Joint CSCE Construction Specialty & CRC Conférence 2025
*Conférence conjointe spécialisée en construction de la SCGC et CRC-2025*

Montréal, Québec
July 28-31, 2025 / *28-31 juillet 2025*

# DEVELOPING AN INFORMATION DELIVERY FRAMEWORK FOR OPENBIM-LCA INTEGRATION TO ENHANCE DATA INTEROPERABILITY DURING THE DESIGN AND CONSTRUCTION OF SUSTAINABLE BUILDINGS

Rostaminikoo, R.[1], Jalilzadeh Eirdmousa, S.[1], Jrade, A.[1], Hosseini Gourabpasi, A[2]., Jalaei, F.[2], Jalaei, F.[1], Rostamiasl, V.[1]

[1] Department of Civil Engineering, University of Ottawa, Canada
[2] National Research Council Canada, Government of Canada, Ottawa, Canada

**ABSTRACT:** The construction industry is facing increased pressure to reduce its environmental impacts, with a special focus on Decarbonization. Integrating Life Cycle Assessment (LCA) with Building Information Modeling (BIM) has proven to be a valuable means for evaluating environmental impacts. However, the effective integration of BIM and LCA is still a challenge due to the fragmented workflows, the inconsistent data formats, and the absence of protocols for data exchange. To address these gaps, this paper presents an Information Delivery framework, explicitly designed for OpenBIM-LCA integration. OpenBIM, which emphasizes collaboration and data interoperability through open standards like Industry Foundation Classes (IFC), provides the basis for the framework. This study introduces an Information Delivery Specification (IDS) that defines the minimum data requirements to ensure that stakeholders can deliver and access accurate data to support LCA workflows. Furthermore, the framework is aligned with the sustainability standards and incorporates automatic validation processes, which enhance the efficiency of OpenBIM-LCA workflows and reduce errors during the data exchanging process. This framework can determine how objects need to be delivered and includes the rules and requirements to verify an IFC file as a valid data source for LCA. This procedure brings the validation of IFC to the modeler to select the tools that best perform the LCA analysis. To validate its effectiveness, the proposed framework will be tested by using a case project to demonstrate its ability to enhance interoperability, to improve the accuracy of calculating the embodied carbon, and to streamline the collaboration between the different stakeholders.

## 1. INTRODUCTION AND RESEARCH BACKGROUND

The construction sector is one of the main sources for global carbon emissions and yet it plays a pivotal role in addressing climate change. The Intergovernmental Panel on Climate Change (IPCC) report emphasizes about the need for rapid decarbonization to mitigate the environmental impacts generated by the construction industry to meet the carbon emission reduction's goals by 2050 (Shukla et al., 2022). Whitin this context, life cycle assessment (LCA) is considered as an influential method to evaluate the environmental impacts of buildings over their lifecycle. Compared with other sectors, LCA calculation for buildings is more complex because of the various materials used in them, the quantity of fuel consumed, the construction activities, maintenance, long service life, and end-of-life processes. Therefore, there is a need to implement a new approach to apply LCA for buildings (Jrade et al., 2023).

On the other hand, the construction industry is lacking efficient means of communication between the different parties involved in the construction of projects, which has created lots of conflicts and issues. Nevertheless, a recently adopted concept known as Building Information Modeling (BIM) has positively revolutionized the industry by enabling a digital representation of building's elements. BIM allows for sharing and transmitting data in an efficient and safe mode across the whole life of a project (Dauletbek & Zhou, 2022; Mostafazadeh et al., 2023; Tavakolan et al., 2022). In this vein, adopting the concept of BIM early during the design stage of a project permits decision-makers to make efficient judgements related to the best course of action when quantifying the embodied environmental impacts of the construction materials throughout a its lifecycle.

There is a growing interest in integrating BIM and LCA to streamline the evaluation of environmental impacts of building projects. BIM-LCA integration can help facilitate the calculation of embodied carbon emissions and other greenhouse gas emissions, which is crucial for the goals of decarbonization and sustainability. BIM models, which provide digital representation of a building's projects, can support the calculation of LCA with less effort and high accuracy. This integration provides benefits over the different stages of the building's lifecycle. Exploring different design options with different materials within a BIM environment can significantly reduce the calculation time for LCA and reach lower environmental impacts. Also, monitoring the real-time data and emissions produced by equipment, construction activities, and transportation are also easier to be simulated with BIM tools. Therefore, automating the process of exchanging data, preventing manual errors, improving the speed of LCA's calculation, and enhancing the collaborations with BIM models can lead to significant benefits for the integration of BIM with LCA.

