OPEN STANDARDS FOR DATA INTEGRATION AND VISUALIZATION ACROSS THE PROJECT LIFECYCLE: CHALLENGES AND OPPORTUNITIES OF IFC5

Jacopo Cassandro[1], Alessandro Bruttini[2], Andrea Bongini[2], Lukas Guntermann[3], and Markus König[3]
[1]Department of Architecture, Built Environment, and Construction Engineering (DABC), Politecnico di Milano, Milan, Italy
[2]Department of Architecture (DIDA), University of Florence, Florence, Italy
[3]Chair of Computing in Engineering, Ruhr University Bochum, Bochum, Germany

Abstract

Industry Foundation Classes (IFC) enable interoperability across the AECO sector, yet IFC2x3 and IFC4 remain constrained by monolithic structures, limited external data integration, and weak support for real-time and web-based workflows. This paper applies comparative schema analysis and domain-based evaluation across four lifecycle phases, design, construction, operation, and deconstruction, to critically assess these limitations. Emerging IFC5 concepts are examined against identified requirements, highlighting both improvements and unsolved challenges, including governance complexity and implementation maturity. Results indicate increased flexibility and potential, alongside new dependencies and trade-offs. In conclusion, a forward-looking assessment and early-adoption priorities for IFC5-enabled data-centric workflows are provided.

Introduction

The architecture, engineering, construction, and operation (AECO) sector increasingly relies on Building Information Modeling (BIM) to meet growing demands for coordination, efficiency, and information exchange. Initially used for geometric representation, BIM has expanded to support model-based collaboration and a wide range of domain-specific use cases across the project lifecycle (Wang and Chen, 2023). However, to deliver its full value, such collaboration requires the continuous exchange of structured data among stakeholders (Shelden et al., 2020). Addressing this need, the Industry Foundation Classes (IFC) standard, developed by buildingSMART International (bSI), serves as an open and vendor-neutral data schema to support interoperability. It provides a standardized object-based digital description through entities, attributes, and relationships. This includes the geometry of elements as well as information related to processes and operations from design and construction, through safety, operational, and maintenance, to deconstruction (Li et al., 2025).

As industry requirements evolve, IFC technical committees extend the standard with new domain-specific definitions (Laakso and Kiviniemi, 2012), but formal adoption into official releases depends on lengthy ISO-compliant review processes. Consequently, practitioners and researchers frequently used custom solutions and dedicated IFC extensions, highlighting the need for more flexible data structures and interoperable information exchange (Yu et al., 2023).

With the construction industry becoming increasingly data-intensive and reliant on dynamic, multi-source digital workflows, the limitations of existing IFC versions (IFC2x3 and IFC4) have become more evident. These versions lack native support for real-time data exchange, integration with external data sources, advanced analytics, and modern visualization tools. To address these gaps, bSI started the development of IFC5 as a next-generation schema (Berlo, van et al., 2021).

Currently under development, IFC5 adopts modular and extensible architecture and supports multiple interoperable formats, including XML Schema Definition (XSD), Web Ontology Language (OWL), and JavaScript Object Notation (JSON). Moreover, its integration with visualization technologies, such as Universal Scene Description (USD), combines semantic content with real-time, interactive visualizations.

This paper examines current challenges and future opportunities of IFC5 for heterogeneous data integration and visualization across the project lifecycle. Four lifecycle phases and representative use cases are considered: design (cost and time management), construction site health and safety (H&S) management, operation and maintenance (O&M), and circular deconstruction. Based on a literature review of IFC-based approaches for integrating BIM data, a set of functional requirements that the schema should support in each domain, with emphasis on data representation, exchange, and integration, was identified. These requirements ensure a comparative schema analysis of IFC2x3 and IFC4, highlighting recurring gaps and challenges across phases. The analysis subsequently examines emerging IFC5 concepts to discuss how far they address these limitations and to what extent they can support more flexible and interoperable data environments. Overall, the paper analyses the ongoing evolution of IFC and discusses early adoption, as well as the practical implications of integrating IFC5 into data-centric AECO workflows.

