AUTOMATED QUANTITY TAKEOFF AND LIFE-CYCLE COSTING IN CONSTRUCTION PROJECTS USING AN OPENBIM–IFC APPROACH

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Abstract

BIM-based cost estimation often depends on proprietary tools and ad-hoc mappings to external cost databases, limiting interoperability and auditability. This paper presents an openBIM workflow that enriches material definitions with standardized Canadian-specific cost items and automatically generates element-level quantity takeoff and capital cost breakdowns. A case study demonstrates automated extraction of material, labor, and equipment costs, as well as structured inputs for maintenance-and-replacement-oriented life-cycle cost analysis. In the current implementation, automated computations focus on construction-phase capital costs, while LCC support is limited to structured inputs for external RSMeans-based estimators.

Introduction

Accurate cost estimation remains a continuous challenge in construction projects, where early decisions are made under uncertainty and information is fragmented across stakeholders and tools (Lee et al., 2012). Building Information Modeling (BIM) has enabled automated quantity takeoff (QTO) and facilitated 5D BIM workflows, yet many BIM-based cost estimation pipelines remain tightly coupled to specific authoring platforms or proprietary estimating systems (Fazeli et al., 2021). These constraints impede reproducibility, limit integration with alternative cost databases, and complicate longitudinal use of cost information across the asset life cycle (Ramaji et al., 2020).

OpenBIM addresses these limitations by promoting vendor-neutral data exchange through the Industry Foundation Classes (IFC) schema (Hosseini Gourabpasi et al., 2025; Laakso & Kiviniemi, 2012). IFC is standardized as ISO 16739 and is widely used for interoperable model exchange. However, the representation of cost information in open standard formats is still uneven in practice: cost data are frequently exported as spreadsheets, maintained in separate systems, or stored as project-specific properties without consistent semantics (Khudhair et al., 2023, Hosseini Gourabpasi et al., 2025).

This study develops and evaluates an openBIM-based framework for automated QTO and costing in which cost items are explicitly linked to IFC material definitions and then propagated to building elements for computation. In addition, the framework extracts a defined set of building attributes to support LCC inputs focused on preventive maintenance and replacement planning (ISO 15686-5). The paper also addresses whether embedding detailed cost parameters within the BIM/IFC model is preferable to keeping them in linked external containers. Accordingly, a balanced assessment and approach relative to BIM-Cost-Container frameworks (e.g., DIN 18290-3) is proposed that packages cost determinations externally while maintaining links to model objects. According to ISO 15686-5, life-cycle costing covers acquisition, operation, maintenance, and end-of-life costs over the asset's service life. In this study, the term LCC is used in a narrower, implementation-specific sense: the proposed workflow automates construction-phase capital cost estimation based on IFC quantities and RSMeans unit rates and extracts structured model attributes (e.g., building area, number of floors, perimeter) needed by RSMeans' online LCC estimators for maintenance and replacement planning. Operational energy costs, water and utility charges, and explicit end-of-life scenarios are outside the current prototype's scope and are identified as targets for future work.

Literature Review

BIM-driven cost estimation has been studied for the past two decades and remains an active area of research, including ontology-based approaches for measurement rules and standardized cost semantics (Abanda et al., 2017; Lee et al., 2014, Fazeli et al., 2024), and automated QTO methods for compound and interior elements (Khosakitchalert et al., 2019; Kim et al., 2019, Fazeli et al., 2022). Several studies integrate BIM with cost databases to automate estimation or to support 5D BIM workflows (Elbeltagi et al., 2014; Banihashemi et al., 2022). Previous studies have also explored Industry Foundation Classes (IFC)-based cost estimation pipelines and extensions for construction-related data exchange (Ma et al., 2013; Cassandro et al., 2024; Zhang et al., 2024).

Despite this progress, two gaps are highlighted. First, many implementations rely on exports from proprietary BIM tools and do not preserve a consistent, reusable linkage between model objects and cost items in an open schema. Second, the term life-cycle costing (LCC) is used inconsistently: some studies address full whole-life costing across construction, operation, and end-of-life, while others focus primarily on construction-phase capital costs or limited maintenance scenarios (Rad et al., 2021). This paper explicitly distinguishes capital cost estimation based on quantities and unit rates and a maintenance-and-replacement-oriented LCC view enabled through structured data extraction and mapping to an external LCC estimator that is precisely used in Canadian context. In parallel, European standardization efforts have advanced the concept of linked containers for multimodal exchange. DIN 18290-2 (2023) defines a BIM-LV container for linking models with bills of quantities, and DIN 18290-3 (2023) defines a BIM cost container for structured exchange of model-based cost determinations linked to IFC reference objects. These container approaches externalize cost documents while maintaining traceable links to the BIM model, offering an alternative to embedding detailed cost parameters directly within the model.