Several studies done by scholars on the integration of BIM and LCA but most of them highlighted the existing challenges to achieve an efficient and complete integration, such as the conflicts among BIM tools and life cycle inventory (LCI) databases, the lack of coordination in managing the information, and the human intervention. Najjar et al. ( 2019) introduced a novel model that used LCA, BIM, and mathematical optimization methods to improve buildings' energy efficiency and to reduce the carbon emissions. The model would provide alternative sustainable designs, however, it only considered the operation stage of the life cycle and disregarded the embodied carbon emissions. Alwan et al., (2021) provided an IFC-based embodied carbon benchmarking for the early design stage to reduce the impacts of carbon emissions. They used ArchiCAD as BIM tool, the Inventory of Carbon and Energy (ICE) database for the embodied carbon database, and Python for the programming. In addition to embodied carbon, looking at the operational energy can improve the accuracy and reliability of the model to be used at a larger scale in the construction industry. Mohammed, (2023) presented a process mapping to streamline the automatization of LCA with BIM to have a qualified BIM for LCA workflows. That method overcomes the challenges related to the integration of BIM and LCA. The mapping process was validated by an analytical hierarchy process (AHP) using interviews and questionaries among experts in this field. Tushar et al. ( 2021) developed on an integrated approach using BIM, LCA, and energy simulation to reach energy-efficient solutions for buildings and to reduce the carbon footprints. Autodesk Revit was used as BIM tool to create the design model, Tally software for the LCA, and FirstRate 5 tool for the energy rating. Akbari et al., (2024) provided a new BIM-based Life cycle sustainability assessment (LCSA) tool, which considers social assessment, environmental assessment, and economic assessment for buildings, but needed more development to improve the automation of the exchanging process and the data interoperability difficulties. One of the most important challenges for the integration of BIM and LCA is related to the absence of a proper and structured approach to interoperability. A method should be provided to facilitate the process of exchanging data between BIM models and LCA workflows.

However, inconsistent data formats, lack of having standardized protocols, and fragmented processes that prevent the seamless exchange of data and information between LCA and BIM tools, and the full use of BIM tools' abilities for assessing the carbon emissions. In this regard, OpenBIM, which relies on open standards and data formats, such as Industry Foundation Classes (IFC), can ensure better solutions and can be universally applied across different software platforms and project stages, fostering efficient collaboration and consistent data sharing. Llatas et al., (2020) developed a life cycle sustainability assessment tool based on BIM concept to use at the early design stages of projects. They use IFC to exchange BIM model's data to LCA tools with a level of development (LOD) of 200 at the early stage of design, which falls short of an LOD of 300 as being the minimum recommended LOD for LCA calculations. Also, they needed manual data extraction before implementing LCA calculations using Dynamo script. Klumbyte et al., (2023) proposed an Application Programming Interface (API) to link LCA with BIM. Their study highlighted the need for a guideline or protocol before starting the LCA's calculations to classify the materials used to measure their environmental impacts and to automate the data extraction from BIM models. Yeung et al., (2023) developed an OpenBIM for environmental life cycle assessment based on Python Programming with a user interface. However, the core of their work was linked to the static background processes of the Ecoinvent LCI database, however the lack of dynamic perspective to LCA remains. Hence, defining an information delivery framework can help to promote interoperability for the integration of BIM and LCA. Having such a framework, reliable data support through LCA workflows can be applicable.

While information requirements are often communicated in formats such as PDFs or Excel sheets, they are only machine-readable when the data is well-structured, allowing for efficient extraction and use in digital workflows, but making it challenging for the users to obtain relevant information under any circumstance (van Berlo et al., 2019). An information delivery specification (IDS) is a file format for defining the requirements for exchanging data. These requirements define how the materials, objects, elements, classifications, properties, and classifications have to be delivered with references to IFC. IDS is based on the buidlingSMART framework so that to make those requirements machine-readable. In this way, the exchange of information would be improved throughout the entire lifecycle (*Information Delivery Specification - buildingSMART International*, 2024.). Therefore, IDS removes the problems related to the traditional approaches by enabling an accurate exchange of information. IDS allows for the predefined specification of rules or conditions that dictate the data's behavior, eliminating the need to create rules during the execution process. An IDS is a document outlining the requirements for Building Information Modeling (BIM) at the time of exchanging the information, which can bring the validation of IFC to the users and the tools used to perform the analysis. It details what must be included in the model, such as specific asset specifications or adherence to naming conventions for zones and rooms (Kremer & Beetz, 2023). By using IDS to establish rules for the BIM model and enable the automatic checks to ensure compliance with these rules, significant improvements in the project efficiency and accuracy can be achieved. This reduces the need for human intervention and enhances the data consistency throughout the lifecycle process. IDS can enhance IFC by enabling the computer-interpretable exchanges and by offering developers the tools to create user-friendly interfaces to meeting specific requirements. When properly configured, IDS allows non-technical team members to query and validate the integrity BIM model's data, enabling verification by users. Therefore, IDS is used to determine, configure, and check the requirements and delivery at any stage of the building or infrastructure life cycle (Tomczak et al., 2022).