Research questions and methodology

To assess the current limitations and future potential of IFC for data-centric integration and visualization across four representative lifecycle use cases, the following research questions (RQs) were identified:

- RQ1: *Which limitations emerge for data representation, exchange, integration, and visualization in the IFC2x3 and IFC4 versions across key lifecycle phases of the built asset?*
- RQ2: *To what extent do emerging IFC5 concepts address these gaps, and what trade-offs and implications emerge for implementation across the same lifecycle phases?*

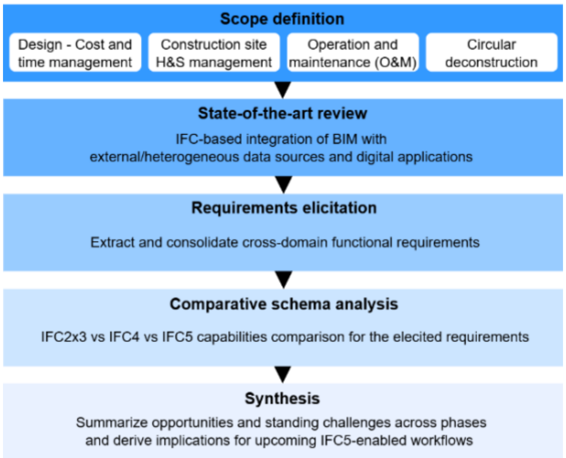

Figure 1: Research methodology

Building on these RQs, the study follows the workflow reported in Figure 1. First, the scope is defined by selecting four lifecycle phases and representative use cases: cost and time management, construction site H&S management, O&M, and circular deconstruction. A state-of-the-art review is then conducted, focusing on IFC-based approaches that integrate data sources and digital applications in these domains. Building on the literature, both specific and cross-domain functional requirements are derived and are intended to capture recurring patterns across lifecycle phases and use cases. These are subsequently used as evaluation criteria in a comparative assessment of IFC versions' capabilities, to determine which address the identified needs and to highlight gaps, trade-offs, and implications for upcoming implementations. Finally, findings are synthesized to summarize key challenges and opportunities.

Background

Since its early releases, IFC has been developed as a vendor-neutral schema to support information exchange across the AECO sector. Its evolution since the late 1990s reflects growing industry requirements alongside data modeling constraints (Laakso and Kiviniemi, 2012).

IFC2x3, standardized as ISO/PAS 16739:2005, remains the most widely implemented version. Based on a monolithic STEP/EXPRESS architecture optimized for file-based exchange, it reliably represents geometry and core building semantics. However, limited extensibility, weak integration of external data, and reduced support for process-oriented information constrain its suitability for data and real-time workflows (Jia et al., 2024).

IFC4 ADD2 TC1, standardized as ISO 16739-1:2018, following a first release in 2013, introduced incremental refinements over IFC2x3, including improved geometric representations, clearer and more extensive property sets (PSets), stronger semantic consistency, and closer alignment with Model View Definitions (MVDs). Complementary Information Delivery Specifications (IDS) and buildingSMART Data Dictionary (bSDD), further support the validation and definition of information requirements. IFC4 also expanded process-related modeling and domain coverage, though it preserved the underlying monolithic exchange paradigm. Subsequent revisions culminated in IFC4.3, released in 2024 as ISO 16739-1:2024, extending the schema to infrastructure assets with the same architectural foundations. As a result, despite a broader scope and richer semantics, persistent structural constraints remain, particularly regarding extensibility, modular evolution, and alignment with web and cloud-native environments (Yu et al., 2023). To address these constraints, IFC5 is under development as a step-change toward a modular, decomposed architecture supporting multiple serializations (e.g., XSD, OWL, JSON). This shift aims to improve interoperability with digital ecosystems and real-time workflows, while introducing new challenges related to governance, migration, and tooling maturity. In parallel, emerging OpenUSD-based pipelines illustrate how IFC semantics can be integrated with high-performance visualization frameworks to support digital twins and interactive applications (Ren et al., 2025).