Methodology

This study provides an openBIM-based approach to cost estimation and preparing the model for a high-level LCC. Figure 1 shows the overall design of the current study, which began with quantitative inputs to establish an OpenBIM-based cost-estimation framework. Quantitative inputs include both IFC External database and IFC Internal database. In the IFC External database, cost specification database (RSMeans) will be connected to the IFC Materials of the model. This database includes all Canadian-specific cost information for materials, equipment, labour, and total cost, along with their corresponding Overhead & profit costs. In addition, each item taken from the RSMeans dataset includes ID, Name, Unit, and Crew, which specify the type of material, unit, and workers used in the cost estimation process. This information provides full cost estimates for every element in the IFC model. IFC Internal database also includes all information about quantities of elements, including Area, Volume, and Length and Layer Thickness. The entire process of cost estimation, including the connection between cost information and model quantity, as well as its corresponding calculations, is in the simulation stages, where it evaluates the causes and impacts on various variables and potential reactions in various scenarios (Privé and Errico, 2016).

The proposed methodology comprises four steps. The first step is to develop an IFC model. The next step is to connect cost database into IFC materials. The authors developed a new framework to automatically import all cost data into IFC materials. Following this, the user must enrich elements inside the IFC Model with RSMeans database and new developed IFCMaterials. Finally, the cost estimation process has been conducted using the IFC geometric information and IFC materials inside the model. The implementation uses IfcOpenShell to read and write IFC, create and attach property sets, and compute quantities from IFC physical quantity definitions.

1) Develop an IFC model: 3D modelling capability is regarded as one of the most important benefits of OpenBIM application. 3D modelling can help visualize both elements and data within elements, enabling project practitioners to manage and control time and cost effectively and other data within the project. Accordingly, the whole list of cost items can be stored in a material list of elements in the 3D modelling as inputs for cost estimation.

   i) Required IFC model and Level of Information Need: The proposed workflow presumes an IFC model with necessary data to support quantity takeoff and material-based costing. Concretely, the following minimum Level of Information Need (LOIN) is required for reliable operation:

      a. Geometry: Explicit solid or layered representations for main elements (IfcWall, IfcSlab, IfcCovering, IfcWindow, IfcDoor) with consistent units, enabling derivation of length, area, and volume from IFC physical quantities and material layer sets.
      b. Materials: Each cost-relevant assembly must be associated with one or more IfcMaterials or IfcMaterialLayers that can be enriched with RSMeans-linked properties (cost item ID, unit, formula, unit rates).
      c. Quantities: Either IfcElementQuantity sets or material layer quantities must be present or derivable (e.g., base quantities for walls, slabs, ceilings), as the prototype relies on these definitions for automated QTO
      d. Identification: Stable global identifiers for elements and materials (GlobalId, consistent naming conventions) to support repeatable mapping between IFC objects and cost items.

   In cases where these conditions are not met—for example, models lacking material assignments or relying solely on symbolic representations the workflow may still operate but will require additional pre-processing, manual material mapping, or default quantity assumptions.

2) Develop new IFC Materials with cost specifications: In this step of the process, a list of the most important cost items is retrieved from the RSMeans database. The ID, name, and unit shows the identity of material and units. Crew specify the type of workers needed for the cost estimation process. Then, all other information are the cost information in RSMEANS database. The formula also specifies which geometric information of elements is needed for the cost estimation process. A new framework is developed to import all RSmeans database inside IFC Materials of the project using IFCOpenShell.
3) Equip IFC Elements with new IFC Materials: In this step, project managers can either replace Materials inside elements with IFCMaterials or create new elements with new IFC Materials.
4) OpenBIM-based Cost estimation: In this step, Quantities are retrieved from IFC physical quantities,