The integration of an information delivery manual (IDM) and model view definition (MVD) by considering buildingSMART Data Dictionary (bSDD) was a new method developed by Son et al., (2022). However, it lacks a validation feature for further use in the integration of LCA and BIM. Jeon et al. (2021) proposed a relational framework for smart, readable, machine-applicable IDM to specify exchange requirements (ERs) and their use cases. Their IDM data schema can be used as an international standard by considering more sharable and reusable data requirements and extending the schema to cover all items and attributes required for consideration. Tomczak et al. ( 2022) developed an IDS standard based on IFC to allow semi-automated compliance checking of BIM files, which includes material compositions, environmental impacts and disassembly aspects. They aimed to bring the circular economy in BIM tool with information delivery specification, but further study needs to be done to extend the scope in order to reach adaptability and scalability in actual project data.

While many studies have been done in relation to integrating BIM and LCA, lacking a structured approach to define and validate the data requirements for LCA workflows and limited application of IDS for environmental impact assessments does exist. Developed IDS typically focus on project specifications, design data, and construction planning. However, integrating environmental metrics into the IDS framework is still in its first stage. This constraint results from the intricacy and unpredictability of environmental impact data, which necessitates highly accurate, structured, and interoperable datasets for efficient transfer across various software systems. The integration of BIM with LCA is made more difficult by the fact that environmental impact data is frequently given in formats that are not directly machine-readable or compatible with current BIM systems. As a result, there is a crucial gap in the smooth integration of IDS with environmental assessments, which restricts the possibility of accurate and effective environmental impact assessments during the design and construction stages.

Therefore, defining an automated validation process for the integration of OpenBIM with LCA is required. This study aims to present the development of an IDS-integrated framework to standardize the life cycle environmental benchmarking of building projects. By leveraging the capabilities of openBIM, this framework seeks to enhance transparency, improve data interoperability, and facilitate comprehensive environmental assessments. The aim is to provide a robust approach to make informed decisions that promote decarbonization in the built environment. Thus, this study will contribute to advancing openBIM-based sustainability practices and will empower the construction industry to achieve considerable carbon reductions aligned with global sustainability goals.

## 2. METHODOLOGY

This study employs Information Delivery Specification (IDS) as a safe approach to the minimum required data extraction from an IFC file and the main component of the OpenBIM ecosystem, which will be used in the process of Life Cycle Assessment (LCA). LCA, in this study, follows the ISO 14040 and ISO 14044 standards, to ensure a systematic assessment of embodied carbon throughout the life cycle stages. The system boundary is defined as cradle-to-gate, encompassing raw material extraction, manufacturing, and transportation, excluding the use and end-of-life phases. The primary focus is on embodied carbon, which represent the total greenhouse gas (GHG) emissions associated with the material and energy inputs. The goal of this study is to introduce an LCA-specific IDS file as a minimum requirement for data validation strategy embedded in a system to enable users to validate the IFC file so that they can deliver the IFC file as an approved source of data for LCA assessments. In this research, IFC4X3 has been employed. The following outlines the research methodology employed in this study, including the LCA-specific IDS development, and validation system design in more detail.

### 2.1. Developing LCA-specific IDS

The IDS, a new OpenBIM standard developed by buildingSMART, is basically an XML file with a predefined schema and types to be readable by computer and human, including sections such as: a) details related to the whole file, for instance, title, description and version; and b) a list of specifications or rules, which are checked against an IFC file (de Marco et al., 2024). Each specification applied to IFC has its own applicability domain defined by the entity's name, specific attributes, properties, materials, or classifications, followed by the requirements, which are limited to checking the IFC entities in terms of: a) existing such entity in the model; b) being part of another entity; c) being in a specific classification; or d) having specific attributes, properties, or materials. Another aspect of IDS specifications is the rule modality, such as a rule that can be either in prohibited or optional mode, which means the applicability domain of each MUST or MAY comply with that rule. For example, all IFCWALL entities in IFC files MUST have required quantities (dimensions and the type of material) and IFCMATERIAL may have ReinforcementAreaRatio property to estimate the quantities of rebars correctly.

IFC4X3 specification includes more than 800 entities. Many of them are related to the graphical presentation but still, many of them will remain to carry information, therefore writing rules for all the entities is useless. To determine all IFC entities that are useful for the LCA part, all the IFC entities were investigated to specify the usage scope of each of them, and then they were mapped to the LCA stages to select the entities that are encompassed with the cradle-to-gate boundary. Moreover, key attributes and properties having a role in either the quantity take off extracted out of the BIM model or peripheral information like project location were determined. Finally, based on the above-mentioned criteria of IDS development and mapped IFC entities, requirements were defined as IDS specifications. In relation to the requirements, 33 specifications were defined in the IDS to be able to cover the required information for embodied carbon calculation as necessary. Figure 1 shows a sample of IDS file in XML format.


