INTEGRATING TIME, COST, AND RESOURCES IN BIM: A PROCESS-ORIENTED FRAMEWORK

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Abstract

Current practices in scheduling, cost estimation, and resource accounting rely on fragmented workflows, unclear use of Industry Foundation Classes (IFC), and proprietary tools that hinder interoperability. These limitations lead to error-prone, non-standardized processes. This study proposes a framework based on IFC4.3 that defines construction processes and process templates to integrate time, cost, and resource data within IFC. A web-based prototype demonstrates the approach, enabling automatic generation of WBS, CBS, Bills of Quantities, and 4D simulations. Results confirm the feasibility and completeness of IFC for these domains, providing a foundation for interoperable, standardized project-control tools and future real-case implementations.

Introduction

Effective project control is essential for achieving objectives related to time, cost, quality, and safety. This discipline relies on systematic processes for planning, measuring, monitoring, and managing project performance. The present study focuses specifically on time scheduling, cost estimation, and resource accounting. Traditional methods for managing these domains are often labor-intensive, error-prone, and inefficient (Sheik et al., 2023). In particular, time scheduling frequently depends on the subjective experience of planners rather than on objective and verifiable data (Ciribini et al., 2015). Current practices generally do not support an integrated approach to cost, time, and resource management. Consequently, calculations are duplicated, multiple software tools—often incompatible unless part of the same proprietary ecosystem—must be used, and the same information is stored across separate databases, increasing the risk of data inconsistency (Al-Sinan et al., 2024). When such procedures are not aligned with a common standard such as IFC (International Organization for Standardization, 2024), collaboration becomes fragmented, data exchange becomes unreliable, and stakeholders cannot rely on a shared, consistent representation of project information (Lu et al., 2022).

This paper proposes a process-oriented, integrated framework for managing costs, tasks, and resources based on the IFC4.3 standard (International Organization for Standardization, 2024) through the conceptualization of process templates. The primary contribution of this work is a fully IFC-compliant framework that demonstrates how IFC classes can work together to support the use case of integrated management of time scheduling, cost estimation, and resource accounting. The framework provides a standardized, repeatable, and open-source, data-driven approach. In the ongoing discussion and formalization of the IFC5 standard, the development and dissemination of use cases and frameworks are particularly important. The emerging IFC5 version aims to preserve the semantic scope of IFC4.3 (van Berlo et al., 2021); however, certain branches, such as *IfcProcess* and *IfcControl*, may require reconsideration. Contributions such as the present work can help identify strategical or critical aspects, potential gaps, and redundancies within the standard, thereby supporting informed feedback for future revisions.

Additionally, a prototype web application is presented to demonstrate the practical feasibility and potential of this framework in real-world applications.

Background

Traditional practices rely on manually measuring elements from CAD drawings and calculating task costs, resource usage, or task progress using spreadsheets. Even when Building Information Modeling (BIM) workflows are adopted, practitioners frequently depend on proprietary software or closed ecosystems that limit interoperability among stakeholders. In many cases, BIM is used primarily for quantity extraction, while subsequent data processing continues to be performed in spreadsheets. In other cases, organizations introduce user-defined parameters to encode 4D (planning-related BIM data) and 5D (cost-related BIM data) information, enabling integration with external software tools or spreadsheets through export tables or direct file import. However, these approaches lack standardization and consequently hinder interoperability. Nevertheless, proprietary software continues to dominate the market, likely due to its current robustness and maturity.

Among approaches based on the IFC standard, a systematic literature review (Avogaro & Zanchetta, 2025) demonstrates that existing research provides limited guidance on managing these domains individually, and even less on their integrated handling. The same study also highlights the lack of tools capable of supporting comprehensive, IFC-based management of time, cost, and resources. While adopting IFC is a crucial step toward achieving interoperability in data management, it is not sufficient to enable effective collaboration on its own. Professionals also require practical tools for handling IFC data and supporting collaborative workflows. In this context, web-based platforms represent an effective solution (Park et al., 2017), as they enable remote collaboration, facilitate the reuse of shared information, and provide intuitive interfaces that do not require specialized programming skills.

