

## Standardizing whole-building lifecycle assessment (wbLCA) benchmarking framework facilitated by adopting openBIM for Canadian building sector

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**ABSTRACT:** The industry is increasingly recognizing the importance of reducing greenhouse gas (GHG) emissions, leading to the widespread adoption of Whole-Building Lifecycle Assessment (wbLCA) as a crucial tool for evaluating environmental impacts. However, the effectiveness of wbLCA is limited by the lack of standardized benchmarking methods, resulting in significant variability in benchmark values.

To address this issue, this paper proposes a framework for standardizing wbLCA benchmarking using a statistical model to enable comparability analysis, facilitated by both the adoption of Open Building Information Modeling (openBIM), and identification of optimal number of buildings to be studied. Utilization of the openBIM enables interoperability and standardization of data into the wbLCA, which enhance the accuracy and reliability of wbLCA. By leveraging openBIM, the framework aims to improve the transparency and comparability of wbLCA results, promoting informed decision-making for decision/policy makers. Furthermore, an optimal number of buildings, also known as sample size, is proposed to achieve optimal/adequate benchmarking values. The proposed framework is mainly based on modified graduated approach, and it enables identification of reference value and best practice value for residential and office buildings in the Canadian building domain, which enables reliable and comparable comparisons, and enable decision makers to set policies and standards accordingly. This paper outlines the key components of the framework, discusses the benefits and challenges of implementing Open BIM for wbLCA, and provides practical recommendations for policymakers and industry stakeholders to facilitate the adoption of standardization process through statistical model. This research supports sustainable building practices and the integration of BIM models into environmental assessments.

### 1. INTRODUCTION

The built environment is massively responsible for global greenhouse gas emissions, accounting for over a third of the emissions worldwide (AIA, n.d.; Alwan & Ilhan Jones, 2022). It includes emissions from both operations of a building facility and from the processes of construction activities. With a global increase in building floor area estimated to be at around twofold by the year 2060, sustainable practices for construction need to be applied more than ever. Lifecycle assessment is an important step towards quantification of building's environmental impact and is applicable throughout building's lifecycle; hence, wbLCA plays a critical role. There is insufficient concordance between these sustainability certifications and wbLCA tools and no international standardization and, thus, do not lend to comparable results (Dos & Dimova, 2018; Nizam et al., 2018). Decarbonization efforts in this sector are from policies and strategies like the Paris Climate Agreement, Architecture 2030, etc., and all are directed towards achieving a significant reduction in carbon emissions. However, effective comparisons using wbLCA are hindered because of the lack of a standardized procedure (Jalalei, 2022).

This paper proposes a framework for standardization of wbLCA benchmarking via openBIM to enhance accuracy and reliability. This study will provide a statistical model for standardized wbLCA benchmarking in Canada's building sector. Through input data standardization and digital building model facilitation, this framework identifies present gaps in the research and enhances the practical approaches towards environmental impact assessment.

## 2. LITERATURE REVIEW

### 2.1 Current Practices in wbLCA and need to have wbLCA benchmark

Current practices in wbLCA involve various methodologies and tools, such as the Athena Impact Estimator for Buildings, One Click LCA, SimaPro, and GaBi. These tools enable quick LCA calculations based on building share, size, types of materials, and quantification of environmental impacts (EI) associated with different building materials and processes using available input information (Li et al., 2023). However, the input information used by these tools is not consistent, resulting in wbLCA outcomes that are not directly comparable. This inconsistency leads to variations and potential inaccuracies in the reported environmental impacts, thereby undermining the reliability and comparability of wbLCA results. Moreover, in current practice, benchmark values defined as the process of collecting, analyzing, and relating performance data of comparable buildings or other types of construction works, typically used for evaluating and comparing performance between or within objects of consideration (14:00-17:00, n.d.) or wbLCA are derived from these tools. However, the methods of benchmarking used are also not comparable. On one hand, the input information for each tool is inconsistent; on the other hand, a consistent benchmarking method is not employed to enable comparability of results. Thus, there are several challenges in wbLCA benchmarking development. While there are numerous publications related to BIM-LCA integration, there is a need for a standardized and systematic method of utilizing BIM for LCA partly due to lack of sufficient methodological details required for integration of BIM with LCA. Studies emphasize that these methodological insufficiencies need to extend beyond knowledge inquiry and organization to support decision-making in the construction sector and the built environment. While BIM-LCA integration is still at an early stage, Open-BIM integration with LCA is less common in literature case studies, often due to the poor design of BIM models (Soust-Verdaguer et al., 2017; Zimmermann et al., n.d.).