Figure 1: Sample of LCA-specific IDS rule definitions

Whenever a user uploads the IFC file in the tool, the model will check and validate the IFC file against the specifications and provides the report in different formats. At the end of this process, the model will provide a list of errors and needed modifications based on IDS to the user to modify the IFC file to get ready for the next step of LCA analysis.

### 2.2. Validation of the system design

This section presents the design of a validation system for exchanging the data, to ensure compliance with LCA data requirements. The system is designed to automate the verification process by checking whether IFC files adhere to the predefined LCA data requirements, enhancing the data quality and interoperability in BIM workflows, facilitating a seamless integration between OpenBIM-based data and LCA requirements, and leveraging open standards such as IFC. The system consists of several interconnected components, each playing a crucial role in ensuring the integrity of data flow. These components work together to streamline the validation workflow, enhancing the reliability and efficiency of managing IFC data in OpenBIM environments. Below are the outlines of the system's architecture, components, and validation workflow, detailing how IDS rules are applied on IFC.

**Storage Service:** It serves as the backbone of the validation system, providing a structured and reliable repository for handling IFC files throughout their lifecycle. Its primary function is to store, retrieve, and manage IFC files, ensuring secure and efficient data access for users and system components. This service plays a crucial role in facilitating seamless validation, reporting, and modification workflows by ensuring that files are available when needed. One of its key functionalities is versioning, which ensures that multiple iterations of the same file are preserved, allowing users to track changes, revert to previous versions, and maintain a comprehensive history of modifications. This capability is essential for auditability and collaborative workflows, as it enables seamless comparison between the different file versions. The storage system is designed to support high availability and fast access, ensuring smooth integration with other system components such as the IDS validation engine and reporting modules.

Security is another critical aspect of the Storage Service. It implements access control mechanisms to ensure that only authorized users can upload, retrieve, or modify files. This is particularly important in collaborative BIM environments where multiple stakeholders, including architects, engineers, and project managers, need access to IFC data while maintaining strict control over modifications. Furthermore, the

Storage Service is designed to handle different formats of the data and dependencies, making it compatible with both raw IFC files and additional data inputs like IDS (Information Delivery Specification) files. This flexibility ensures that the validation process has access to all the necessary components, enabling accurate and reliable compliance checks. By providing a scalable, secure, and version-controlled storage solution, the Storage Service acts as a central hub for managing IFC files throughout their validation, modification, and reporting lifecycle, ultimately supporting data integrity and collaboration within openBIM workflows.

**Validator Service**: The Validation Service is the core component responsible for verifying that IFC files conform to the Information Delivery Specification (IDS) defined in the previous section. This service ensures that IFC data meets LCA-specific requirements, enhancing interoperability and data quality through openBIM workflows. To perform validation, the service applies IDS specifications to an IFC file, systematically checking whether the file satisfies predefined constraints related to attributes, relationships, property sets, and other peripheral data requirements such as project location. The validation process is powered by IfcOpenShell version 0.8.1, an open-source library for parsing and processing IFC files. IfcOpenShell enables efficient extraction and evaluation of IFC data, allowing the service to cross-check IDS-defined rules against the actual file content. Once the validation is complete, the Validation Service generates a structured validation result containing details of compliance and non-compliance. This result is formatted and prepared for the Reporter Service.

**Reporter Service**: is responsible for transforming raw validation results into structured, insightful reports that help users identify, understand, and resolve issues within their IFC models. By linking non-compliant elements to their corresponding IFC entities, attributes, and properties, the service provides users with clear insights into model inconsistencies such as error descriptions, missing attributes, and any deviations from the IDS rules, enabling efficient corrective actions. One of the core functionalities of the Reporter Service is generating reports in multiple formats, catering to different project needs. Users can choose between: PDF Reports – Designed for formal documentation, review, and archiving. These reports provide a comprehensive summary of the validation results, including error descriptions, missing attributes, and deviations from the IDS. PDF reports are particularly useful for project managers, stakeholders, and compliance auditors who require a structured and easy-to-read document. BCF (BIM Collaboration Format) Reports – Tailored for issue tracking and coordination within BIM workflows. BCF reports allow users to integrate validation results into BIM coordination platforms, enabling seamless communication between architects, engineers, and project managers. By linking validation issues directly to specific IFC elements, BCF reports facilitate a more dynamic and efficient resolution process.