Relevant contributions in the literature include (Cassandro et al., 2025), who propose a resource-centric approach that integrates building geometry with scheduling and cost data using ontologies as a semantic foundation. In addition, (Sheik et al., 2023) developed an automated progress monitoring framework based on IFC, leveraging classes such as *IfcTask*, *IfcCostItem*, and *IfcConstructionResource*, and implemented a supporting web-based application. Moreover, Blender, when used with the Bonsai extension (IfcOpenShell, 2025), provides dedicated functionalities for time scheduling, cost estimation, and resource accounting based on IFC classes.

Methodology

A previous study (Avogaro et al., 2024) demonstrated that the IFC standard provides a high level of product definition, offering a substantial number of properties that cover most construction domains. This enables the definition of *IfcElementType* entities containing the shared information required to describe their corresponding *IfcElement* instances. In practical terms, this allows the creation of reusable product templates that can be applied across multiple projects, thereby reducing professional effort and enhancing interoperability and collaboration. The same logic can be extended to the construction processes associated with specific element types. In most cases, all instances of a given product type follow a similar sequence of construction processes. This observation led to the conceptualization of *process templates*, defined as the digital representation of all processes required to construct a given product. Two categories of processes are identified: (1) *construction processes*, which consume resources to produce a building element, and (2) *other processes*, such as transport or curing, which do not directly contribute to the physical creation of the product.

Construction processes typically consume four types of resources: human resources, materials, products, and equipment. Each resource is associated with a cost, and the aggregation of these costs determines the total cost of the process. However, only human resources and equipment contribute to time consumption, thereby defining the duration of each process. Within a process template, multiple processes may occur sequentially or in parallel, and the total duration of an element is determined by the time elapsed between the start of the first process and the completion of the last.

Processes are generally associated with different phases of a project. For example, within a process template for a concrete wall, concrete casting belongs to the structural phase, whereas painting belongs to the finishing phase. To ensure effective project scheduling, each task must be correctly assigned to its corresponding phase. This hierarchical organization defines a Work Breakdown Structure (WBS) for the project. Similarly, a Cost Breakdown Structure (CBS) aligned with the WBS is required to enable consistent cost management across different phases and processes.

Following the conceptualization of the framework based on project management principles, a detailed analysis of the IFC4.3 standard (buildingSMART Technical, 2024) was conducted to assess its capability to represent these data structures and relationships. The results of this analysis are presented in the following section.

Subsequently, a prototype web application was developed to test the proposed framework and to provide an open-source environment for managing and inputting the associated data. The implementation details are described in the Implementation section.

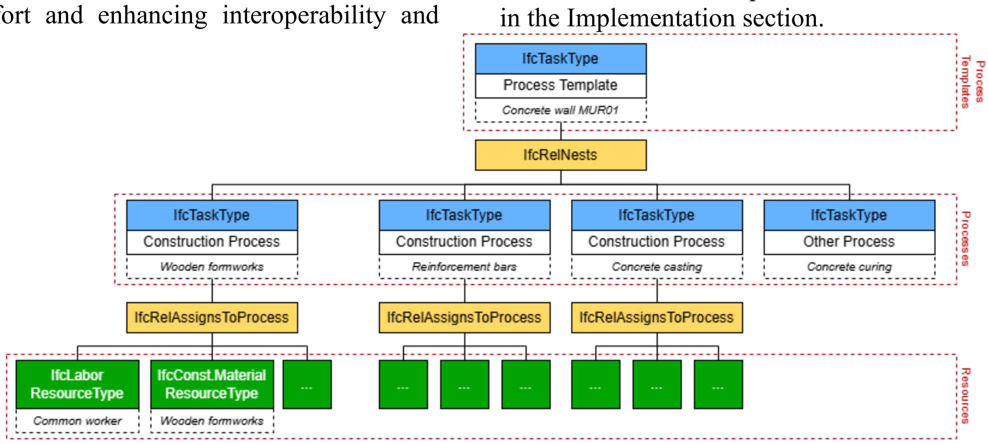


Figure 1: Process Template structure

Analysis

Within the IFC data model, a process template can be represented by an *IfcTaskType* entity that aggregates other *IfcTaskType* entities corresponding to individual processes, as illustrated in Figure 1. Each construction process consumes different types of resources, which in IFC are modeled as subclasses of *IfcConstructionResourceType*. These include *IfcLaborResourceType*, *IfcConstructionMaterialResourceType*, *IfcConstructionProductResourceType*, and *IfcConstructionEquipmentResourceType*, representing human resources, materials, products, and equipment, respectively. In this structure, a construction process represented by an *IfcTaskType* is associated with one or more *IfcConstructionResourceType* entities, as shown in Figure 1.