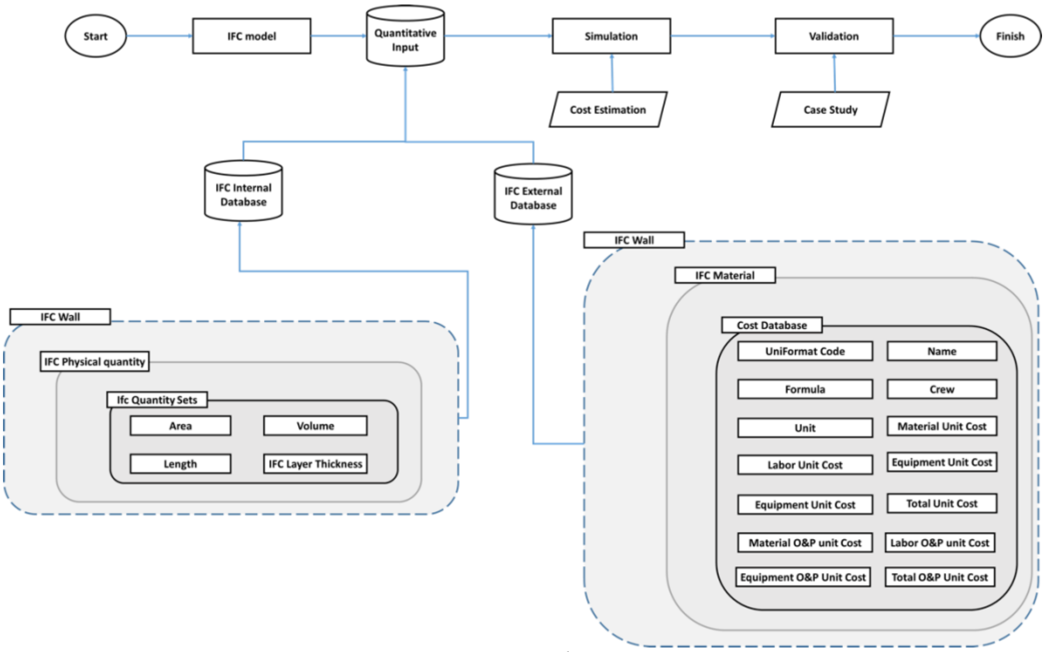


Figure 1: Research Design

evaluated against the cost formula, and multiplied by unit rates to produce element-level cost components. Results are stored back into the IFC as element properties to enable downstream queries, auditing, and visualization. The formula is used to change all units to SI units using a coefficient. Figure 2 shows the overview of the calculation made for cost estimation.

This workflow is most beneficial from late schematic design through detailed design and pre-construction, when key assemblies and material systems have been defined but design iterations and cost feedback are still frequent. At these stages, the IFC model typically contains sufficient geometry and material assignments to support reliable quantity takeoff while remaining flexible enough for design changes, enabling rapid re-estimation as materials, assemblies, or quantities evolve. During early conceptual design, the approach may be used with simplified template assemblies and approximate quantities, whereas in later construction phases it can support auditing and change impact analysis provided that as-built models and updated cost data are available.

Figure 3 shows how IFC structure for wall elements was used to implement the cost estimation of current study. As shown in the figure, the prototype first finds the elements inside the IFC Model. The IFC has standard structure to reach elements of the IFC model. In order to reach elements, firstly, IFCbuidingproduct will be found from IFCRoot. Inside IFC product, there are many elements including IFCWall, IFCSlab, IFCCovering, IFCDoor, and IFCWindows. The next step is to find IFCMaterials of elements inside the element. IFCRelAssociatesMaterials will be used to reach IFCMaterials of elements. Then, all RSMEANS information will be extracted from IFCMaterials through IFCMaterialProperties. The quantities of elements will be extracted through both IFCQuantitySets and IFCMaterialLayerSets. Finally, both quantities and RSMEANS data will be used to

