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Theoretical Mechanisms of Building Information Modelling (BIM): Information Representation, Data Exchange, and Decision Support

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Abstract: The existing literature focused primarily on practical applications of the BIM in project management, sustainable development, and facility management (FM), while the theoretical foundations of the model remained largely underdeveloped. This article provides a systematic literature review on the basic mechanisms of the BIM, including information representation, data exchange mechanisms, decision support, and new network models integrating semantic, topological, and spatial aspects. Despite the widespread adoption of standards such as Industry Foundation Classes (IFC), Construction Operations Building Information Exchange (COBie), and BIM Collaboration Format (BCF), there is a lack of consistent ontologies integrating the function, structure, and behavior of objects. As data exchange mechanisms remain limited by interoperability issues, the impact of the BIM on decision-making processes has not been captured in universal theoretical models. The latest approaches, based on networked data representation, offer promising prospects but require further empirical validation. The results of the review imply the development of integrated ontological frameworks, formalization of information exchange processes, and creation of theoretical models to support decision-making.

Keywords: Building Information Modeling; Information representation; Data exchange; Decision support; IFC; Ontologies; Network models

1 Introduction

For over two decades, Building Information Modeling (BIM) has been one of the key tools for digital transformation of the architecture, engineering, and construction (AEC) sector, and its importance in practice is growing worldwide [1]. Defined as the process of creating and managing information about a building throughout its life cycle, the BIM enables the integration of geometric and semantic data, hence facilitating the coordination of design, execution, and operation activities [2, 3]. The literature highlights its role in improving the efficiency of project management, reducing costs, supporting sustainable development, and increasing the safety and quality of construction processes [4, 5].

Despite numerous evidence for the benefits of implementing the BIM, there is a significant research gap in its theoretical foundations. Previous studies focused mainly on practical applications such as project management [6], building life cycle analysis [7], and facility management [8]. Relatively few publications address the basic mechanisms of the BIM, including ways of representing information, exchanging data, and supporting decisions [9]. What is more, the BIM is often defined in different ways as a tool, a process, a management philosophy, or a data platform [10] that leads to a dispersion of research approaches, and thus hinders the development of a coherent theoretical framework.

To reduce ambiguities at the outset, four recurrent viewpoints on the BIM can be distinguished, together with their theoretical and practical implications:

(1) BIM as a digital product/model (object-centred representation).

Theoretical focus: Formal semantics of building elements, information representation schemas, ontologies/graph models, and model fidelity.

Practical focus: Model authoring and coordination, Level of Development (LOD)/Level of Information (LOI) specification, clash detection, data quality metrics, and validation rules.

(2) BIM as a collaborative process/method.

Theoretical focus: Process theory and workflow orchestration, capability/maturity constructs, governance of information flows.

Practical focus: BIM Execution Plans, role and responsibility matrices, International Organization for Standardization (ISO)-aligned information management, Common Data Environments, and Quality Assurance (QA) procedures.

(3) BIM as an information-management framework/platform.

Theoretical focus: Interoperability mechanisms, exchange protocols, and interfaces between heterogeneous systems.

Practical focus: openBIM practices, Information Delivery Specification (IDS)/Information Delivery Manual (IDM) specifications, Construction Operations Building Information Exchange (COBie)-style handover, Application Programming Interface (API)-based integrations, and lifecycle data continuity.

(4) BIM as a socio-technical paradigm (organizational change).

Theoretical focus: Socio-technical systems, knowledge sharing, learning, and decision-making models in multi-actor settings.

Practical focus: Change management and training, incentive structures, procurement strategies, and alignment of responsibilities across disciplines.

These viewpoints map directly onto the three mechanisms examined in the present review, i.e., information representation, data exchange, and decision support, and explain the divergence of empirical findings. Studies about the *product* view emphasize representational formalisms; the *process* and *platform* views foreground workflows and information requirements; and the *socio-technical* view highlights behavioural and organizational determinants of decision quality. Integrating these perspectives provides the conceptual scaffolding for the subsequent sections of the paper.

The emergence of a promising direction of research is the development of networked models for semantic-topological-spatial data representation, which integrates the function, structure, and behavior of building elements and components with their geometric connections and spatial relationships [11]. These models may pave the way for automated inference and provide more precise support for the decision-making processes in construction projects. The implementation of these models, however, is still in its infancy and a lack of empirical research on this topic affects the assessment of their effectiveness.