The “openBIM” initiative enables BIM data to be exchanged using open standards such as Industry Foundation Classes (IFC), which is not proprietary in nature and hence can enhance collaboration and is widely adopted as a universal language for built environment data exchange and management enabling access to operational data through BIM environment. It is envisioned openBIM initiatives can lead to a streamlined procedure for energy model development that can be reproduced, enhanced, or allow the exchange of data for other uses (Cozzitorto et al., 2024). There are various advantages to adopting building information modelling and using the IFC as exchange format to retrieve relevant data from BIM model. One significant advantage of this approach is the elimination of manual data entry for LCA, which is very time-consuming (Nizam et al., 2018; Soust-Verdaguer et al., 2017).

### 2.2 Relationship between the structure of input information for wbLCA and wbLCA benchmarking

Although whole-building Life Cycle Assessment (wbLCA) and benchmarking can be examined independently, a benchmark fundamentally comprises a set of wbLCA results. The standardization of wbLCA processes is crucial, as it facilitates the standardization of input information for benchmarking, thereby enhancing the reliability and comparability of wbLCA benchmarking results. Figure 1. represents the existing relationship between Standardized wbLCA and on the other hand the Standardized wbLCA

benchmarking.

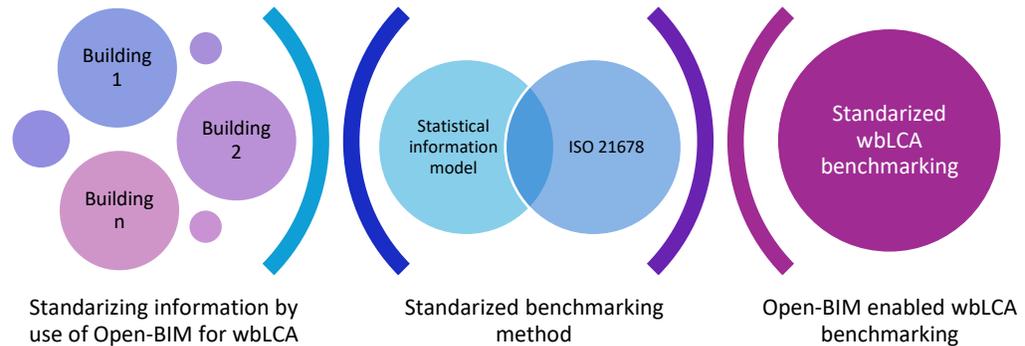


Figure 1: Relationship between Standardized wbLCA and Standardized wbLCA benchmarking

The two main challenges identified that have led to uncertainty regarding the comparability and reliability of wbLCA benchmarking and especially its values are: 1) the lack of standardized information delivery for wbLCA, and 2) inconsistencies in benchmarking methodologies. These challenges are well-recognized within both industry and practice. Several resolutions have been proposed to address the above stated issues, which will be discussed further below. In this exploration, we delve into two solutions which can be leveraged for enhancing sustainability in the construction industry. That is the integration of Building Information Modelling (BIM) with Life Cycle Analysis (LCA) and the standardization of whole-building Life Cycle Assessment (wbLCA) benchmarking methods. In the next sections we will investigate how these existing solutions can be utilized to address some of the challenges and contribute to more sustainable building practices.

### 3. OPENBIM WBLCA FRAMEWORK DEFINATION RESEARCH METHODOLOGY:

This methodology outlines the development of a standardized framework for whole-building lifecycle assessment (wbLCA) benchmarking facilitated by Open BIM for the Canadian building sector. This involves integrating BIM and LCA to standardize benchmarking methods by employing statistical model for analysis

#### 3.1 Integration of BIM and LCA

The framework proposed uses Building Information Modeling (BIM) to provide information required for the standardization and interoperability of data used in lifecycle assessments. To do so, Industry Foundation Classes (IFC) format is used as the schema of exchange of data required. This allows detailed building information to be exported from BIM authoring tools. This information is then verified against Information Delivery Specifications (IDS) for materials, energy, and water to ensure data accuracy and presence before being exported for LCA analysis. The integration process addresses the current gap in interoperability by facilitating seamless data exchanges, thus improving the reliability of environmental impact assessments throughout a building's lifecycle.

#### 3.2 Standardization of wbLCA Benchmarking

In addition to data requirement availability to standardize wbLCA benchmarking, the proposed framework takes a dual approach, utilizing both top-down and bottom-up strategies; in which the bottom-up models focus on individual building parameters to assess energy use and environmental impact, while the top-down models specify building lifecycle reductions. This dual approach ensures comprehensive benchmarking by incorporating component-specific and global ecosystem benchmarks, thereby providing an integrated perspective on building performance. The framework emphasizes the need for standardized processes for material quantity labeling and model checking, as informed by existing guidelines.