The following subsections review IFC-based implementations across the selected lifecycle phases, summarizing the state of the art and informing of the functional requirements used in the comparative analysis.

Cost and time management – Design phase

During the design phase, BIM has been increasingly adopted to support cost estimation and scheduling, enabling earlier and more informed decision-making. In this context, 4D and 5D BIM, which integrate time and cost information with 3D geometry, have been widely investigated to improve transparency and control during design (Yang et al., 2022). Prior research has shown that model-based quantity take-off, automated cost calculation, and links to external cost databases can improve accuracy and consistency compared to document-based workflows (Sacks et al., 2018).

Recent studies have revisited the role of IFC in cost estimation and scheduling, demonstrating that cost and time information can be explicitly modeled using entities such as *IfcCostItem*, *IfcCostSchedule*, *IfcTask*, and *IfcWorkSchedule*. For example, Cassandro et al. (2024) propose an IFC-based approach linking cost items directly to geometric elements, enabling semi-automated cost calculation and validation, while comparative results indicate reductions in manual coding and errors relative to traditional 5D BIM software. Similarly, Fürstenberg et al. (2021) show that IFC4-based process models can support data exchange across stakeholders and software.

Despite these advances, cost and scheduling information are still rarely managed directly within IFC in practice. Instead, they are typically handled in external tools using proprietary formats (Borrmann et al., 2018). Links between geometry, cost, and time are commonly established through key–value mechanisms (e.g., identifiers, classification systems, or WBS codes), rather than through semantically explicit relationships (Boje et al., 2020). Consequently, current IFC-based workflows support data exchange rather than full data integration, leaving cost and time data external to the model and highlighting persistent challenges in modeling effort, tool support, and workflow integration.

Site and safety management – Construction phase

During construction, processes become more dynamic and seamless information exchange becomes crucial. Construction site H&S management is shaped by spatiotemporal complexity, as risk emerges from changing conditions, temporary works, and interactions among workers, equipment, and partially completed assets. Therefore, effective digital support requires situational awareness of what is being built, the sequencing and spatial context of activities, and the evolution of hazards and mitigation measures as the site layout changes (Zhang et al., 2024). IFC-based workflows address these needs by offering a shared, vendor-neutral backbone that anchors H&S information to a consistent spatial and semantic reference (Hu et al., 2024). Safety relevant attributes can be linked to elements and spaces via PSets and classifications, while process constructs (e.g., tasks, schedules) connect activities to affected components, enabling 4D safety reasoning and automated or semi-automated checks (e.g., fall risks) and visual outputs such as hazard maps (Hong and Teizer, 2025). Temporary works and site logistics remain essential yet often under-specified, so many approaches rely on modeling conventions, dedicated libraries, or external datasets linked through IFC identifiers to maintain consistency across revisions (Getuli et al., 2025). Given the document-intensive nature of H&S, exchanges must preserve traceability (e.g., inspection reports or photos) and support heterogeneous, frequently updated data streams (e.g., sensor observations) through linked services or databases rather than embedding volatile data in static files (Amo Larbi et al., 2024). Issue communication and visualization-ready delivery (e.g., dashboards) are also central, with growing attention to AR-assisted compliance checks (Corneli et al., 2025) and integrated VR/AR safety training (Getuli et al., 2020).

Operation and Maintenance – Operational phase

Effective management decisions during the operational phase require timely, accurate information on building components, systems, and their performance over time. IFC-based methodologies have been investigated to support the transition from construction to O&M. Key IFC entities, including MEP element classes, O&M-related PSets, and space-related constructs, provide the semantic linking of physical assets with maintenance data, performance indicators, and lifecycle cost data (Patacas et al., 2016). Several extensions to IFC4 have been proposed to improve the representation of maintenance activities, inspection, and failure modes. In parallel, COBie has become a widely adopted standard for structuring O&M data at handover; however, its implementation continues to face challenges related to data consistency and tool interoperability (Oliveira et al., 2024).