To support the standardized definition of construction processes, price lists can be used as databases that provide detailed descriptions of construction activities. These lists typically include the unit cost of each activity, the required quantities of resources, and the associated costs for each resource, as illustrated in Figure 2. Additionally, information on the time consumption of labor and equipment resources provides a robust basis for calculating man-hours or machine-hours, enabling accurate estimation of the time required to complete a unit of work.

Construction Process					
Code	**Description**			**Meas. unit**	**Price**
VEN25-01.08.02b	PRE-MIXED DURABLE CONCRETE XC1 workability class S3 (semi-fluid), exposure class XC1, C 25/30			m^3	129,21
Resources					
Code	**Description**	**Qta**	**Meas. unit**	**Unit Price**	**Price**
VEN25-RU.01.04.a	GENERAL CONSTRUCTION WORKER	0,150	h	27,33 €	4,10 €
VEN25-PR-B.02.03.b	PRE-MIXED DURABLE CONCRETE XC1 workability class S3 (semi-fluid), exposure class XC1, C 25/30	1,050	m^3	114,02 €	119,72 €
VEN25-AT.14.05.00	HOT RENTAL OF ELECTRIC CONCRETE VIBRATOR	0,150	h	35,96 €	5,39 €

Figure 2: Example of price voice data

By leveraging *IfcConstructionResourceType* entities, all relevant price list data can be encoded within the IFC model. In subsequent stages, these data are combined with the quantities associated with each *IfcElement* to derive overall costs and durations. Specifically, the *BaseCosts* attribute of an *IfcConstructionResourceType* is used to represent the unit cost of a resource, while the *BaseQuantity* attribute defines an *IfcPhysicalQuantity* that expresses the resource consumption per unit of product. The *Name* attribute of this quantity specifies the relevant measured parameter (e.g., *GrossVolume*) or a calculation formula, as illustrated in Figure 3.

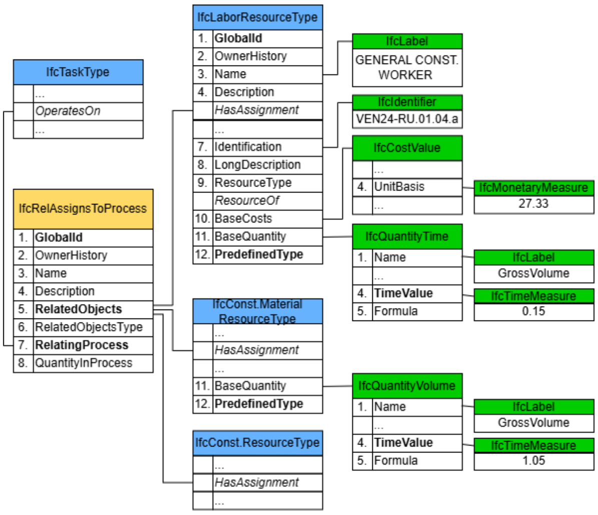


Figure 3: Use of the IfcConstructionResourceType subclasses

The total unit cost of a product corresponds to the sum of all associated resource costs. In this regard, a process template is considered as a structured arrangement of *IfcTaskType* and *IfcConstructionResourceType* entities that enables the standardized representation of price-list information within the IFC schema.

In the preceding paragraph, the procedure for encoding price list data into the IFC data model using process templates was described. The following section explains how to relate and instantiate the classes of a process template with specific *IfcElement* instances. The objective is to associate one or more *IfcBuildingElement* instances with an instantiated process template. As illustrated in Figure 4, the hierarchical structure of the process template represented through *IfcTaskType* entities is replicated using *IfcTask* entities, which now contain the actual duration of each process. The sum of these durations yields the total duration of the process template. A parallel structure is created for *IfcCostItem* entities, where the *IfcCostItem* corresponding to the process template aggregates the values of the individual process-level *IfcCostItem* instances.