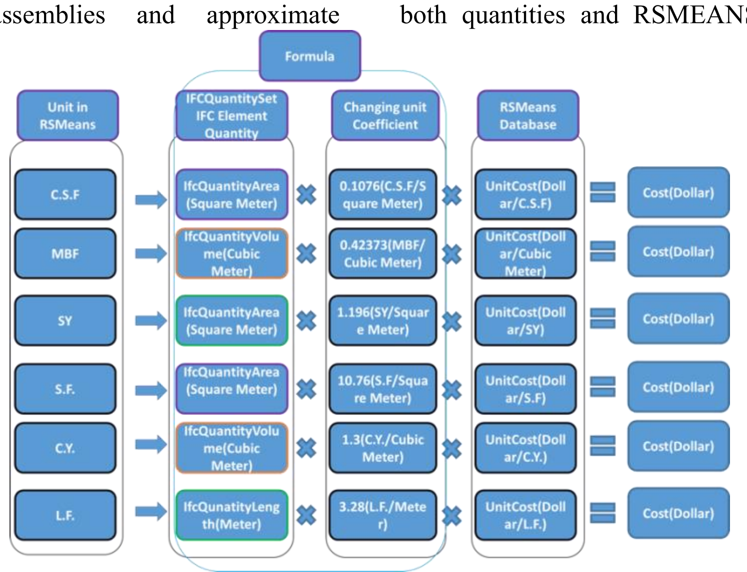


Figure 1: Cost estimation process

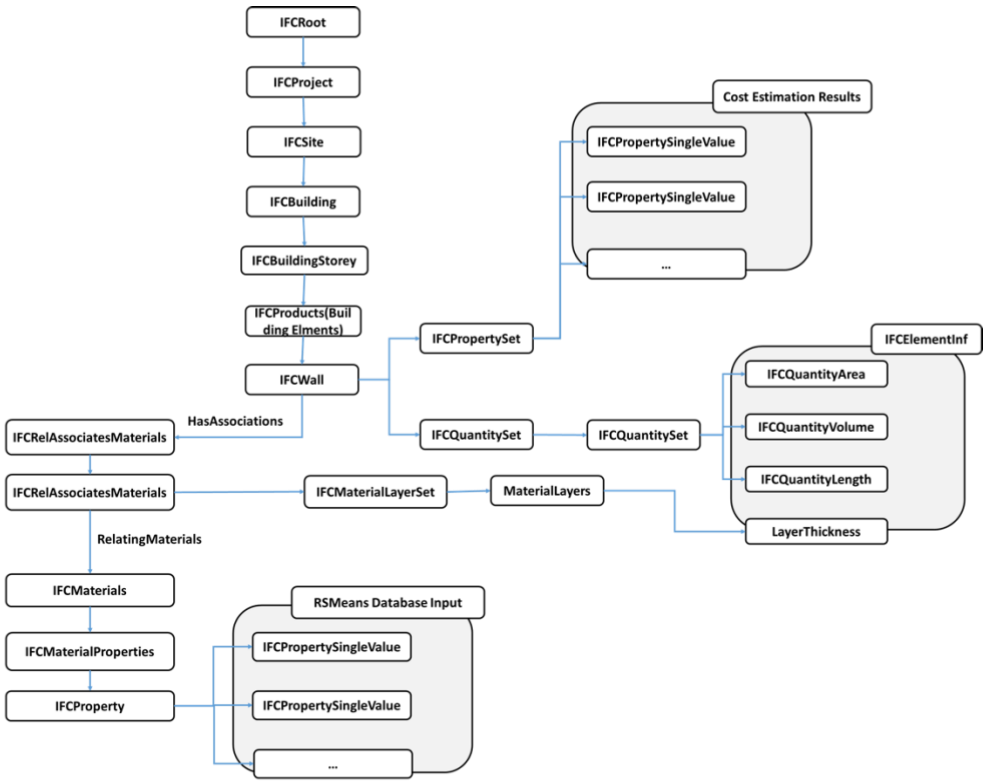


Figure 2: IFC-linked cost data architecture used for estimation

estimate the cost of project. The results of cost estimation will be imported through new developed property inside IFCPropertySet of elements.

The RSMeans website can estimate LCC costs of IFC project using some specific information from IFC project. The process of getting this information from IFC project is very challenging and time consuming. A new framework is needed to retrieve this information from IFC project. The LCC component of the workflow does not compute a full whole-life cost model inside IFC. Instead, it automates extraction of RSMeans-required input parameters (gross area, floor count, floor heights, perimeter) from the IFC model and delegates detailed maintenance and replacement costing to RSMeans' external LCC engine. As a result, the current prototype effectively covers construction-phase capital costs internally, while mid-life maintenance and replacement are handled externally; operational energy performance and end-of-life stages will require coupling with BIM-to-BEM methods and deconstruction/disposal datasets in future extensions. Therefore, In this step of the study, a framework has been developed to retrieve LCC information from IFC project to estimate LCC cost using RSMeans database. This framework can retrieve information, including the number of floors, the total floor area, the floor heights, and the total perimeter of the project. This information can be the primary input on the RSMeans website for LCC estimation. After entering this information on the RSMeans website, the total lifecycle cost is estimated.

Figure 4 shows the overview of the process. The first step is to retrieve LCC information from IFC model. A new prototype is developed to automatically extract all LCC information from IFC model. Then, the information should be imported in the next step and finally, LCC would be estimated from RSMeans. Using the current prototype saves a lot of time and prevents errors.