The aim of this article is to present a systematic review of the literature about the theoretical mechanisms of the BIM, with an emphasis on: (1) methods of information representation, (2) data exchange mechanisms, (3) decision support, and (4) new network approaches. The work is based on an analysis of scientific publications from year 2000 to 2025 to identify key research gaps and indicate directions for further research.

2 Methodology

To enhance transparency and reproducibility, the identification, screening, and selection of the literature followed a structured protocol:

(1) Scope and questions. The review targets theoretical mechanisms of the BIM across three lenses, i.e., information representation, data exchange, and decision support, and queries the ways in which these mechanisms are conceptualized and operationalized in practice.

(2) Sources and time window. Searches covered major bibliographic databases like Scopus, Web of Science Core Collection, IEEE Xplore, and ACM Digital Library, and targeted venues in AEC and information management. Grey literature such as standards documents and technical reports was consulted selectively to clarify definitions. The time window spanned from January 2010 to August 2025; English-language records were prioritized.

(3) Query strategy. Keyword blocks combined the BIM terms with mechanism-specific terms; for example, ("BIM" OR "building information model*" OR "openBIM") AND (IFC OR "Model View Definition" OR IDS OR "BIM Collaboration Format" OR BCF OR ontology OR "knowledge graph" OR "semantic network" OR "data exchange" OR interoperability OR "decision support" OR MCDA OR Bayesian). Queries were adapted per database syntax.

(4) Eligibility criteria. These included peer-reviewed journal and full-paper conference articles reporting theoretical frameworks, formal models, or empirical evaluations relevant to at least one of the three mechanisms. Those excluded were editorials, short abstracts, theses, non-AEC applications without the BIM linkage, duplicates, and studies lacking sufficient methodological details for appraisal.

(5) Screening process. Titles/abstracts were screened independently by two reviewers against the criteria, followed by full-text assessment. Disagreements were resolved through discussion and justifications for exclusion were recorded. Backward and forward snowballing was applied to key papers.

(6) Quality appraisal. Methodological quality was assessed using a checklist covering clarity of research aims, data provenance, validity of models/assumptions, transparency of procedures, adequacy of evaluation like datasets,

metrics, and baselines, and threats to validity. Studies not meeting minimum quality thresholds informed background but were not used for comparative claims.

(7) Data extraction and synthesis. A structured codebook captured the: mechanism(s) addressed; domain and asset type; BIM standards and versions (e.g., Industry Foundation Classes (IFC) 2x3, 4, 4.3; BIM Collaboration Format (BCF); IDS/Model View Definitions (MVD)); data types and integration approach; decision context and stakeholders; evaluation design and metrics; reported benefits and limitations. Findings were synthesized thematically and mapped onto the conceptual framework introduced in Section 1.

This procedure yields a transparent trail from search to synthesis and supports consistent comparison across heterogeneous studies and application contexts.

The literature review was conducted using a systematic approach in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which ensure the transparency and replicability of the research process [12]. The analysis, covering the period from year 2000 to 2025, captured early publications on the BIM implementation and the latest concepts like network data representation models (Figure 1). Sources were searched in Scopus, Web of Science, IEEE Xplore, ScienceDirect, and the arXiv repositories, which guarantee a wide range of topics and access to the latest research.