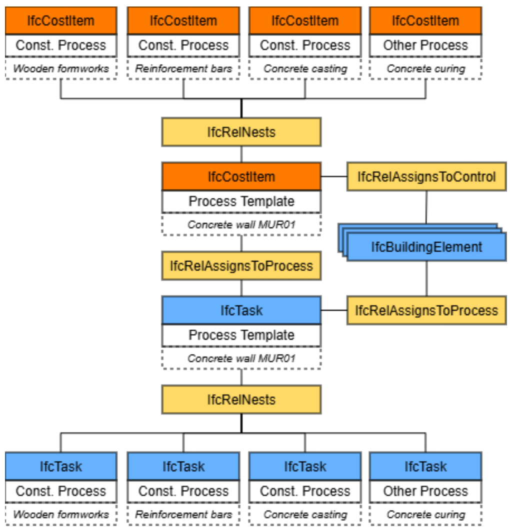


Figure 4: Symmetry in the hierarchical structure of IfcTask and IfcCostItem entities

Once the quantities of the various *IfcBuildingElement* instances associated with a process template are known, they are aggregated—through a scripted procedure—to enable the calculation of the corresponding resource quantities. For each *IfcConstructionResourceType* defined within the process template, the *BaseQuantity* attribute is retrieved, allowing identification of both the target parameter specified in the *Name* attribute of the *IfcPhysicalQuantity* (e.g., *GrossVolume*) and the quantity of resource consumed per unit of product. The target parameter is then extracted from the quantities of the building elements and used in the calculation by multiplying it by the consumption rate per unit of product. The resulting value is assigned as the *BaseQuantity* of the instantiated *IfcConstructionResource*. Based on this quantity, an *IfcCostItem* is created for the resource, and its *IfcCostValue* is computed by multiplying the resource quantity by the unit cost defined in the corresponding *IfcConstructionResourceType* (*BaseCosts* attribute). This procedure is repeated for each *IfcConstructionResourceType* associated with the process template. All resource-level *IfcCostItem* entities are then aggregated under a parent *IfcCostItem*, which sums their values and is associated with the corresponding *IfcTask* representing the construction process. This logic is consistent with the ISO 9000 definition of processes and with the ICOM process diagram. The resulting structure is presented in Fig. 5.

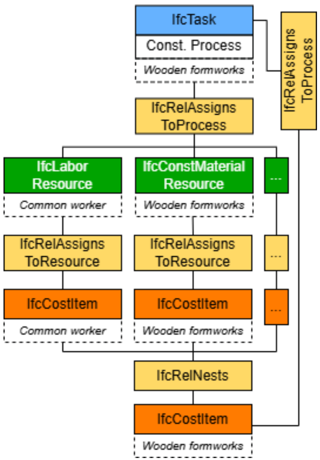


Figure 5: Relationships between IfcConstructionResource, IfcTask, and IfcCostItem entities

The duration of each *IfcTask* corresponding to a construction process is determined by the duration of the resources that consume time. As shown in Figure 2, resources such as labor and equipment require measurable time inputs. Using this information, it is possible to calculate the number of man-hours or machine-hours required to perform each construction process. However, these values represent workloads, not durations. For example, eight man-hours performed by two workers correspond to a four-hour task duration. The *Usage* attribute of *IfcConstructionResource* enables the use of the *IfcResourceTime* class, which includes the *ScheduleUsage* attribute that specifies the number of resources working concurrently. The ratio between *ScheduleUsage* and the required work quantity yields the resource-based duration. For each construction process, a script identifies the longest resource duration, which becomes the duration of the corresponding *IfcTask*.

Other processes—such as maturation or transportation—that do not rely on resource consumption may also have predefined durations and costs, which contribute to the overall duration and total cost of the process template.

Each process within a process template may include a defined starting date, from which its finishing date can be derived by adding the corresponding duration. Tasks may also incorporate sequencing relationships, constraints, and other scheduling logic. All temporal information is stored in the *IfcTask* entities and their associated *IfcTaskTime* objects. These data can be used to generate Gantt charts and construct a WBS. Furthermore, the hierarchical organization of *IfcCostItem* entities enables the creation of a CBS that mirrors the WBS, supporting procedures for monitoring actual costs over time and improving the overall quality of project control. Finally, for each task in the WBS, it is possible to extract a detailed list of resources and thereby generate task-specific Bills of Quantities.