Despite these efforts, interoperability and data quality problems remain significant. O&M systems (such as CAFM and CMMS) rely on proprietary schemas that are incompatible with IFC, often requiring custom integrations that increase complexity and error risk (Farghaly et al., 2018). Operational data, including sensor measurements and work orders, are typically stored in external databases and only referenced in BIM models. Existing PSets frequently fail to meet O&M needs, leading to custom extensions and data loss during data exchanges (Tomczak et al., 2022). Additional barriers include inaccurate as-built models, generic O&M MVD, and organizational limitations such as insufficient BIM expertise and high implementation costs (Otranto et al., 2025). Emerging digital twin approaches aim to address these limitations by integrating real-time Internet of Things (IoT) sensor data with IFC, enabling continuous monitoring and predictive maintenance (Biagini et al., 2024). However, challenges related to data governance, interoperability, and standardized workflows limit large-scale implementation.

Circularity and reuse – Deconstruction phase

Robust reuse outcomes require reliable data: accurate as-built models and maintenance records enable assessment of reuse potential. Requirements for circularity, reuse, and deconstruction are inconsistently defined. Life Cycle Assessment (LCA) is central, but in IFC2x3/IFC4, its integration typically relies on custom PSets (Guntermann et al., 2025). Diverse metrics (e.g., global warming potential, service life, disassemblability) complicate integration. Harmonization efforts, as in the bSDD, are critical for a design for deconstruction (DfD) and for planning with reused components in a closed-loop circular economy. Kim, S. and Kim, S.-A. (2023) developed a graph-based DfD tool for steel construction using *IfcRelConnectsElements,* and Allam and Nik-Bakht (2025) combined knowledge graphs with IFC to automate deconstruction planning, deriving XML-based schedules with 4D simulations from PSets and IFC classes. Representation and extraction of circular information remain challenging. Tomczak et al. (2024) reported difficulties documenting disassembly instructions and element connections in IFC. While *IfcStructuralPointConnection* captures connection types for structural elements, non-structural components (e.g., windows) are more problematic. Mantelatto et al. (2026) used a Python routine based on IfcOpenShell to extract interdependence between structural elements.

IDS validates IFC information requirements. For circularity, limitations stem from IDS v1.0, not IFC: requirements address only individual entities (no cross-entity generalization), and abstract IFC classes cannot be referenced – since *IfcPort* is abstract, non-structural elements cannot be validated this way (Guntermann et al., 2025; Tomczak et al., 2024). Reuse Marketplaces

(Hagedorn et al., 2025) impose further requirements: component separability is critical; workflows require extracting and publishing component-level IFC files, raising feasibility questions around reliable extraction/integration and ID management, especially the fate of GUIDs when components are cut and whether parent IDs can generate child IDs.

Data requirements for IFC standards

This section consolidates five shared, cross-domain requirements for data integration and visualization, identified through analysis of the four lifecycle use cases. Although their relative importance varies across different stages, all requirements recur in multiple domains and therefore constitute shared evaluation criteria for the comparative analysis of IFC2x3, IFC4, and IFC5 concepts presented in the following sections.

Data model extensibility

To support evolving lifecycle needs, a schema is required that can be extended with additional concepts, attributes, and relationships while remaining stable across versions. This is essential for integrating heterogeneous data, such as cost structures, safety rules, operational and deconstruction data, without compromising interoperability, since limited extensibility often leads to proprietary extensions or reliance on external data, weakening standard-based integration.

Integration with external datasets

The capability to reference, align, and synchronize non-IFC data sources with IFC-based models is critical for integrating cost databases, construction schedules, sensor streams, regulatory documents, maintenance records, and environmental data. Beyond simple identifiers or file references, it requires semantically explicit links, version awareness, and support for heterogeneous data models, since authoritative information often resides outside BIM authoring environments across all lifecycle phases.

Time-aware and real-time application support

Representing and managing time-dependent states, events, and changes is essential to support dynamic workflows such as construction sequencing, safety monitoring, asset condition tracking, and lifecycle performance analysis. Time-aware data support includes explicit temporal relationships, event modelling, and the capacity to accommodate incremental updates and streaming observations. Without these capabilities, IFC models remain difficult to use in real-time applications.