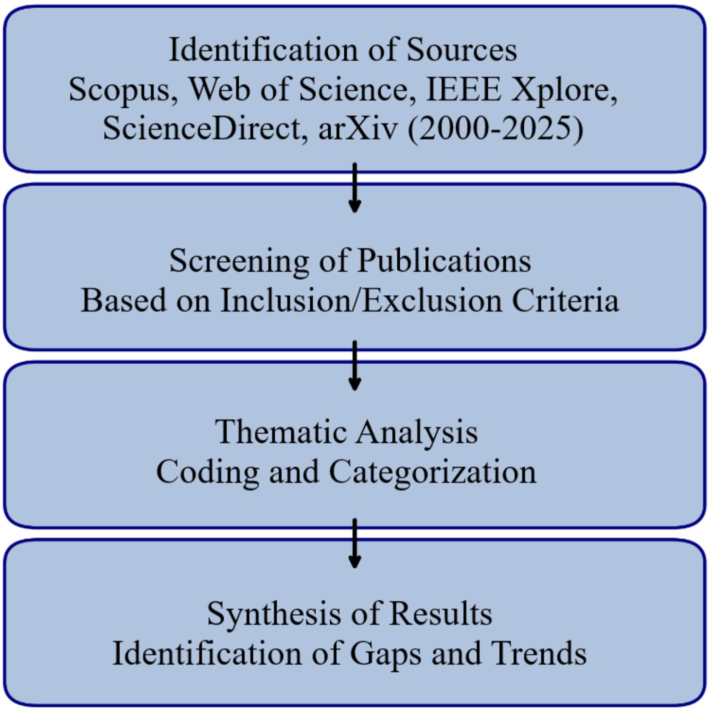

Figure 1. Flow of research methodology

Note: This figure was prepared by the authors

The first stage was to identify publications with a set of keywords, including Building Information Modeling (BIM), ontology, interoperability, decision support, and semantic-topological-spatial models. Next, articles were selected based on the inclusion criteria focusing on the theoretical aspects of the BIM, information exchange mechanisms, decision support, and new representation models. Empirical publications describing industrial implementations without a theoretical framework were excluded so as to be in line with the approach adopted in similar systematic reviews in the field of AEC [13, 14].

The next stage was a thematic analysis, in which the articles were coded and grouped into four categories, i.e., information representation, data exchange, decision support, and new network models. The final synthesis of the results could identify both the strengths and key research gaps in the existing literature. The research methodology allowed a comprehensive overview of the topic and identification of areas for in-depth research.

3 Results

3.1 Information Representation

As shown in the literature review, the dominant standard for information representation in the BIM remains to be the Industry Foundation Classes (IFC), developed by buildingSMART and included in ISO 16739. The IFC provides a hierarchical structure describing building elements along with their geometry, properties, and relationships, hence allowing broad interoperability between different information systems [15]. Despite the significant adoption of the IFC, research indicated numerous limitations, namely incomplete mapping of functional relationships, difficulties in handling large files, and limited integration with semantic ontologies [16, 17].

An alternative to the geometry-only approach is formal ontologies, such as Function—Behaviour—Structure (FBS) framework developed by Gero [18], extending traditional models with the descriptions of functions and behaviors of objects in a usage context. In turn, domain-specific ontologies such as Building Topology Ontology (BOT) and Holistic Building Performance Ontology (HBPO) provide richer semantic tools for describing building topologies and their performance parameters [19]. However, a universal theoretical framework integrating different approaches has yet to be developed.

3.2 Data Exchange Mechanisms

Despite the widespread use of the IFC, there are still some serious interoperability problems. The most common ones include data loss during model export and import, and a lack of consistent object identifiers in different design environments [16]. Alternative formats such as Construction Operations Building Information Exchange (COBie) focus on operational data, while the BCF allows exchange of comments and collision reports without transferring complete models [20]. Although the BCF facilitates collaboration in multidisciplinary teams, its effectiveness depends on the quality of implementation in individual tools. The standards of process such as ISO 19650 organize information management by defining roles and responsibilities, but all problems related to data transfer and interpretation could not be eliminated [21].

In multidisciplinary coordination, the BCF functions as a lightweight and tool-agnostic issue container that links discussion, viewpoints, and element identifiers to specific model contexts. In practice, the BCF enables asynchronous review across authoring and analysis tools. It preserves traceability through issue identifiers, statuses, assignees, and due dates, reduces rework by capturing decisions alongside the affected geometry, and lowers vendor lock-in by decoupling issue exchange from native files. The teams also benefit from faster triage during coordination meetings, clearer accountability across disciplines, and easier audit of what was changed, why, and by whom.

The adoption of the BCF also presents challenges. Implementations vary across platforms, which can lead to inconsistent field support and partial loss of metadata. Element GUIDs may break when models are reauthored, compromising the link between issues and geometry; versioning across multiple CDEs can create duplicates and synchronization gaps. Long-running threads fragment when issues are split or merged, and BCF payloads typically lack richer semantics (e.g., explicit requirement references), limiting downstream analytics. Governance and security require attention—particularly role definitions, approval trails, and retention policies—and teams often face overlap between BCF workflows and proprietary issue trackers. Effective use therefore depends on disciplined model versioning, a shared issue taxonomy and status workflow, periodic issue grooming, and integration with CDEs so that issue histories remain aligned with approved model releases.