Implementation

To evaluate the proposed framework, the authors developed a prototype application. The system is implemented as a Single-Page Application (SPA) using the React framework. The web application relies on libraries from That Open Company (*That Open Company*,

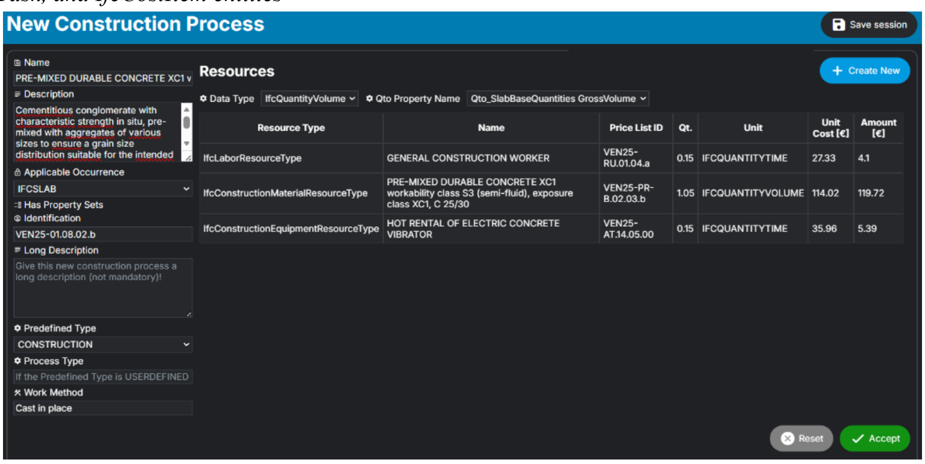


Figure 6: New Construction Process page

2025) to visualize IFC models and to read, write, and manage IFC objects.

The first interface page enables users to create new processes, as shown in Figure 6. The user interface allows the input of all attributes of an *IfcTaskType* entity. Among the most relevant attributes, *ApplicableOccurrence* specifies the IFC class to which the process applies (e.g., *IfcWall*), while *PredefinedType* allows the application to distinguish between construction processes (e.g., CONSTRUCTION, INSTALLATION, etc…) and other types of processes (e.g., MOVE, ATTENDANCE, etc…). For construction processes, the user can define the physical quantity to be considered (e.g., *IfcQuantityVolume*) and the corresponding property (e.g., *GrossVolume*), including formulas where necessary (e.g., "Qto_WallBaseQuantities GrossVolume − Qto_WallBaseQuantities GrossSideArea × 0.1"). The application provides selectable options for physical quantities and properties based on the IFC class specified in *ApplicableOccurrence*. These data are stored in the *BaseQuantity* attribute of the associated *IfcConstructionResourceType* entities. Within the same interface, the user can also define the list of *IfcConstructionResourceType* entities and their attributes. Upon saving, all information is written to an IFC-SPF file stored on a server, which functions as a shared database to support data reuse across users and to minimize redundant input.

The second interface page mirrors the structure of the first but is dedicated to creating new Process Templates, as shown in Figure 7. As before, the user completes a set of attributes for an *IfcTaskType* entity; however, *PredefinedType* is pre-filled as USERDEFINED, and the *ProcessType* attribute is set to PROCESSTEMPLATE. The user can assemble the set of processes that compose the template by selecting from those previously stored in the IFC-SPF database. Once completed, the template is saved to the shared database. An additional interface page presents multiple synchronized panels. The first panel, shown in Figure 8, provides a 3D model viewer alongside a list of available process templates. After selecting one or more model elements, the user can associate a process template with them.