In this study, a platform has been developed to estimate the cost of construction project. Figure 5 shows the overall view of new developed framework. The first part is element part which has three types of elements including Wall, Floor, and ceiling. The main purpose of element part is to implement quantity take off from all parameters inside IFC model. The second part is edit part. The first button in edit part is the import RSMeans data. This button aims to import all RSMeans database inside

Figure 3: LCC estimation process

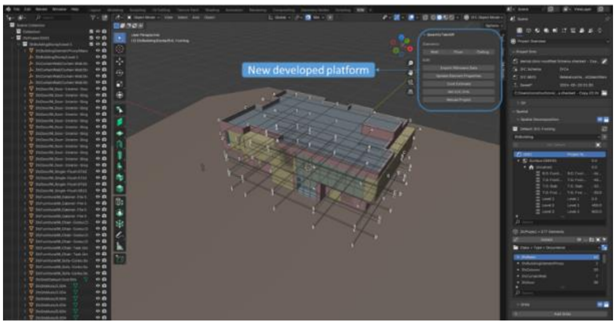


Figure 5 . Overview of the proposed OpenBIM costing workflow

materials of elements in the IFC project. The main purpose of second button (Update Element Properties) is to develop cost parameters in the elements of the project. The third button implement cost estimation from IFC project and update cost parameters in the IFC project.

The proposed framework is designed to align cost properties with shared semantics rather than ad-hoc custom fields. The buildingSMART Data Dictionary (bSDD) can host definitions for cost-related properties and classifications, enabling software-agnostic referencing of property meaning. Thus, Information Delivery Specifications (IDS) can be authored to formally specify which cost properties must be present for a given exchange (e.g., required cost code, unit, currency, and date), enabling automated compliance checking of IFC submissions before estimation. While full operationalization of bSDD- and IDS-driven governance is left as future work, these standards provide a practical path to scale the approach to other cost databases, regional cost indices, and organizational taxonomies without changing the underlying IFC computation logic.

Case Study and Results

The proposed framework was tested on a two-story office building in Toronto as a representative case. This building has a total gross area of 1005.35 m^2 and a net area of 781.91 m^2. The two-story office building model used in this study corresponds to a design-development level of detail, which aligns with the intended primary use-phase of the proposed workflow.

The model includes layered wall, floor, and ceiling assemblies with explicit material assignments. RSMeans unit rates were mapped to the enriched IFC material library, and quantities were extracted from the IFC physical quantities. Table 1 shows the results of cost estimation by the developed framework. The current methodology can estimate three main costs within the project: Material Cost, Equipment Cost, and Labour Cost, for both construction costs and Overhead and Profit costs.

The next step is to estimate the LCC cost of the office building from IFC format using RSMeans website. Figure 6 shows the LCC information required for LCC cost estimation, based on RSMeans requirements.

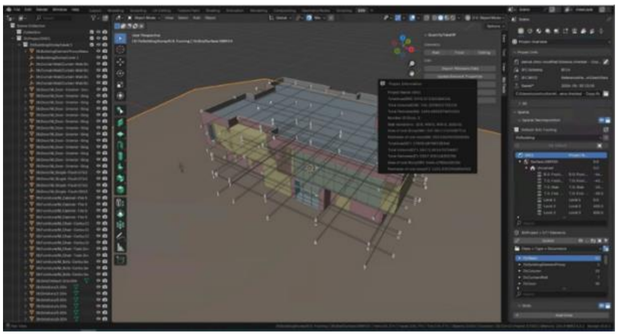
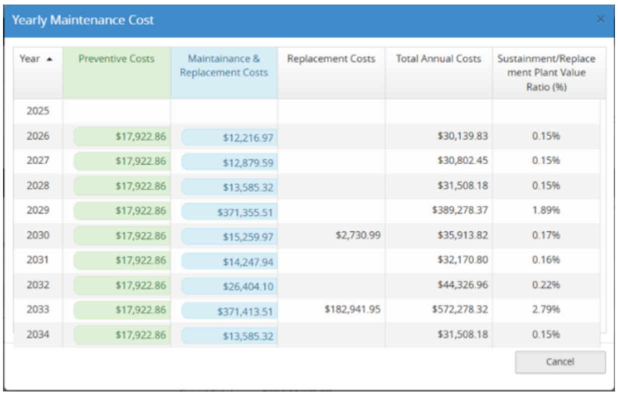


Figure 6: LCC information collection from new developed tool

Figure 7 shows an overview of maintenance cost results from RSMeans, including maintenance costs for the next 10 years, estimated for the case project.