**Modifier Service**: The Modifier Service is responsible for preprocessing IFC files by applying necessary modifications before or after validation, ensuring that the data structure aligns with IDS requirements. This service enhances data consistency and correctness by automatically adjusting, enriching, or reclassifying IFC elements to meet predefined validation criteria. One of the key functionalities of the Modifier Service is the ability to add, modify, or remove attributes, properties, materials, and classifications from an IFC file. These modifications help resolve issues detected during the validation process, such as missing attributes, incorrect relationships, or inconsistencies in project data. The Modifier Service is powered by IfcOpenShell 0.8.1, an open-source library specifically designed to handle IFC files. This enables precise and efficient parsing and editing of IFC elements while preserving the integrity of the original data. The service can update property sets, fix attribute values, and apply standardized classifications based on project-specific rules. Version control is another critical aspect of the Modifier Service. Every modification request result in a new version of the IFC file being stored, allowing users to track changes and revert to the previous iterations if necessary. This versioning system enhances transparency, auditability, and collaboration, especially in large-scale BIM projects involving multiple stakeholders. The Modifier Service seamlessly integrates with the Web Service, allowing users to initiate modification requests through an interactive interface. If a validation report indicates non-compliance, users can trigger the modification workflow directly from the report, ensuring a continuous improvement cycle. Once modifications are applied, the updated IFC file can be revalidated.

**Web Service**: The Web Service acts as the primary interface between users and the backend validation system, facilitating interactions for file uploads, validation requests, report generation, and IFC file modifications. Designed as a user-friendly and interactive platform, it streamlines the process of managing IFC files within an openBIM workflow. This service integrates with various backend components—such as the Storage Service, Validator Service, Reporter Service, and Modifier Service—to ensure smooth execution of BIM validation and reporting tasks. One of the core responsibilities of the Web Service is file management. Users can upload IFC files directly through the web interface, triggering automatic storage and indexing within the Storage Service. Once stored, the system allows users to retrieve and manage their files, ensuring that they have full control over their data throughout the validation and modification processes.

The validation process is another critical function of the Web Service. Users can initiate validation by selecting an uploaded IFC file and triggering the validation workflow. The system communicates with the Validator Service, which processes the file against the Information Delivery Specification (IDS) using IfcOpenShell. The Web Service then presents the validation results in a structured and intuitive format, enabling users to review compliance checks and identify potential issues within their BIM models. Upon completing the validation, users can generate detailed reports that summarize the compliance results. The Web Service interacts with the Reporter Service to allow users to choose between different report formats, such as PDF for formal documentation or BCF (BIM Collaboration Format) for issue tracking and coordination. This ensures flexibility, enabling users to integrate validation feedback into their existing BIM workflows effectively. If a validation report reveals any issue, the Web Service provides an option for modification. Users can edit their IFC files directly by initiating a modification request, which is handled by the Modifier Service. This process allows for targeted adjustments, such as adding or correcting missing properties, materials, or classifications. Once the modifications are complete, the updated file is stored as a new version, preserving the history of changes. Beyond its functional responsibilities, the Web Service emphasizes usability and accessibility. It is designed with an intuitive UI, making it easy for users—whether BIM experts or project managers—to interact with the system. Security is also a priority, with authentication and authorization mechanisms ensuring that only permitted users can access and modify IFC files.

## 3. WORKFLOW AND VALIDATION

Figure 2 shows the diagram that represents a structured workflow for handling IFC file validation, modification, reporting, and storage within a web-based system. The system is divided into four primary services: Storage Service; Validator Service; Reporter Service; and Modifier Service, all of which interact with a Web App for user engagement. The process begins with the Storage Service, where a user uploads an IFC file. This file is stored and later retrieved as needed. When a validation request is initiated, the Validator Service retrieves the IFC file along with an IDS file from storage. The validation process is executed by using IfcOpenShell, an open-source tool designed to handle IFC files. Within the Web App, the user starts by uploading the file to storage. Once the file is uploaded, they can trigger the validation process, which leads to genertating a report. The validation results are displayed on a web page, where the user evaluates whether the validation is satisfactory. If the validation passes, the process concludes. However, if the validation does not meet expectations, the user can proceed with modifying the IFC file. For modification, the Modifier Service allows users to add, remove, or change properties, materials, and classifications within the IFC file. The modified version is then stored with a new version assignment. This ensures that modifications are tracked, and previous versions can be referenced if needed. Once validation is complete, users can request a report through the Reporter Service. They are given the option to generate a report in either PDF or BCF (BIM Collaboration Format). Depending on the chosen format, the appropriate report is generated and made available for download. This report provides an overview of the validation results and any necessary modifications.