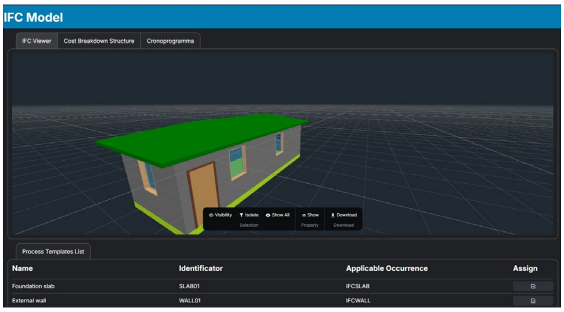


Figure 8: IFC viewer integrated with the process template assignment interface

For each construction process, the application opens a dialog prompting the user to specify the number of resources that contribute to time consumption, enabling accurate calculation of process duration, as shown in Figure 9. The dialog also requires the assignment of the process to a Work Breakdown Structure (WBS) work package, ensuring alignment with the Cost Breakdown Structure (CBS). For non-construction processes, the application instead requires manual input of duration and cost.

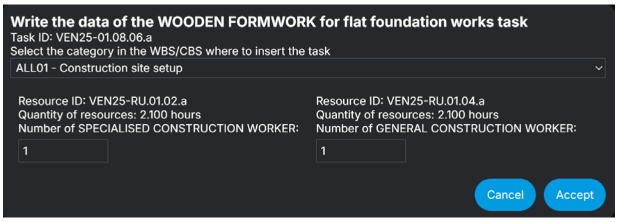


Figure 9: Resources consumption dialog

Results

The prototype enables automated cost estimation, time scheduling, and resource accounting based entirely on data. A second panel presents the Cost Breakdown Structure (CBS), mirroring the hierarchy of the Work Breakdown Structure (WBS) and reporting the cost associated with each process, as shown in Figure 10. A further panel provides an overview of the resources assigned to each process.

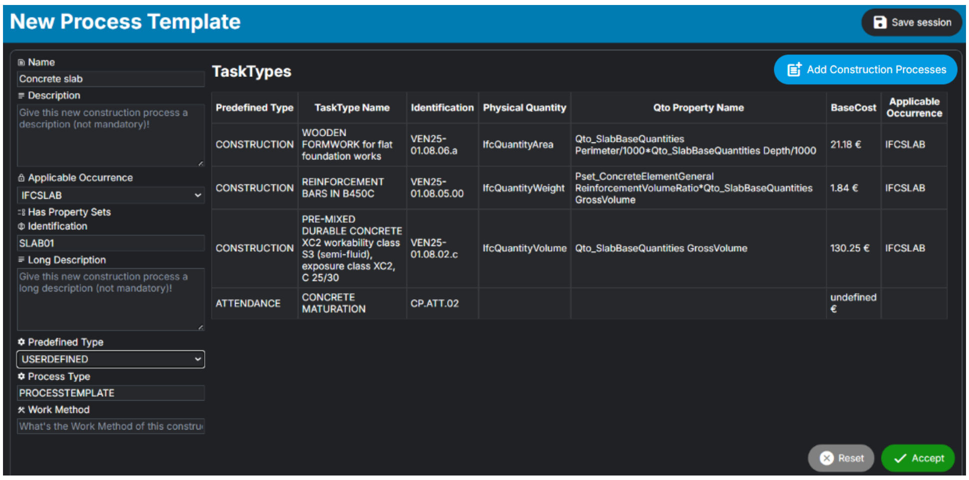
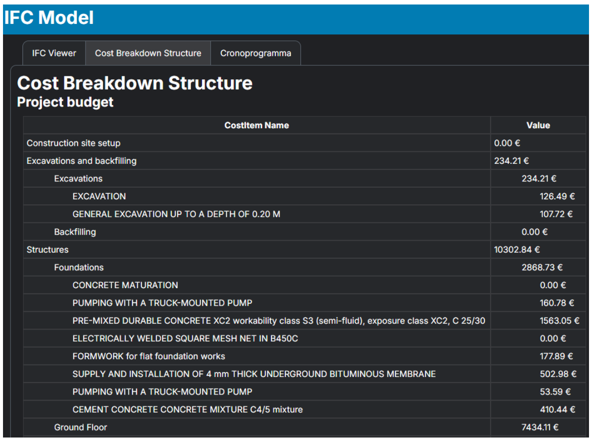