Yearly Maintenance Cost

Year	Preventive Costs	Maintainance & Replacement Costs	Replacement Costs	Total Annual Costs	Sustainment/Replacement Plant Value Ratio (%)
2025					
2026	$17,922.86	$12,216.97		$30,139.83	0.15%
2027	$17,922.86	$12,879.59		$30,802.45	0.15%
2028	$17,922.86	$13,585.32		$31,508.18	0.15%
2029	$17,922.86	$371,355.51		$389,278.37	1.89%
2030	$17,922.86	$15,259.97	$2,730.99	$35,913.82	0.17%
2031	$17,922.86	$14,247.94		$32,170.80	0.16%
2032	$17,922.86	$26,404.10		$44,326.96	0.22%
2033	$17,922.86	$371,413.51	$182,941.95	$572,278.32	2.79%
2034	$17,922.86	$13,585.32		$31,508.18	0.15%

Cancel

Figure 7. LCC information results from RSMeans

Discussion

The main contribution in this study is to propose an explicit and reusable linkage and between openBIM (in IFC data exchange format for objects like materials and assemblies) and standardized cost items, implemented without dependence on a specific BIM authoring tool or estimating platform. By storing both the mapping (cost code, unit, and formula) and the computed results in the IFC, the workflow improves auditability and supports downstream uses such as element-level cost visualization, change impact analysis, and exchange to other systems via non-proprietary solutions.

Table 1: Cost estimation results

	Material Cost	Equipment Cost	Labor Cost	Total Cost	Material Cost O&P	Equipment Cost o&P	Labor Cost O&P	Total Cost O&P
Wall	42262.75	116528.25	20268.5	179059.5	52407.58832	144276.34	25277.82167	221961.75
Floor	8494.8	17802	5580.94	31877.74	9650.463307	20395.04301	6358.093684	36403.6
Ceiling	1765.8	3801	1071	6637.8	2021.340613	4351.067884	1225.991503	7598.4

As specified in the ISO 15686-5, LCC can cover acquisition through operation and disposal. In the current implementation, automated computation focuses on construction-phase capital costs, and the LCC results are restricted to generating structured inputs for maintenance and replacement planning using RSMeans life-cycle cost estimators based on the Canadian-specific datasets. Operational energy costs and performance-driven OPEX (e.g., energy, water, and carbon-related costs) are not calculated in the current workflow; integrating BIM-to-BEM pipelines and measured operational data is in progress and will be covered in future work.

Cost becomes a time-dependent attribute when it is linked to design revisions, procurement decisions, and construction progress or asset condition. The presented openBIM cost layer can act as a foundational dataset for a cost-focused digital twin by providing a traceable mapping between physical components and cost parameters, enabling systematic updates when quantities, rates, or asset states change.

Embedding cost parameters directly in IFC provides a self-contained, portable package that supports offline review, element-level traceability, and automated computation. However, it introduces governance and maintenance burdens. For instance, cost data can become outdated, licensed cost datasets may not be distributable inside models, and large models may not operate properly with detailed pricing information. Container-based approaches such as DIN 18290-3 (BIM cost container) and DIN 18290-2 (BIM-LV container) mitigate these issues by externalizing cost determinations and bills of quantities while preserving explicit links to IFC reference objects. For projects that require strict control over cost document versions, procurement workflows, or licensing constraints, a linked container may be preferable. For early-stage design, alternative analysis, and internal collaboration, in-model cost embedding can be effective when paired with clear update rules and access controls.

To scale across databases and contexts, the openBIM approach should rely on stable semantics for properties and exchange requirements. bSDD offered by buildingSMART can support standardized property definitions, and IDS can specify information requirements and validation rules for exchanges, reducing ambiguity in cost mappings across tools and stakeholders in various life cycle stages. In practice, bSDD and IDS can be used to formalize the Level of Information Need for model-based estimation by specifying which cost-related properties, material assignments, and quantity sets must be present at each project stage. In fact, it enables automated compliance checking of IFC submissions before running the estimation workflow.