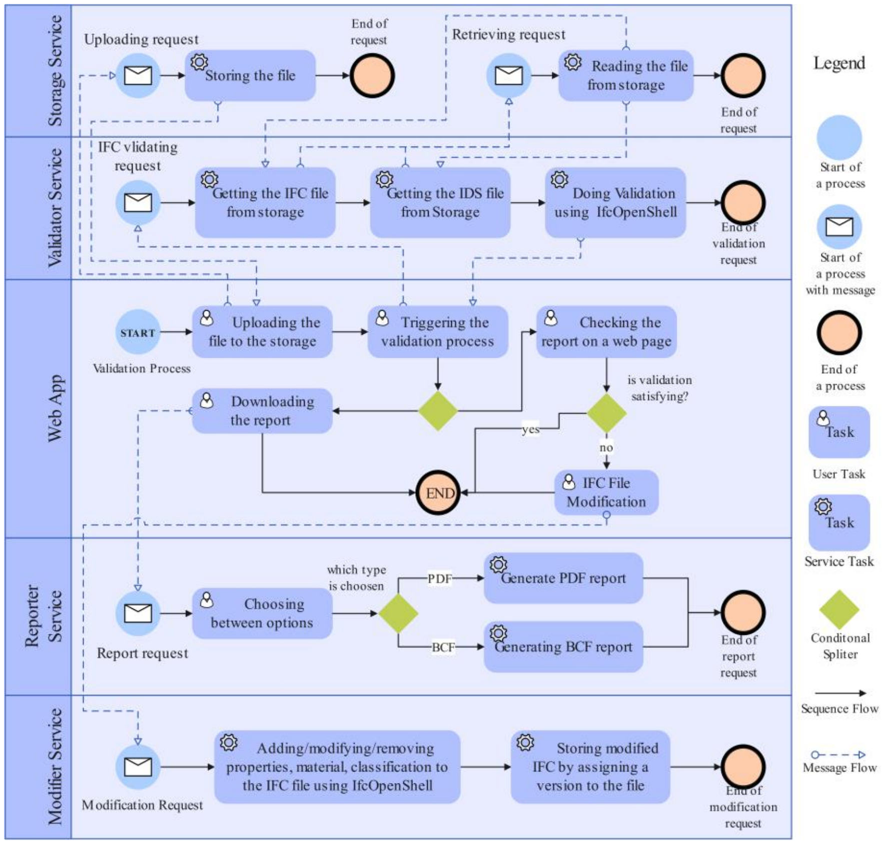


Figure 2: Workflow (Process) of validation in the designed system

The case project's model shown in Figure 3 represents a 3D model for a clinic building that was designed to validate the developed model. It is a BIM model exported in IFC format, ensuring interoperability and data richness that align with industry standards. Unlike a real-world construction project, this clinic was developed solely for experimental and analytical purposes, allowing for testing the developed workflows and methodology.

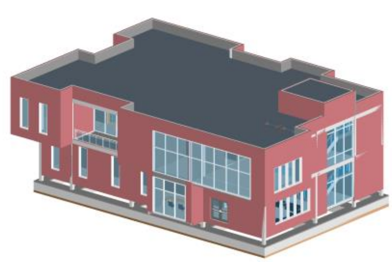

Figure 3: Case project's 3D model

After applying the workflow introduced in this study, the sample validation results are shown in Figure 4. The validation was conducted through the designed system using a developed user interface (Web App), assessing whether the BIM 3D model meets the defined data requirements. In the results, green indicates that the IDS validation has successfully passed for that rule, meaning the required data is correctly provided. Warnings (highlighted in yellow) suggest that the rule was not fully met, and while passing is recommended, it is not strictly mandatory. Red indicates that the validation has failed for critical rules, which means the missing or incorrect data must be corrected to comply with the requirements. The displayed results provide a sample of these validation outcomes, demonstrating how the developed system evaluates the completeness and compliance of the BIM model.

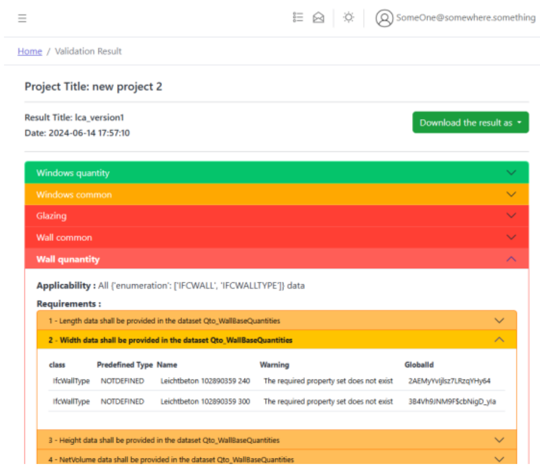


Figure 4: Validation results

## 4. DISCUSSION

The integration of OpenBIM and LCA provides a solution for resolving interoperability issues such as inconsistent standards, data fragmentation, and seamless workflows between BIM and LCA. By proposing this framework, this study presents a novel approach that ensures accurate, efficient and automated validation of the environment for LCA purposes directly from BIM models, which minimizes human errors and enhances data consistency. However, even with several advantages, there are still a number of challenges to using this framework widely. Standardization of data is still one of the most pressing issues. Many BIM tools are used in the construction industry and each of them has its own approach to interoperate IFC standards. Therefore, the lack of a universal approach for the data exchange process is making it difficult to use the BIM and LCA integration. Future research could look into how to refine the IFC standard to support a broader range of tools and develop user-friendly solutions that simplify the adoption of OpenBIM-LCA workflows in practice. In addition, the ISO 14040/14044 standards, which serve as the foundation for LCA, focus on processes and products over the life cycle. On the other hand, OpenBIM guarantees the data is exchanged in an open and standard format and is quite compatible with ISO standards. In this regard, by adhering to both OpenBIM and ISO standards, this framework improves the accuracy and consistency of data used in LCA, which streamlines data flows from the building design to environmental impact assessment.