Web-friendly data exchange

Suitability for modern web-based and cloud-native toolchains depends on efficient exchange and integration mechanisms, including lightweight serializations, API-based access, partial data retrieval, and reduced parsing overhead. These capabilities are increasingly important for collaborative platforms, digital twins, and distributed applications, where file-based, monolithic transfers introduce performance and scalability bottlenecks.

Performance-oriented geometry representation

Efficient use in high-performance visualization and rendering pipelines – such as real-time viewers, simulation engines, and immersive environments – depends on geometry representations that are performant to parse, stream, and render. While semantic richness remains essential, excessive geometric complexity or tightly coupled semantics can hinder interactive performance. This need is especially relevant for large-scale models, for advanced construction monitoring and XR-enabled interactive applications across the lifecycle.

Comparative analysis of IFC capabilities

This section qualitatively evaluates how IFC2x3, IFC4, and IFC5 support the identified requirements. Using the four use cases as reference scenarios, it focuses on structural capabilities rather than tool implementations.

Data model extensibility

IFC2x3 exhibits limited extensibility due to its monolithic schema and rigid inheritance structure. Concepts beyond the design phase are therefore typically introduced through custom PSets and informal conventions rather than controlled domain evolution, leading to inconsistent semantics and weak validation. In cost and time management, entities such as *IfcCostItem* and *IfcTask* exist but offer limited expressiveness, often prompting ad-hoc extensions. In construction H&S, safety concepts (e.g., hazards) are not first-class entities and are commonly represented via custom PSets and linked documents, reducing interoperability. Similarly, in O&M, *IfcAsset* provides only a basic anchor and lacks the operational structures expected by CAFM/CMMS systems, while deconstruction workflows rely almost entirely on project-specific extensions due to minimal native support for circularity and LCA information.

IFC4 expands semantic coverage and improves conceptual clarity, reducing the need for customization in some areas, while largely preserving the same extensibility mechanisms based on PSets, classifications, and external links. As a result, fragmentation persists in domains that require structured, evolving semantics. Refinements in cost and time entities, standardized risk-related properties for H&S, and the introduction of entities for O&M represent incremental progress. Still, they do not fully support complex workflows such as work-order hierarchies or lifecycle-oriented extensions. Deconstruction-related information still depends heavily on custom PSets and external vocabularies (e.g., bSDD).

IFC5 explicitly addresses these limitations through a modular architecture that separates stable core concepts from domain-specific modules, enabling parallel and governed semantic evolution across lifecycle phases. While this improves the feasibility of dedicated extensions, it also introduces coordination challenges related to versioning and cross-module consistency. Moreover, while increased extensibility facilitates customization, it must be carefully managed to avoid a proliferation of project-specific data that could compromise interoperability.

A comparative overview of IFC extensibility across lifecycle phases is provided in Figure 2.

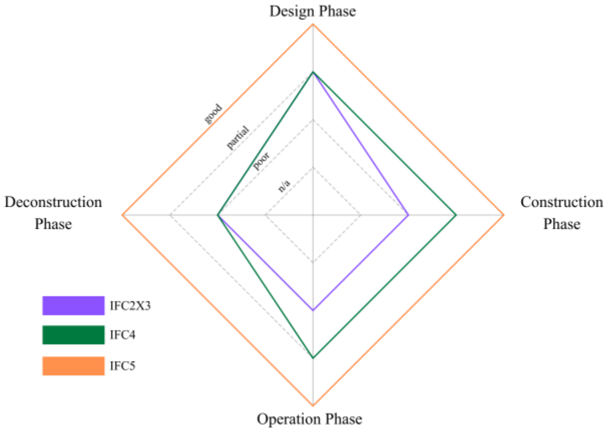

Figure 2: Data model extensibility chart

Integration with external datasets

In IFC2x3, integration with external datasets is largely implicit and identifier-based, relying on GUID matching, classification codes, and file references, with limited semantic alignment. In cost estimation, this leads to static connections of costs, schedules, and physical elements, pushing 4D/5D workflows to external systems without mechanisms for consistency checking. In construction H&S, safety documentation and site observations remain outside the model and are merely referenced, limiting traceability, automated compliance checks, and reliable synchronization. Similarly, in O&M, basic reference constructs provide insufficient structure to integrate CMMS work orders, IoT streams, or maintenance data. Deconstruction workflows face comparable limitations, as native support for integration with Geographic Information Systems (GIS) and Environmental Product Declaration (EPD) datasets is largely absent.

