2025 European Conference on Computing in Construction

CIB W78 Conference on IT in Construction

Porto, Portugal
July 14-17, 2025

DIGITAL TWINS IN LARGE INFRASTRUCTURE FACILITIES

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Introduction

Large infrastructure facilities enable the transportation of people and goods. During operation and maintenance (O&M), failure could endanger public safety or increase material usage and pollution. Therefore, their reliability, availability, and accessibility are crucial during the O&M phase (Sabatino et al., 2015).

Bridge management (Brighenti et al., 2024), Structural Health Monitoring (Ko and Ni, 2005), and bridge life-cycle (Frangopol et al., 2017) contribute significantly to its reliability. Heterogeneous information spans from the inner (structure, workers) to the facility's outer scope (traffic users, vessels). Hence, it is vital to manage incoming and outgoing information properly.

The project adopts the concept of Digital Twins (DTs). It enables bi-directional data flow between the physical facility and its virtual counterpart (Fuller et al., 2020). The project aims to develop a structure (Boje et al., 2020; Pregnolato et al., 2022) for the data management and semantic enrichment for the O&M projects using the Linked Data (LD) and Industry Foundation Classes (IFC). This way, the IFC Schema is explored for the maintenance scenarios, which would synergize with Semantic Web Technology, already validated in academic research of built environment.

The aim opens the hypothesis: It is possible to define an open system architecture of DTs for large infrastructure facilities that are reusable and scalable using open data standards and LD principles.

Methodology

The methods consist of the four main steps, with a continuously present activity throughout the project collaborative inquiry and feedback sessions with the experts from the Sund & Belt.

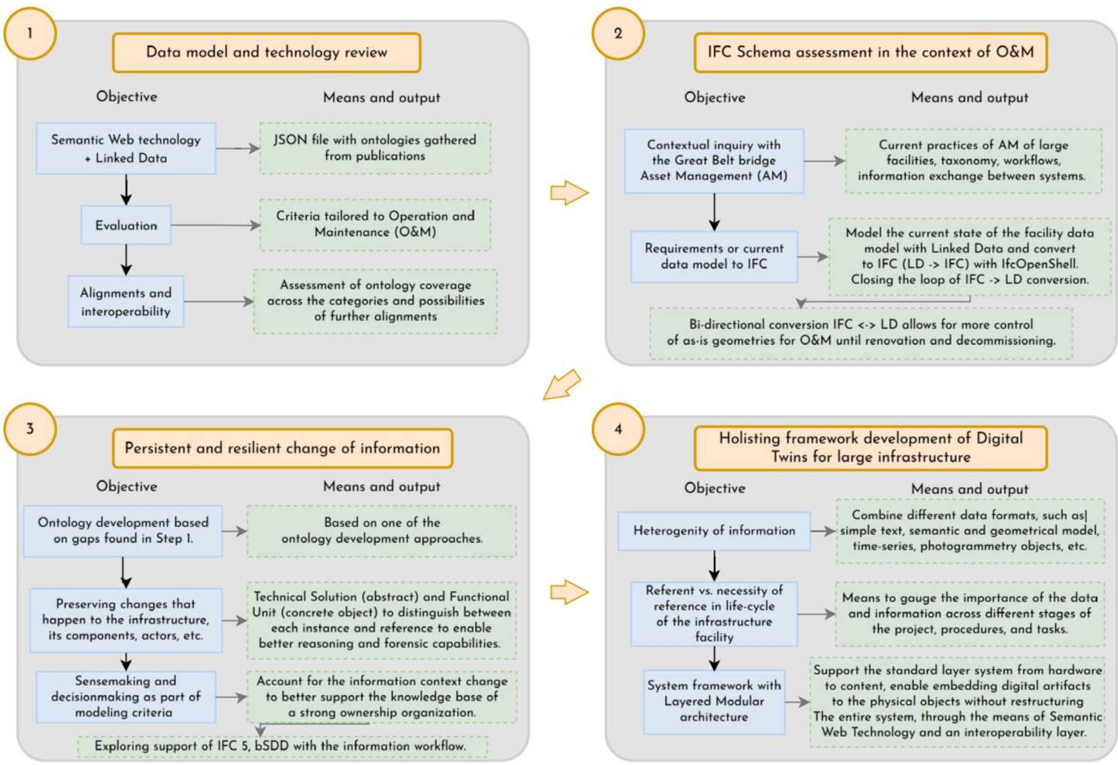

Figure 1: Methodology steps demonstrating objective, means and output of each part of the research

The first step is to review ontologies used in facilities for O&M according to the standard categories in the domain. The second is to investigate the capabilities of the IFC for O&M. The third is to facilitate gaps from the previous study using bridge ontologies. The fourth is to combine findings to enable data and schema integration for DTs framework. Figure 1 illustrates the steps and subtasks that need to be achieved.