Recent empirical studies substantiate these limitations. In a quantified bridge case, commercial structural-analysis tools interpreted on average only 51.16% of geometry-related information imported from an IFC design view, while a purpose-built IFC4.3.2.0 interpreter reached 97.14%; predefined types and material properties were often not read at all, and cross-section semantics were frequently lost [22]. A comparative study of bi-directional exchanges between Revit and four structural analysis packages showed that IFC 2x3 transfers commonly lost element attributes and did not support round-trip analysis results, whereas API-based links preserved most section properties and analysis outputs—albeit mainly within single-vendor ecosystems [23]. Beyond tool-to-tool exchange, a 2024 georeferencing assessment for IFC4.3 demonstrated that multiple alternative encodings can coexist in the same dataset, producing contradictory location information unless constrained by a dedicated Model View Definition (GeoMVD) [24]. Industry-partner surveys and interviews likewise report persistent interoperability pain points—calls for fully interoperable IFC, fragmentation across multiple CDEs, and costly workarounds at handover [25]. Finally, a 2024 systematic review (93 papers) identified structural barriers for downstream analytics and AI—lack of native time-series structures, heterogeneous geometry representations that hinder computation, and immature extraction toolchains—indicating that several IFC limitations are systemic rather than tool-specific [26]. Together these findings motivate stricter view/requirement specifications (MVD/IDS), domain-specific schema extensions, and hybrid graph/ontology mappings alongside IFC to improve reliability of exchanges.

A lack of complete semantic compatibility among systems poses an additional challenge as even correctly imported data could have different interpretations from different applications. In response to these problems, mechanisms supporting data exchange have been used; for instance, Common Data Environments (CDE) is proposed to centralize the process of information collection and distribution. The use of APIs and web services enabling direct communication between applications in real time is also growing. Cloud-based solutions are also important in allowing multiple project participants to access the same resources simultaneously without the need to manually export and import files. The IFC extensions including IFC5 and openBIM initiatives, which aim to standardize and automate data exchange processes, are important in the development of the industry.

3.3 Decision Support

Research indicated that the BIM plays an important role in decision-making processes by supporting three key stages: input preparation, alternative analysis, and solution selection [27]. Models such as Succar's BIM maturity matrix showed that a higher level of the BIM implementation was associated with greater ability of an organization to make data-driven decisions [28]. At the same time, other studies revealed a significant gap between the expectations of the BIM and its actual effectiveness. Miettinen and Paavola [29] emphasized that in many cases, the BIM was perceived as a "digital utopia", whose potential was not fully realized. Formal theories should be provided to explain the reasons for the BIM to support some decisions effectively and fail in others.

The effectiveness of the BIM in decision-making is primarily determined by the quality and timeliness of the data. Inaccurate models, incomplete information, and a lack of uniform standards for describing objects lead to erroneous conclusions and undermine trust in digital tools. The BIM is integrated with advanced analysis methods, such as energy simulations, life cycle costing (LCC) and life cycle assessment (LCA), which enables multi-criteria decision-making. Decision support is also enhanced by using artificial intelligence and machine learning to predict risks and optimize design options. The transparent visualization of analysis results is essential to facilitate communication between different stakeholders. To broaden the theoretical lens on decision support, several established models commonly used with or alongside BIM can be distinguished: multi-criteria decision analysis (e.g., AHP, TOPSIS, PROMETHEE) for structured weighting and ranking of alternatives; probabilistic graphical models (Bayesian networks, including dynamic variants) for representing uncertainty and causal relations; risk- and condition-based schemes that connect inspection and monitoring data to rule-based prioritization of interventions; and knowledge-graph or semantic-query frameworks that map BIM data to ontologies to enable explainable, cross-disciplinary reasoning.

Viewed together, these families offer complementary strengths—trade-off reasoning in MCDA, explicit uncertainty handling in probabilistic models, operational prioritization in risk-based approaches, and transparent, query-driven inference in graph-based methods—providing a concise comparative baseline for the analysis that follows.

3.4 New Network Models

One of the most promising areas of development is network models for semantic-topological-spatial data representation (Figure 2). Han et al. [11] proposed an integrated graph model in which each element of a building was represented as a node, and the relationships between them included semantic, spatial, and topological aspects.

