *Automation in Construction*, *98*, 195–213. https://doi.org/10.1016/j.autcon.2018.10.025

Mehrbod S., Staub-French S., & Tory, M. (2020). BIM-based building design coordination: processes, bottlenecks, and considerations. *Canadian Journal of Civil Engineering*, *47*(1), 25–36. https://doi.org/10.1139/cjce-2018-0287

Nguyen, Q. T., Luu, P. Q., & Ngo, Y. V. (2020). Application of BIM in design conflict detection: a case study of Vietnam. *IOP Conference Series*: *Materials Science and Engineering*, *869*(2), Article 022038. https://doi.org/10.1088/1757-899X/869/2/022038

Paik, S., Leviakangas, P., & Choi, J. (2022). Making most of BIM in design: analysis of the importance of design coordination. *International Journal of Construction Management*, *22*(12), 2225–2233. https://doi.org/10.1080/15623599.2020.1774837

Patacas, J., Dawood, N., & Kassem, M. (2020). BIM for facilities management: A framework and a common data environment using open standards. *Automation in Construction*, *120*, Article 103366. https://doi.org/10.1016/j.autcon.2020.103366

Pärn, E. A., Edwards, D. J., & Sing, M. C. P. (2018). Origins and probabilities of MEP and structural design clashes within a federated BIM model. *Automation in Construction*, *85*, 209–219. https://doi.org/10.1016/j.autcon.2017.09.010

Raut, S. P., & Valunjkar, S. S. (2017). Improve the productivity of building construction project using clash detection application in building information modeling. *International Research Journal of Engineering and Technology*, *4*(3), 1784–1790.

Rowlinson, S., Collins, R., Tuuli, M. M., & Jia, Y. (2010). Implementation of Building Information Modeling (BIM) in construction: A comparative case study. *AIP Conference Proceedings*, *1233*(1), 572–577. https://doi.org/10.1063/1.3452236

Sadek, K., El-Bastawissi, I., Raslan, R., & Sayary, S. (2019). Impact of BIM on building design quality. *BAU Journal - Creative Sustainable Development*, *1*(1), Article 1. https://doi.org/10.54729/2789-8334.1000

Sampaio, A. Z., Gomes, N. R., Gomes, A. M., & Sanchez-Lite, A. (2022). Multi-project in an integrated BIM model: Clash detection and construction planning. *Journal of Software Engineering and Applications*, *15*(10), 345–358. https://doi.org/10.4236/jsea.2022.1510020

Savitri, D. M., & Pramudya, A. A. (2020). Clash detection analysis with BIM-based software on midrise building construction project. *IOP Conference Series*: *Earth and Environmental Science*, *426*(1), Article 012002. https://doi.org/10.1088/1755-1315/426/1/012002

Seo, J. H., Lee, B. R., Kim, J. H., & Kim, J. J. (2012). Collaborative process to facilitate BIM-based clash detection tasks for enhancing constructability. *Journal of the Korea Institute of Building Construction*, *12*(3), 299–314. https://doi.org/10.5345/JKIBC.2012.12.3.299

Tomana, A. (2016). *BIM Innowacyjna technologia w budownictwie*. *Podstawy*, *standardy*, *narzędzia*. PWB MEDIA Ździebłowski Spółka Jawna.

Tommelein, I. D., & Gholami, S. (2012). Root causes of clashes in building information models. In *Proceedings for the 20th Annual Conference of the International Group for Lean Construction*, San Diego, USA.

Trebbi, C., Cianciulli, M., Matarazzo, F., Mirarchi, C., Cianciulli, G., & Pavan, A. (2020). Clash detection and code checking BIM platform for the Italian market. In B. Daniotti, M. Gianinetto, & S. Della Torre (Eds.), *Digital transformation of the design*, *construction and management processes of the built environment* (pp. 115–125). Springer, Cham. https://doi.org/10.1007/978-3-030-33570-0_11

van den Helm, P., Böhms, M., & van Berlo, L. (2019). IFC-based clash detection for the open-source BIMserver. In *Proceedings of the 17th International Workshop on Intelligent Computing in Engineering*, Berlin, Germany.

Wong, J. K., Zhou, J. X., & Chan, A. P. C. (2018). Exploring the linkages between the adoption of BIM and design error reduction. *International Journal of Sustainable Development and Planning*, *13*(1), 108–120. https://doi.org/10.2495/SDP-V13-N1-108-120