Results

Some of the steps have been already completed (Table 1). The outline and the results of the preliminary step are summarized in Figure 2.

In the first step, the results of the ontology review for O&M, based on the method of De Andrade Pereira et al. (2022), , are contained in a paper that is currently under review. The main O&M categories are covered by at least one ontology. Majority of the proposals have not been published on the Web. IFC 4.3 is the most suitable for comprehensive O&M coverage.

In the second step, analysis of IFC 4.3 Schema (International Organization for Standardization, 2024) in workflows in O&M, such as planning or changing equipment, was carried out. Ownership, asset history, document reference, and time-series were successfully included in the IFC.

In the third step, the group used a custom converter for the round-trip IFC-RDF (Resource Data Framework) to study the feasibility of a bi-directional workflow by leveraging LD without the risk of outdating the IFC file considerably. The potential use of IFC 5 (van Berlo et al., 2025) is still to be analyzed.

In the fifth step, IFC and ifcOWL (Beetz et al., 2009) are chosen as reference ontologies. The ongoing assessment is to determine the data model, formats, and specialized ontologies to reuse to complement the core. Primary candidates are Bridge Topology Ontology (BROT) (Hamdan et al., 2020), Damage Topology Ontology (DOT) (Hamdan et al., 2021), Bridge Maintenance Domain Ontology (BMDO) (Zhang et al., 2023).

Table 1:Methodology steps completion

Step	Details
The Great Belt Bridge	Data gathered and examined. Authors need to validate the solution with the Great Belt team.
The Femern Belt Tunnel	Data partially gathered and examined. More feedback sessions are expected
Ontologies for Operation and Maintenance in bridges	Under review. The evaluation has shown the influx of ontological models for O&M for bridges. However, most of them are not accessible online.
IFC Schema assessment	Partially done with testing schema against the Great Belt O&M workflows and important artifacts. It includes asset history, ownership, responsibility, maintenance schedule, document reference, and time-series.
Persistent and resilient change of information	Partially done. Custom IFC-RDF round- trip converter in Python to update IFC and the knowledge graph anytime. The next step is to include IFC 5.
Holistic framework development	Collected ontologies that will be used in connection with other parts of the data models, for example, IFC models, asset history, schedule, and concrete surface photogrammetry. The social aspect of knowledge, expertise, and retention development is set in motion.

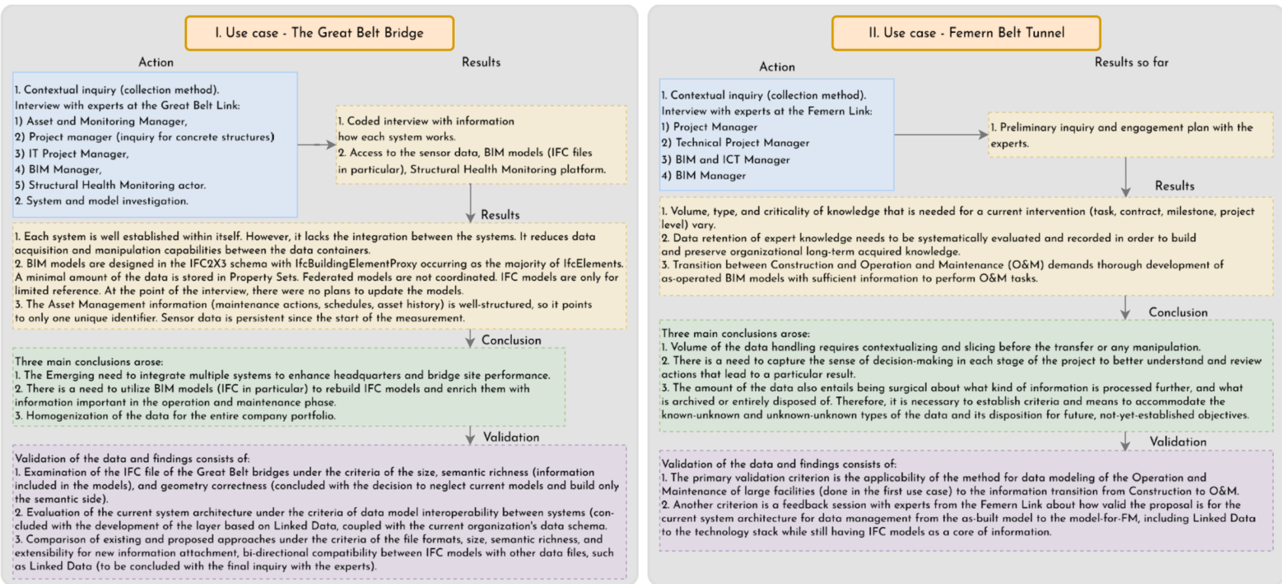

Figure 2: Breakdown of use cases, The Great Belt (Link) and Femern Belt (Link)