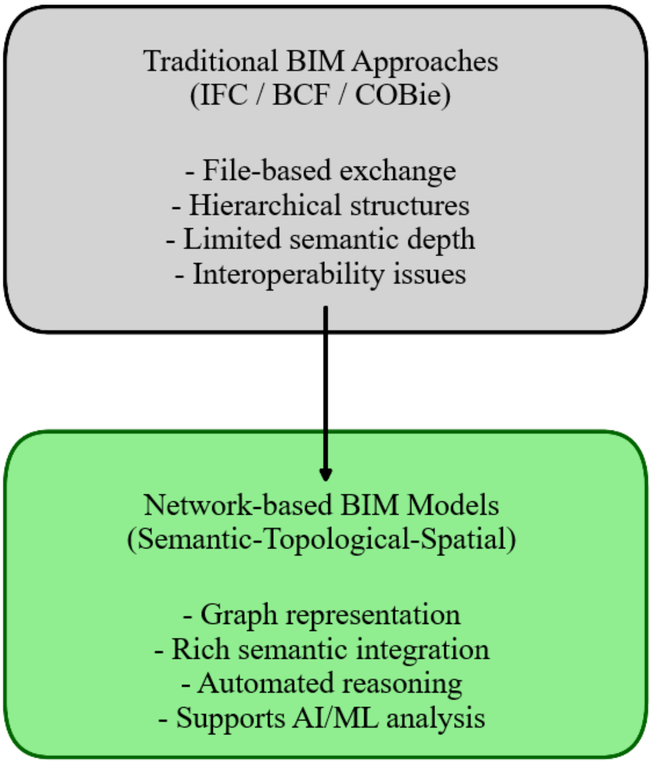

Figure 2. Comparison of traditional and network BIM models

Note: This figure was prepared by the authors

This approach enables automatic inference, e.g., checking compliance with evacuation standards or optimizing Heating, Ventilation, and Air Conditioning (HVAC) systems. In addition, the integration with machine learning methods on graphs opens up the possibility of analyzing design patterns on a previously unavailable scale [30]. Despite their great potential, these models remain at the research stage and require further empirical validation in real construction projects.

4 Discussion

A review of the literature indicated that despite the widespread adoption of the BIM in architecture, engineering, and construction practices, its theoretical foundations remained underdeveloped. Standards such as the IFC and the BCF provide a framework for data exchange, but numerous studies confirmed their limitations in terms of mapping semantic relationships and ensuring full interoperability [31]. The difficulties identified include, among others, loss of information during model export and import, a lack of consistent object identifiers, and limited integration with semantic ontologies.

A brief historical lens helps situate the current theoretical status of the BIM. Early conceptions from the 1990s till 2000s approached the BIM primarily as object-oriented, parametric product models, emphasizing geometry and attributes in file-based exchanges. From the mid-2000s, attention shifted toward collaboration and process integration across the project lifecycle, with information-management practices, common data environments, and capability/maturity viewpoints framing BIM as a socio-technical method rather than a single tool. The 2010s brought stronger semantic and ontological perspectives and the emergence of digital-twin thinking, pushing beyond geometry toward meaning, behavior, and linked data across systems. Over the last decade, cloud platforms, APIs, and data analytics broadened decision-support ambitions, while graph-based, semantic–topological–spatial models have begun to recast BIM as a network of interoperable data services.

Seen through this trajectory, today's challenges—interoperability beyond geometry, consistent semantics for function and behavior, governance and provenance of shared data, and explainable decision support—are continuations of long-running themes rather than isolated issues. Future work should therefore combine unified ontological foundations with stricter exchange specifications and service-oriented architectures, extending BIM toward time-aware, queryable networks that can support auditable, human-in-the-loop decisions across the whole asset lifecycle.

New approaches in the form of networked semantic-topological-spatial data representation models open up the prospect of deeper information integration and more advanced decision support. These models, representing building elements as nodes in a graph, allow automatic inference and machine learning methods to analyze design patterns in large data sets [32]. Their potential is particularly important in the context of the growing complexity of construction projects and the integration of the BIM with artificial intelligence and robotics tools. Nevertheless, the literature emphasized that their validation in practical implementations remained limited as they are still at a conceptual stage [33].