IFC4 improves reference mechanisms and clarifies process-related semantics, enabling more explicit associations between IFC and external datasets such as cost databases, schedules, H&S checklists, and O&M resources. While this reduces ambiguity compared with IFC2x3, data typically remains external to the IFC model, and integration continues to rely on GUIDs. As a result, bidirectional synchronization with frequently updated sources, such as sensors, KPIs, or H&S issue lifecycles, remains weak and project-specific. Deconstruction scenarios still depend on external tools and additional semantic layers for GIS and EPD integration.

IFC5 explicitly targets heterogeneous integration through decoupled representations and web- and Linked-Data-friendly encodings (e.g., JSON/OWL), improving semantic interoperability with external services across domains. Alignment with OWL/RDF and Linked Data principles can support richer, machine-interpretable integration with ontologies (e.g., CI/SOSA/SSN), compliance repositories, CMMS, and issue-tracking systems. However, effective interoperability will ultimately depend on standardized mappings, governance frameworks, and robust identity and version management across data sources. The IFC integration with external datasets across lifecycle phases is provided in Figure 3.

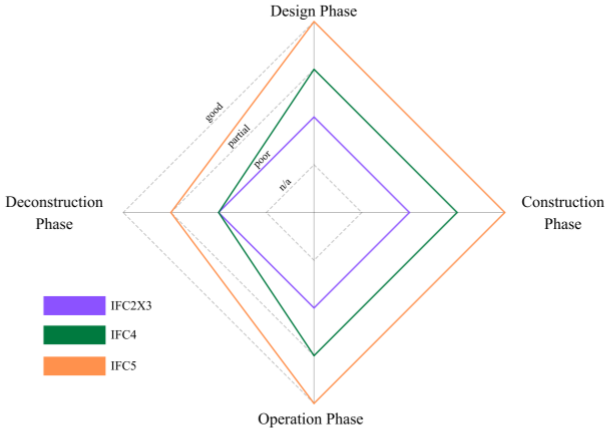

Figure 3: Integration with external datasets chart

Time-aware and real-time application support

In IFC2x3, support for time-aware and real-time applications is minimal and largely planning-oriented, with no effective constructions for dynamic events or state changes. As a result, cost and time management updates (e.g., schedule changes or actual versus planned values) are typically handled outside IFC, and 4D/5D workflows rely on external tools. In construction H&S, time-stamped safety events and evolving site conditions cannot be natively represented, limiting IFC's role to a static geometric reference. In O&M, *IfcTimeSeries* allows storage of time-dependent values but does not support event-driven transitions or maintenance histories, constraining native performance tracking. Circular planning workflows are similarly unsupported, as IFC2x3 provides no mechanisms for real-time monitoring or incremental change management.

IFC4 enhances scheduling semantics through richer process entities and relationships, enabling more explicit representation of planned timelines and dependencies. This supports improved cost and time planning and structured scheduling of H&S activities, such as inspections. However, the model remains essentially static: event-driven updates, state transitions, and continuous data flows are not natively supported. In O&M, although device entities are introduced, real-time data feeds and dynamic updates still depend on external platforms, reducing IFC4 to a reference role. Limitations also persist in circular planning, where incremental model changes and real-time visualization of evolving variants are not directly supported.

IFC5 introduces a conceptual shift toward time-aware and event-based representations, aligning more closely with digital-twin-oriented workflows. This could enable tighter coupling between schedules and changing quantities or costs, explicit modeling of temporal validity and evolving risk states in construction H&S, and dynamic asset states with predictive triggers in O&M. For deconstruction planning, event-based and incremental-change concepts could support more responsive variant tracking. However, their practical impact will depend on specification choices, serialization, querying, synchronization, and performance in time-critical applications. Figure 4 summarizes the IFC time-aware and real-time application support across lifecycle phases.