Conclusions

Traditional cost estimation methods were often reliant on manual processes and licensed tools. This creates many inefficiencies and inaccuracies in the process. The integration of BIM has revolutionized this process by enabling digitalized, automated cost estimation. However, there are still challenges in the process due to the use of different BIM tools and data formats, leading to interoperability issues and data loss during data transformation between them. This study aimed to develop an OpenBIM-based approach to cost estimation. IFC facilitates seamless data exchange between different BIM authoring tools, ensuring consistency and accuracy across platforms. Furthermore, incorporating standardized classification systems (e.g. UniFormat) and reliable cost databases, such as RSMeans, enhances the precision and reliability of cost estimates.

Despite the advantages of the current study, it has some limitations. There is a lack of robust software to handle IFC for large projects. The Blender software used in the current study cannot open large IFC projects, so the authors are limited to medium-sized projects in the validation phase. On the other hand, this study focuses on only three categories of elements. To enhance the precision and accuracy of cost estimation, it is necessary to estimate the costs of all other project elements. A notable limitation of the current implementation is its reliance on explicitly modelled elements for quantity takeoff and costing. Thin finishing layers (e.g., paint, screeds), multi-component façade systems, lightweight partitions (e.g., timber or gypsumboard walls), and temporary works (e.g., scaffolding, cranes, site logistics elements) are often omitted or represented only implicitly in design-stage models, which means their costs are not directly captured by the automated workflow. In practice, practitioners could address these categories using: i)Parametric allowances (e.g., applying finish factors or percentage-based mark-ups tied to gross area or perimeter). ii) Assembly templates that aggregate typical finishing and sub-components into a single modelled proxy with an associated composite cost item. iii) Linked cost containers or external BoQs that include non-modelled items but remain traceable to the model context. In fact, Systematic integration of such non-modelled or partially modelled cost drivers especially temporary works and construction logistics remains an open research direction and is not fully supported by the current prototype. Furthermore, life-cycle cost data were sourced exclusively from the RSMeans. This reliance may limit the model's adaptability across different regional contexts or project types. Future study is in progress to independently estimate the life cycle cost of the project and consider all other factors in the life cycle cost process. Finally, While the present case study and implementation rely on Canadian-specific RSMeans datasets, the core workflow is not tied to a specific vendor or region. Because cost logic is encoded as generic IFC material properties (cost code, unit, formula, unit rates) and the linkage semantics can be governed via bSDD and IDS, the same pattern can be applied to other regional or international cost databases (e.g., national price books, company-specific cost libraries) by changing the external dataset and property definitions without modifying the underlying IFC computation engine. Future work will focus on validating the approach with alternative cost sources and regional indices and on defining reusable IDS templates for cross-context deployment.

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References

Abanda, F.H., Kamsu-Foguem, B. & Tah, J.H.M. (2017) BIM–new rules of measurement ontology for construction cost estimation. Engineering Science and Technology, an International Journal, 20, p.pp.443–459.

Banihashemi, S., Khalili, S., Sheikhkhoshkar, M. & Fazeli, A. (2022) Machine learning-integrated 5D BIM informatics: building materials costs data classification and prototype development. Innovative Infrastructure Solutions, 7, p.215.

buildingSMART (2024) buildingSMART Data Dictionary (bSDD). Available at: https://www.buildingsmart.org/users/services/buildingsmart-data-dictionary/ (accessed 2026-01-17).

buildingSMART (2024) Information Delivery Specification (IDS). Available at: https://www.buildingsmart.org/standards/bsi-standards/information-delivery-specification-ids/ (accessed 2026-01-17).

Cassandro, J., Mirarchi, C. & Pavan, A. (2024) IFC-based cost estimation: application to a structural model. Computing in Construction, 5, p.pp.868–875.

Deutsches Institut für Normung (DIN). (2023) DIN 18290-2:2023-03 (Draft): Linked BIM data exchange of building models with other specialist models—Part 2: Linked BIM data exchange of building models and specified bill of quantities (BIM-LV container). Berlin: DIN.

Deutsches Institut für Normung (DIN). (2023) DIN 18290-3:2023-11: Linked BIM data exchange of building information models with further specialist models—Part 3: Linked BIM data exchange of building information models and cost determinations (BIM cost container). Berlin: DIN.

Elbeltagi, E., Hosny, O., Dawood, M. & Elhakeem, A. (2014) BIM-based cost estimation/monitoring for building construction. International Journal of Engineering Research and Applications, 4, p.pp.56–66.

Fazeli, A., Banihashemi, S., Hajirasouli, A. & Mohandes, S.R. (2024) Automated 4D BIM development: the resource specification and optimization approach. Engineering, Construction and Architectural Management, 31, p.pp.1896–1922.