Recent pilots indicate how the proposed semantic–topological–spatial network models behave in practice. In the City of Vienna's BRISE-Vienna digital permit workflow, a visibility-graph–based escape-route generator and validator was embedded into an openBIM submission process; on published test models most checks executed in under five seconds (worst-case≈16 s), and the approach was accepted by stakeholders for pilot operation, illustrating both performance gains and the need for a curated manual step between automated generation and validation to meet legal requirements [34–36]. In design automation, a BIM-to-graph mapping for modular buildings (IFC-MVD→graph) has been shown to drive automatic generative layout synthesis and code-oriented validation in a prototype environment, demonstrating feasibility on a modular case while highlighting dependency on consistent IFC views and graph queries [37]. For operations and FM, a federated cross-domain BIM knowledge graph that links architectural and MEP models reported millisecond-scale federation (≈292 ms on test data) and supported cross-model queries (e.g., tracing valves that control AHU-connected wastewater segments), evidencing practical utility for maintenance and diagnostics while exposing naming/classification pitfalls that still require governance [38]. Finally, learning-based network models (GNNs) for automated code checking have achieved high accuracy on accessibility checks using graph encodings, yet rely on synthetic training sets and raise auditability concerns; recent reviews recommend hybrid pipelines that combine graph-learning with explicit rules to satisfy regulatory traceability [39, 40]. Complementary graph-based semantic-enrichment pipelines have also reconstructed production models across authoring-tool versions (e.g., Revit 2023→2022) from graph representations derived from geometry, demonstrating interoperability benefits alongside known limitations in spatial hierarchy enrichment [41].

The limitation of this review was its focus on publications indexed in major databases and the exclusion of grey literature, which may have led to the omission of valuable case studies and industry reports. Furthermore, the analysis mainly concerned the literature in English language, so the research perspectives may be narrow. Further research should consider local and multilingual sources to better reflect the global context of the BIM implementations.

Future research should focus on developing integrated ontologies that incorporate the semantics of functions, behaviors, and topologies into a coherent model, formalizing data exchange processes with security and privacy in mind and validating new network models empirically in real-world projects. The implementation of such solutions could remarkably boost the practical effectiveness of the BIM, hence transforming it from a modeling support tool into an integrated decision-making platform.

5 Conclusions

The BIM plays a major role in the digitization of the architecture, engineering, and construction (AEC) sector, but there is still a lack of solid theoretical framework describing its fundamental mechanisms. A review of the literature has shown that despite the widespread adoption of standards such as the IFC, the BCF, and the COBie, serious challenges remain in respect of interoperability, full mapping of semantic relationships, and effective support for decision-making processes. At the same time, new network models are gaining attention as graph-based data representation has combined semantic, spatial, and topological aspects and offered much broader analytical possibilities and potential for integration with artificial intelligence methods.

Nevertheless, these concepts remain in the development phase and require validation in practical projects; this could be a challenge but also an opportunity for future research. The results of the review indicated that further development of the BIM should move towards the creation of integrated ontologies, the formalization of data exchange processes about security and privacy, and the implementation of data-driven decision support tools. Only by establishing a solid theoretical foundation will it be possible to fully exploit the potential of the BIM as a platform not only for design, but also as a strategic tool for the entire life cycle of buildings.

Building on the synthesized evidence, several areas of research emerge for future investigation:

- Semantics beyond geometry. Develop a unified, modular ontological core for function and behavior (systems, performance, operations) with clear alignment to exchange specifications (e.g., MVD/IDS) to reduce ambiguity in downstream use.
- Interoperability under evidence. Establish open, repeatable benchmarks and datasets that quantify exchange fidelity, round-trip loss, georeferencing integrity, and temporal consistency across tools and schema versions.
- Explainable decision pipelines. Advance hybrid decision support that combines MCDA, probabilistic reasoning, and rule-based checks, with standardized audit trails and justification artefacts suitable for regulatory review.
- Scalable graph/network models. Mature semantic–topological–spatial pipelines for portfolio-scale assets, including streaming/time-series integration, incremental updates, and performance guarantees for complex cross-model queries.
- Collaboration workflows with BCF. Specify stable identifiers and versioning across CDEs, extend issue schemas with requirement/risk links, and design governance patterns that prevent drift between issues and approved model states.
- Data governance and provenance. Formalize policies and technical mechanisms for FAIR BIM data, lineage capture across tools, and privacy/security controls for sensitive operational information.
- Socio-technical adoption. Investigate incentive structures, roles, and training that enable sustained use of these mechanisms; evaluate organizational outcomes alongside technical metrics.
- Field validation and impact. Conduct longitudinal pilots that report cost–benefit, safety, energy/carbon, and service-level impacts, using comparable metrics to translate theoretical advances into practice.

These directions target the principal gaps identified in the review—semantic consistency, verifiable interoperability, auditable decision making, and scalable networked representations—offering a focused agenda for subsequent research and standardization.

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Data Availability

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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