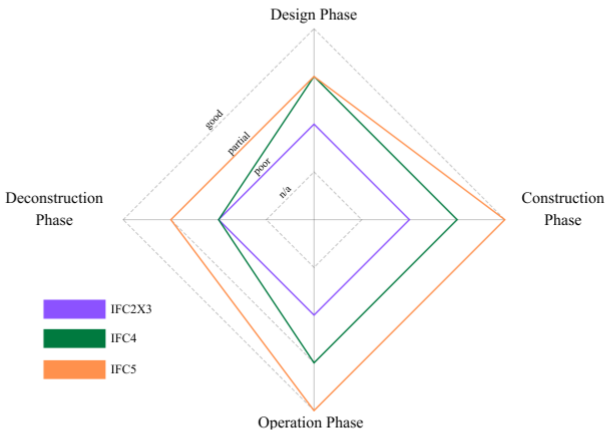

Figure 4: Time-aware and real-time application support chart

components and attributes. The trade-off is greater architectural complexity, requiring standardized interfaces and strong governance across distributed services. The outcomes are summarized in Figure 5.

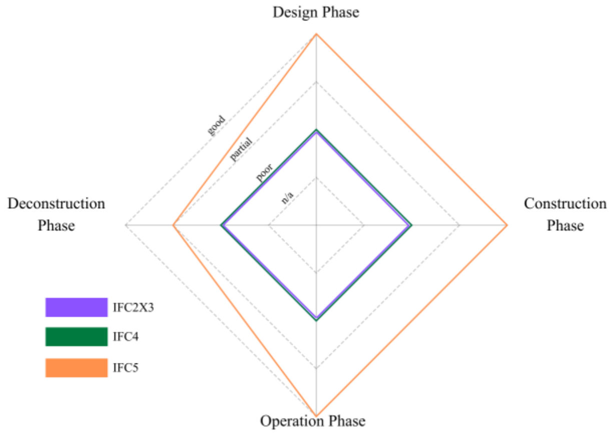

Figure 5: Web-friendly data exchange chart

Web-friendly data exchange

IFC2x3 is fundamentally based on STEP and file-oriented exchange, resulting in large, monolithic datasets that are poorly suited to web-based workflows. This limits scalable collaboration in cost and time management, where querying, incremental updates, and API-driven interactions are weakly supported, and 4D/5D coordination typically relies on external tools and full-file transfers. In construction H&S, frequent dissemination of updated information requires repeated exchange of complete IFC files and linked documents, creating overhead for mobile and field use and weakening traceability. In O&M, routine cloud or mobile queries require full-file parsing, as spatial containment and relationships cannot be selectively accessed, making web-scale operations inefficient. Similar limitations affect deconstruction scenarios involving distributed stakeholders and reuse-oriented platforms.

IFC4 improves schema consistency and clarifies relationships but does not alter the underlying exchange paradigm. Web-based use cases, therefore, still depend on full file transfers or middleware layers. As a result, just-in-time access to relevant model subsets, such as elements affected by a task, safety issue, or cost update, remains difficult without external services. In O&M, despite clearer spatial constructs, the lack of native API patterns and partial extraction mechanisms continues to constrain cloud dashboards and mobile applications. Deconstruction workflows likewise remain poorly supported by monolithic exchange models.

IFC5 explicitly moves toward web-native exchange through lightweight, language-independent encodings that enable API-based access, partial data exchange, and incremental updates aligned with cloud-native toolchains. These capabilities support specific queries and updates in cost/time, fast publication of H&S changes, and REST-like access to assets and spaces for O&M applications. These capabilities suit distributed reuse and urban-mining workflows needing selective extraction and publication of

Performance-oriented geometry representation

IFC2x3 geometry prioritizes semantic completeness over real-time performance, which limits its suitability for interactive and visualization-intensive applications. In cost and time workflows, complex boundary representations and detailed solids often degrade performance in large models. In construction H&S, these limitations are particularly evident in AR/VR-based coordination and safety training, where low latency and stable frame rates are essential, requiring external conversion and simplification. In O&M, detailed geometric representations are excessive for dashboards, space management, and mobile wayfinding, while standardized lightweight proxies are not natively defined. Similar constraints hinder interactive visualization in deconstruction and reuse-oriented scenarios.