Moreover, while LCA tools provide their data validation system, they typically use manual corrections and predefined templates, which might result in errors and inconsistencies. When the right data is not available in these existing LCA tools, most systems either flag the data as incomplete or prompt the user to manually input the missing data However, the proposed framework in this study guarantees the automated data validation directly from BIM models and provides the correct environmental data for LCA calculations which is a novel contribution. In this way, the primary contribution of this method is the ability to provide seamless data exchange between OpenBIM and LCA by automating environmental data validation. This framework can increase data accuracy by making sure that only accurate and reliable data is utilized for environmental assessment through the automated BIM data validation process against the required LCA parameters. Therefore, this approach improved data interoperability across various BIM tools for LCA purposes by providing the developed IDS in this study to standardize data exchange criteria. Applying this framework can prevent current manual data exchange in many tools by this automated validation process. Finally, the framework ensures that the right data is accessible for accurate LCA calculations, which makes it simpler to evaluate the environmental impacts of buildings and supports decarbonization efforts. Because of these improvements, the proposed solution is a crucial step toward better decisions in the design and construction of sustainable buildings.

## 5. CONCLUSION

This study highlighted the potential integration of OpenBIM and LCA to address the current interoperability challenges practices by presenting an information delivery framework. The framework defines minimum data requirements for alignment with OpenBIM to increase interoperability by leveraging the industry foundation classes (IFC) standard and the developed IDS for LCA workflows. Defining validation rules for facilitating the provided automatic method to use in the integration of OpenBIM with LCA workflows to facilitate LCA calculations. Based on the IDS framework, users can conduct embodied carbon calculations with a more reliable and accurate way. By using this framework, users can ensure that imported IFC files are validated through the framework to be used as reliable files for LCA assessments, leading to address the gap between the inconsistent data format and fragmented workflows. Moreover, using IFC4X3 enables the application of advanced standards in the integration of OpenBIM with LCA environment, providing more accurate and scalable solutions.

The presented framework aims to address the current gaps through a scalable, automated OpenBIM-based LCA model by considering improved data exchange procedures. The framework automates the processes of data extraction, validation, mapping, and modification, providing a comprehensive solution to support sustainable design and environmental impact analysis within BIM workflows. The framework includes multiple steps that systematically process BIM data, from IFC file submission through validation and report generation. Users engage with the system by uploading an IFC file containing the building model data. A simple case study was used to show the applicability of the framework and the validation of workflow to increase the accuracy and interoperability of LCA calculations. The findings of this study can help advance decarbonization, empowering stakeholders to meet global carbon reduction goals. Future studies can be conducted to enhance the framework with more environmental categories, and other life cycle stages such as use and end-of-life phases. Furthermore, incorporating real-time data with IoT sensors can improve the OpenBIM-LCA integration capabilities.

## ACKNOWLEDGMENTS

The authors acknowledge the financial support of the National Research Council of Canada (NRC) - Construction Sector Digitalization and Productivity Challenge program (CSDP) under Agreement # CSDP-001-1, Project Number A1-023829, titled "Developing an Open Building Information Modeling (BIM) Integrated Framework to Standardize the Life Cycle Environmental Benchmarking of Building Projects."

## REFERENCES

Akbari, S., Sheikhkhoshkar, M., Pour Rahimian, F., El Haouzi, H. B., Najafi, M., & Talebi, S. (2024). Sustainability and building information modelling: Integration, research gaps, and future directions. *Automation in Construction*, *163*, 105420. https://doi.org/10.1016/j.autcon.2024.105420

Alwan, Z., Nawarathna, A., Ayman, R., Zhu, M., & ElGhazi, Y. (2021). Framework for parametric assessment of operational and embodied energy impacts utilising BIM. *Journal of Building Engineering*, *42*(May), 102768–102768. https://doi.org/10.1016/j.jobe.2021.102768

Dauletbek, A., & Zhou, P. (2022). BIM-based LCA as a comprehensive method for the refurbishment of existing dwellings considering environmental compatibility, energy efficiency, and profitability: A case study in China. *Journal of Building Engineering*, *46*(November 2021), 103852–103852. https://doi.org/10.1016/j.jobe.2021.103852

de Marco, G., Slongo, C., & Siegele, D. (2024). Enriching Building Information Modeling Models through Information Delivery Specification. *Buildings*, *14*(7), Article 7. https://doi.org/10.3390/buildings14072206