Fazeli, A., Jalaei, F., Khanzadi, M. & Banihashemi, S. (2022) BIM-integrated TOPSIS-fuzzy framework to optimize selection of sustainable building components. International Journal of Construction Management, 22, p.pp.1240–1259.

Fazeli, A., Dashti, M.S., Jalaei, F. & Khanzadi, M. (2021) An integrated BIM-based approach for cost estimation in construction projects. Engineering, Construction and Architectural Management, 28, p.pp.2828–2854.

Gholamzadehmir, M., Cassandro, J., Mirarchi, C. & Pavan, A. (2025) Advancing cost estimation through BIM development: focus on energy-related data associated with IFC elements. Applied Sciences, 15, p.7814.

Hosseini Gourabpasi, A., Jalaei, F. & Ghobadi, M. (2025) Developing an openBIM information delivery specifications framework for operational carbon impact assessment of building projects. Sustainability, 17, p.673.

IfcOpenShell (2025) IfcOpenShell: the open source IFC toolkit. Available at: https://ifcopenshell.org/ (accessed 2026-01-17).

International Organization for Standardization (ISO). (2024) ISO 16739-1: Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries—Part 1: Data schema. Geneva: ISO.

International Organization for Standardization (ISO). (2017) ISO 15686-5: Buildings and constructed assets—Service life planning—Part 5: Life-cycle costing. Geneva: ISO.

Khosakitchalert, C., Yabuki, N. & Fukuda, T. (2019) Improving the accuracy of BIM-based quantity takeoff for compound elements. Automation in Construction, 106, p.102891.

Khosakitchalert, C., Yabuki, N. & Fukuda, T. (2020) Automated modification of compound elements for accurate BIM-based quantity takeoff. Automation in Construction, 113, p.103142.

Khudhair, A., Li, H. & Ren, G. (2023) Knowledge-based openBIM data exchange for building design. Automation in Construction, 156, p.105144.

Kim, S., Chin, S. & Kwon, S. (2019) A discrepancy analysis of BIM-based quantity take-off for building interior components. Journal of Management in Engineering, 35, p.05019001.

Laakso, M. & Kiviniemi, A. (2012) The IFC standard: a review of history, development, and standardization. ITcon, 17.

Lee, S.-K., Kim, K.-R. & Yu, J.-H. (2014) BIM and ontology-based approach for building cost estimation. Automation in Construction, 41, p.pp.96–105.

Lee, G., Park, H.K. & Won, J. (2012) D3 City project—Economic impact of BIM-assisted design validation. Automation in Construction, 22, p.pp.577–586.

Ma, Z., Wei, Z. & Zhang, X. (2013) Semi-automatic and specification-compliant cost estimation for tendering of building projects based on IFC data of design model. Automation in Construction, 30, p.pp.126–135.

Naderi, M., Nazari, A., Shafaat, A. & Abrishami, S. (2025) Enhancing accuracy in construction overhead cost estimation: a novel integration of activity-based costing and building information modelling. Smart and Sustainable Built Environment, 14, p.pp.758–775.

Privé, N.C. & Errico, R.M. (2016) Observing system simulation experiments: an overview. Weather and Chaos.

Rad, M.A.H., Jalaei, F., Golpour, A., Varzande, S.S.H. & Guest, G. (2021) BIM-based approach to conduct life cycle cost analysis of resilient buildings at the conceptual stage. Automation in Construction, 123, p.103480.

Ramaji, I.J., Messner, J.I. & Mostavi, E. (2020) IFC-based BIM-to-BEM model transformation. Journal of Computing in Civil Engineering, 34, p.04020005.

RSMeans (2025) Using the life cycle cost estimator in RSMeans Data Online. Available at: https://www.rsmeans.com/resources/using-lifecycle-cost-estimator-rsmeans-online (accessed 2026-01-17).

Wahab, A. & Wang, J. (2022) Factors-driven comparison between BIM-based and traditional 2D quantity takeoff in construction cost estimation. Engineering, Construction and Architectural Management, 29, p.pp.702–715.

Yang, B., Zhang, B., Wu, J., Liu, B. & Wang, Z. (2019) A BIM-based quantity calculation framework for frame-shear wall structure. Structural Engineering International, 29, p.pp.282–291.

Zhang, S., Zhang, S., Wang, C., Zhu, G., Liu, H. & Wang, X. (2024) Extended IFC-based information exchange for construction management of roller-compacted concrete dam. Automation in Construction, 163, p.105427.