IFC4 improves geometric robustness and introduces tessellated representations, which better align with real-time rendering pipelines. However, performance-oriented geometry remains a secondary concern. Visualization workflows across cost/time analysis, H&S AR/VR applications, and O&M digital twins still depend on external optimization techniques or conversion to alternative formats. A key limitation is the tight coupling between semantics and geometry within product shape structures, which restricts selective extraction of lightweight, visualization-only subsets for streaming, incremental loading, and mobile or immersive use. Circular planning workflows face comparable constraints.

IFC5 explores a clearer separation between authoritative semantics and visualization-optimized geometry, with conceptual alignment to high-performance scene frameworks such as USD. This approach can support responsive model exploration in cost/time management, multiple levels of geometry tailored to AR/VR safety coordination, and simplified operational views for O&M applications consumed directly by web or AR tools. For circular design, it enables interactive evaluation of reuse scenarios. The main challenge lies in preserving semantic-geometric coherence and traceability, ensuring that optimized visual assets remain reliably linked to authoritative IFC entities for auditing and regulatory purposes. A comparative overview of outcomes is provided in Figure 6.

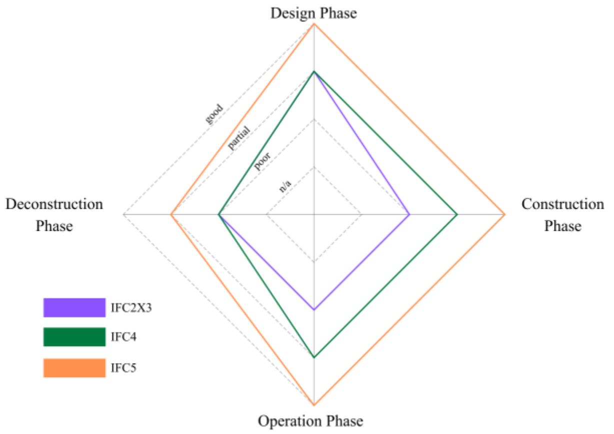

Figure 6: Performance-oriented geometry representation chart

Conclusion

This paper evaluates the current state of IFC2x3 and IFC4 and examines the future potential of IFC5 for data-centric integration across the building lifecycle. The comparative analysis highlights that IFC2x3 and IFC4 remain largely constrained by a monolithic, file-based exchange paradigm. Although IFC4 introduces notable semantic and geometric improvements, persistent limitations affect all lifecycle phases, particularly in operation and deconstruction. These include limited extensibility beyond geometry-centric models, reliance on identifier-based links to external data sources, and insufficient support for time-aware and real-time workflows.

The analysis of IFC5 indicates a strategic shift toward modular, web-aligned architectures, supporting multiple encodings and improved integration with contemporary toolchains. However, these advances redistribute rather than eliminate complexity, introducing new challenges related to governance, tooling maturity, identity management, and semantic consistency across distributed representations. Moreover, while increased extensibility facilitates customization, it must be carefully managed to avoid a proliferation of project-specific data that could undermine interoperability. Several critical capabilities also remain dependent on implementation choices.

The main limitations of the study comprise the lack of quantitative evaluation and empirical validation, as well as limited consideration of context-specific regulatory aspects and management implications. Future work will address these issues through quantitative metrics, real-world validation, and further investigation of governance and coordination aspects.

In conclusion, while IFC4 represents an essential evolution beyond IFC2x3, it does not fully address interoperability constraints. IFC5 offers a promising reorientation toward integration-oriented workflows, whose success will depend on robust governance frameworks, mature tooling, and standardized integration patterns beyond traditional file-based exchange.

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