*Information Delivery Specification—buildingSMART International*. (2024). Retrieved February 20, 2025, from https://www.buildingsmart.org/standards/bsi-standards/information-delivery-specification-ids/

Jeon, K., Lee, G., Kang, S., Roh, H., Jung, J., Lee, K., & Baldwin, M. (2021). A relational framework for smart information delivery manual (IDM) specifications. *Advanced Engineering Informatics*, *49*, 101319. https://doi.org/10.1016/j.aei.2021.101319

Jrade, A., Jalaei, F., Zhang, J. J., Jalilzadeh Eirdmousa, S., & Jalaei, F. (2023). Potential Integration of Bridge Information Modeling and Life Cycle Assessment/Life Cycle Costing Tools for Infrastructure Projects within Construction 4.0: A Review. *Sustainability*, *15*(20). https://doi.org/10.3390/su152015049

Klumbyte, E., Georgali, P.-Z., Spudys, P., Giama, E., Morkunaite, L., Pupeikis, D., Jurelionis, A., & Fokaides, P. (2023). Enhancing whole building life cycle assessment through building information modelling: Principles and best practices. *Energy and Buildings*, *296*, 113401. https://doi.org/10.1016/j.enbuild.2023.113401

Kremer, N. C., & Beetz, J. (2023, July 10). *Extending—Information delivery specification—For linking distributed model checking services*. 2023 European Conference on Computing in Construction and the 40th International CIB W78 Conference. https://doi.org/10.35490/EC3.2023.266

Llatas, C., Soust-Verdaguer, B., & Passer, A. (2020). Implementing Life Cycle Sustainability Assessment during design stages in Building Information Modelling: From systematic literature review to a methodological approach. *Building and Environment*, *182*, 107164. https://doi.org/10.1016/j.buildenv.2020.107164

Mohammed, A. B. (2023). Process Map for Accessing Automatization of Life Cycle Assessment Utilizing Building Information Modeling. *Journal of Architectural Engineering*, *29*(3), 04023012. https://doi.org/10.1061/JAEIED.AEENG-1449

Mostafazadeh, F., Eirdmousa, S. J., & Tavakolan, M. (2023). Energy, economic and comfort optimization of building retrofits considering climate change: A simulation-based NSGA-III approach. *Energy and Buildings*, *280*, 112721. https://doi.org/10.1016/j.enbuild.2022.112721

Najjar, M., Figueiredo, K., Hammad, A. W. A., & Haddad, A. (2019). Integrated optimization with building information modeling and life cycle assessment for generating energy efficient buildings. *Applied Energy*, *250*(January), 1366–1382. https://doi.org/10.1016/j.apenergy.2019.05.101

Shukla, P. R., Skea, J., Slade, R., Al Khourdajie, A., van Diemen, R., McCollum, D., Pathak, M., Some, S., Vyas, P., Fradera, R., Belkacemi, M., Hasija, A., Lisboa, G., Luz, S., & Malley, J. (Eds.). (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* https://doi.org/10.1017/9781009157926

Son, S., Lee, G., Jung, J., Kim, J., & Jeon, K. (2022). Automated generation of a model view definition from an information delivery manual using idmXSD and buildingSMART data dictionary. *Advanced Engineering Informatics*, *54*, 101731. https://doi.org/10.1016/j.aei.2022.101731

Tavakolan, M., Mostafazadeh, F., Jalilzadeh Eirdmousa, S., Safari, A., & Mirzaei, K. (2022). A parallel computing simulation-based multi-objective optimization framework for economic analysis of building energy retrofit: A case study in Iran. *Journal of Building Engineering*, *45*(August). https://doi.org/10.1016/j.jobe.2021.103485

Tomczak, A., Berlo, L. V., Krijnen, T., Borrmann, A., & Bolpagni, M. (2022). A review of methods to specify information requirements in digital construction projects. *IOP Conference Series: Earth and Environmental Science*, *1101*(9), 092024. https://doi.org/10.1088/1755-1315/1101/9/092024

Tushar, Q., Bhuiyan, M. A., Zhang, G., & Maqsood, T. (2021). An integrated approach of BIM-enabled LCA and energy simulation: The optimized solution towards sustainable development. *Journal of Cleaner Production*, *289*, 125622. https://doi.org/10.1016/j.jclepro.2020.125622

van Berlo, L., Willems, P., & Pauwels, P. (2019). *Creating Information Delivery Specifications using Linked Data*.

Yeung, J., J Hahn Menacho, A., Marvuglia, A., Navarrete Gutiérrez, T., Beach, T., & Rezgui, Y. (2023). An open building information modelling based co-simulation architecture to model building energy and environmental life cycle assessment: A case study on two buildings in the United Kingdom and Luxembourg. *Renewable and Sustainable Energy Reviews*, *183*, 113419. https://doi.org/10.1016/j.rser.2023.113419