Figure 7: New Process Template page



CostItem Name	Value
Construction site setup	0.00 €
Excavations and backfilling	234.21 €
Excavations	234.21 €
EXCAVATION	126.49 €
GENERAL EXCAVATION UP TO A DEPTH OF 0.20 M	107.72 €
Backfilling	0.00 €
Structures	10302.84 €
Foundations	2868.73 €
CONCRETE MATURATION	0.00 €
PUMPING WITH A TRUCK-MOUNTED PUMP	160.78 €
PRE-MIXED DURABLE CONCRETE XC2 workability class S3 (semi-fluid), exposure class XC2, C 25/30	1563.05 €
ELECTRICALLY WELDED SQUARE MESH NET IN B450C	0.00 €
FORMWORK for flat foundation works	177.89 €
SUPPLY AND INSTALLATION OF 4 mm THICK UNDERGROUND BITUMINOUS MEMBRANE	502.98 €
PUMPING WITH A TRUCK-MOUNTED PUMP	53.59 €
CEMENT CONCRETE CONCRETE MIXTURE C4/5 mixture	410.44 €
Ground Floor	7434.11 €

Figure 10: Cost Breakdown Structure page

The third panel displays the WBS, aligned with the CBS, and visualized through a Gantt chart representation, as illustrated in Figure 11. Within this panel, users can refine task durations, assign constraints, reorder tasks, and adjust dependencies through intuitive drag-and-drop interactions. Although the automatically calculated durations provide a reliable baseline, professional judgment is often required to adapt them to project-specific conditions; therefore, manual editing is supported. All modifications are not only reflected in the user interface but are also written back into the IFC model.

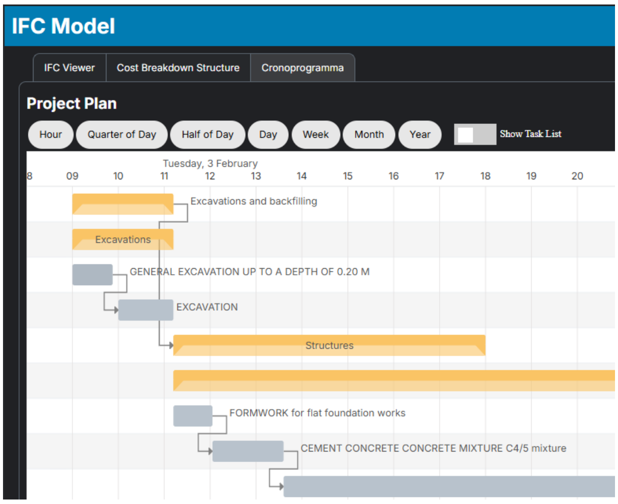


Figure 11: Work Breakdown Structure page trough a Gantt representation of the IfcTask

An additional interface page is dedicated to 4D simulation, allowing users to visualize the temporal progression of the project through animated model playback, as shown in Figure 12.

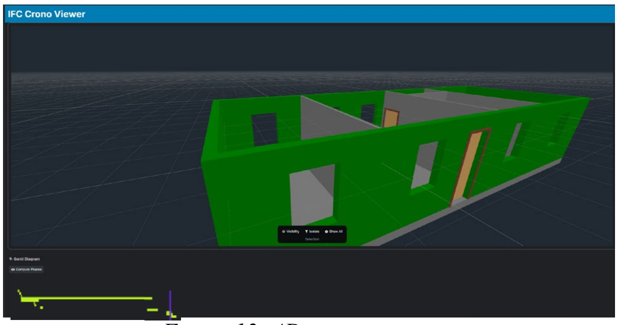


Figure 12: 4D animation page

All IFC files generated by the prototype—both those used as a shared database and those produced as project models—were successfully interpreted using external tools such as KITModelViewer (Institute for Automation and Applied Informatics (IAI), 2025).

Discussion

The testing phase conducted so far has focused on relatively simple building elements, including cast-in-place walls, slabs, windows, and doors. For cost data, the 2025 Veneto Region Price List (Veneto Region, 2025) was adopted, as it was considered appropriate for the scope of the initial experiments. Given that price lists vary significantly across regions and countries, future research will investigate the application of the methodology to real-world case studies, additional IFC classes, and alternative price lists. Although the workflow has been designed to be flexible and adaptable, further validation is required.