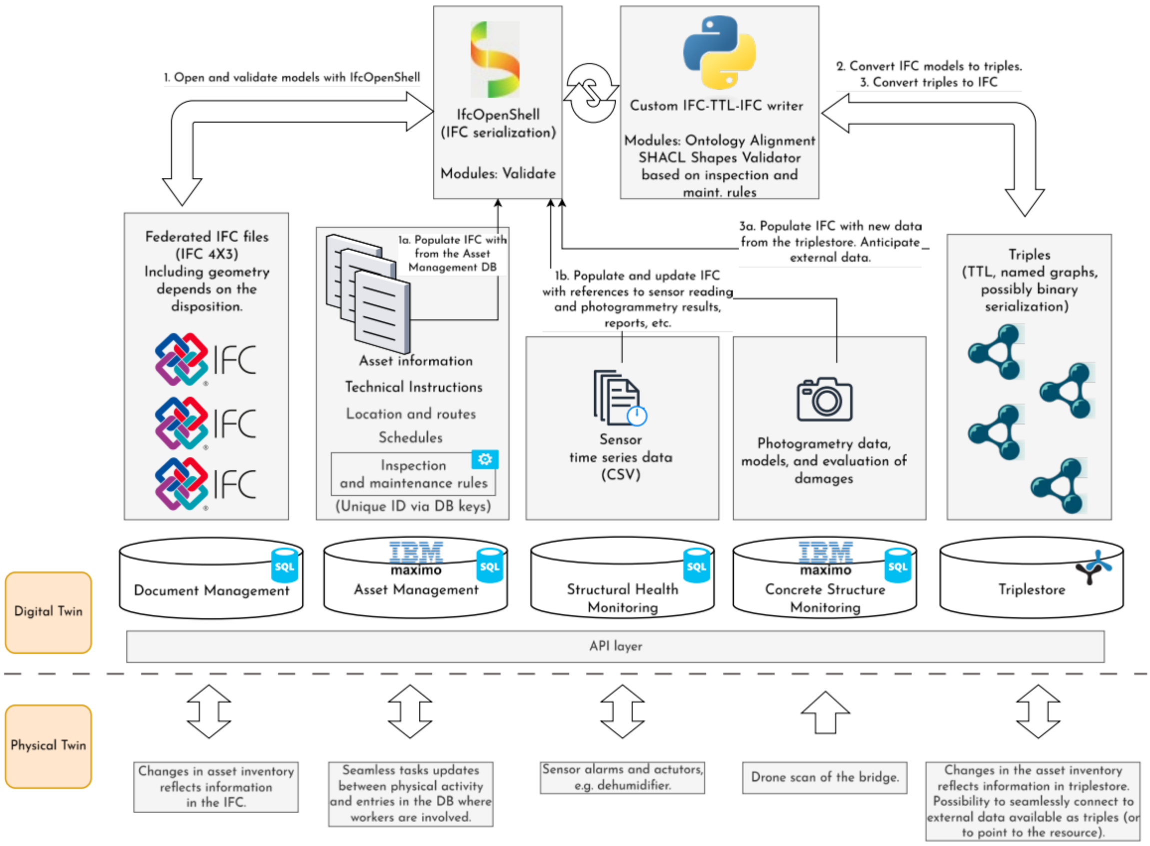

Figure 3: Information management for use case 1 - the Great Belt with the division on Digital and Physical Layer.

Completed steps are shown as system information management in Figure 3. Main containers in the organization are not completely connected so they cannot communicate freely. Enhanced capabilities are possible by utilizing batch processing of IFC files with IfcOpenShell library (IfcOpenShell, 2025), and serialization to the triples (TTL format).

Discussion

Case studies show different data management approaches for the same project stages. It is due to the technological gap between the projects. Femern Belt uses the IFC models. Conversely, the Great Belt prefers to maintain the usage of CAD and PDF drawings. The common denominator is asset-oriented maintenance which means that any activity must be connected to an element. One of the challenges is to balance system rigidity with evolving data models while also ensuring proper integration of BIM models with other data sources.

Conclusion

The compound approach of IFC and LD for the O&M allows flexibility and keeps the models consistent. However, it requires robust, tight integration between the models. This implies that extension of the data graph must be compatible with IFC. Nevertheless, this strategy creates opportunities for further stages such as renovation, decommissioning, and reuse because the model is already up to date for use in authoring tools.

Acknowledgments

The authors would like to acknowledge the funding from the Technical University of Denmark. We would like to thank the Sund & Bælt organization and individual members for sharing their experience and work.

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