The developed prototype also highlights the relevance of web-based applications, which eliminate the need for specialized software installation and provide readily accessible tools for practitioners. The use of open-source libraries, such as those provided by That Open Company, enables professionals with programming expertise to develop customized solutions, helping to address the current lack of IFC-based software tools in these domains. Moreover, as these tools rely on open standards rather than proprietary ecosystems, they support the adoption of IFC and enhance interoperability and standardization across the sector.

The study emphasizes the importance of data reuse and sharing to reduce redundant work and improve interoperability, both through the conceptualization of process templates and the architecture of the prototype. However, the current implementation presents limitations in this regard. The IFC-SPF file used as a database does not provide the robustness of a dedicated database system: concurrent access by multiple users may result in overwriting conflicts, and essential functionalities—such as data consistency checks, input validation, and error handling—are not inherently supported. Future work will focus on developing a dedicated price list database based on Semantic Web technologies using the IfcOWL ontology (buildingSMART Technical, 2025). This approach would ensure consistency with the IFC data model while leveraging Semantic Web capabilities to enable real-time collaboration among stakeholders (Yang et al., 2021).

To further reduce manual effort, future developments will also explore automated procedures for converting price lists into IFC-based databases, thereby minimizing the workload required from professionals. At the same time, the prototype requires further refinement to improve the user experience and to better address the complexity and variability of real-world projects. For example, it is necessary to support exceptions and variations by allowing users to define additional processes for specific elements that deviate from the standard process template. Once the prototype reaches a more stable stage, it will be possible to evaluate its effectiveness through quantitative metrics such as time savings, productivity gains, and error rates.

Furthermore, the study demonstrates the central role of an effective user interface. The prototype shows that even a complex structure of IFC classes can be navigated and managed by users without prior knowledge of the standard. This is particularly relevant for professionals without programming skills and for public administrations that require BIM data to be delivered in open formats.

Despite the identified technical and functional limitations, the prototype successfully validates the proposed methodology and demonstrates the feasibility of developing applications entirely based on IFC. More importantly, it highlights the potential of the IFC standard to support integrated cost, scheduling, and resource management, and underscores the need for consistent and shared research on standardized methods for its application.

Conclusions

The literature indicates that BIM methodologies can overcome traditional practices for time scheduling, cost estimation, and resource accounting, which are often time-consuming, error-prone, and based on subjective experience rather than data. However, current BIM practices in these domains still rely heavily on proprietary ecosystems, manual procedures, or user-defined approaches that hinder interoperability, lack standardization, and fragment data across multiple environments. The adoption of a common standard such as IFC, which encompasses these domains, offers a promising solution. Nevertheless, previous research (Avogaro & Zanchetta, 2025) highlights key barriers to the widespread use of IFC, including uncertainty regarding the correct use of IFC classes and the appropriate structuring of project-control data within the schema, as well as the lack of software tools capable of effectively managing such data through the IFC standard.

This study presents a process-oriented framework for the integrated management of time scheduling, cost estimation, and resource accounting based on the IFC4.3 standard. By introducing the concept of process templates and systematically mapping them to IFC entities, the research demonstrates that IFC can support a coherent, data-driven representation of construction processes, including their associated resources, costs, and temporal attributes. The proposed methodology enables the standardization and reuse of construction knowledge through template-based structures, reducing redundancy and improving consistency across projects. The implementation of a web-based prototype further validates the practical feasibility of the approach, showing that key project-control outputs—such as WBS, CBS, Bills of Quantities, and 4D simulations—can be generated automatically from IFC-compliant data. These results confirm that IFC can function not only as a data exchange format but also as a central data model for integrated project management workflows.

At the same time, the study identifies several challenges that must be addressed to enable real-world adoption. These include the need for more robust data management infrastructures, improved handling of concurrent data access, and enhanced support for variability and exceptions in construction processes. Furthermore, additional validation through more complex case studies and diverse price lists is required to assess scalability and generalizability.

Overall, this work lays the foundation for interoperable, standardized, and fully data-driven project-control tools, supporting a transition from fragmented and proprietary workflows toward more collaborative and transparent practices in the construction industry. It provides both a methodological foundation and a proof of concept demonstrating that integrated, standardized, and interoperable project-control workflows based entirely on IFC are achievable and beneficial, and it outlines a pathway for future research and tool development aimed at reducing inefficiencies, enhancing collaboration, and promoting the adoption of open standards in the sector.

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