#### 3.3 Statistical Model for Benchmarking

A statistical model is used to derive wbLCA benchmark values, focusing on metrics such as Global Warming Potential (GWP). The framework uses a modified graduated approach to determine the optimal sample size and benchmarking needs.

### 3.4 Framework Implementation

The framework is divided into two interrelated modules:

Module A: Focuses on standardizing the openBIM enabled wbLCA process, integrating IFC, IDS, and LCA profiles to ensure data consistency.

Module B: Concentrates on wbLCA benchmarking, utilizing comprehensive datasets to derive benchmark values through quantitative analysis.

This proposed methodology aims to identify the foundational requirements for informed decision-making to all stakeholders such as policymakers. The aim is to ultimately promote sustainable building practices through standardized wbLCA processes.

## 4. EXISTING SOLUTION/RESOLUTION 1 – STANDARDIZATION OF INFORMATION FACILITATED BY OPENBIM FOR WBLCA

The integration of BIM and LCA offers a significant opportunity for enhancing sustainability in the construction industry. BIM, which can be defined as a set of technologies and processes enabling collaborative building design, construction, and operation in a virtual environment, plays an important role in standardizing information. Hence, BIM can be further utilized for evaluating the environmental impacts through LCA as shown in Figure 2. Past research indicates integration of BIM and wbLCA can potentially streamline the collection and compilation of Life Cycle Inventory (LCI) data, hence, enhancing environmental impact assessments throughout a building's lifecycle (Ajayi et al., 2015). Even though BIM presents a viable solution for wbLCA, its implementations are limited in practice. This is because, current BIM-LCA integration in practice is often manual, underscoring the need for more automated and seamless data exchanges (Li et al., 2023). Also, the lack of standardized benchmarking methods for wbLCA does not allow for consistency and comparability across assessments. In addition, aforementioned, methodological gaps, such as insufficient details on how to effectively integrate BIM and LCA, adds an extra layer of challenge to effective decision-making in construction (Najjar et al., 2017; Xue et al., 2021). Furthermore, such integration is often limited by numerous technical issues like software compatibility and data exchange format. Informational challenges include determining the required data at various stages of the building lifecycle and ensuring data quality and availability within BIM models (Röck et al., 2018). Some technical challenges involve choosing between embedding all essential information within the BIM model or using other appropriate applications to process data. The use of the Industry Foundation Class (IFC) format, OpenBIM for data transfer is quite considerable, but thus requires the clear specification of the requirements to ensure that the information may be passed properly. Ultimately, software interoperability is extremely complex, requiring one to be able to secure that semantics and ontologies of the data are maintained during data transfer (Abdelaal, n.d.; Cabeza et al., 2013).

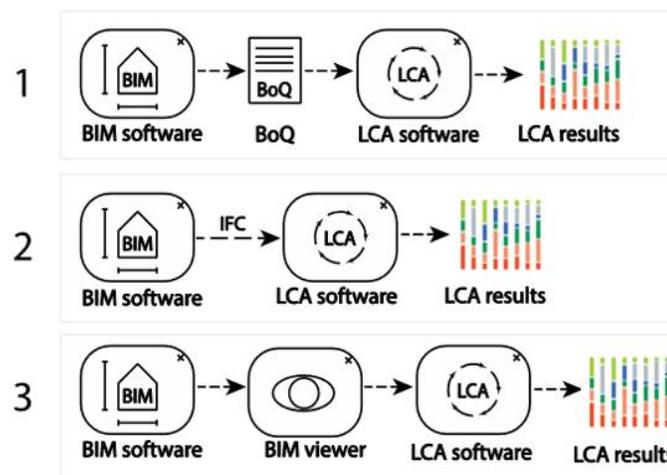


Figure 2: wbLCA stages and Resource use streams (Adapted from: Bowick et al. 2022)

Organizationally, BIM and LCA function as separate silos with very little if any collaboration because the methodologies underlying modelling future-building techniques seldom share the same tools, terminologies, and data structures. Such organizational hurdles require integration of these two divided domains with clearly laid out processes and standards. Though there are many tools available that can help extract material quantities from the BIM model for LCA, they rarely analyse the environmental impacts totally against the backdrop of the early stages of design. This limitation reduces their effectiveness in accommodating design changes or exploring alternatives. In conclusion, while BIM-LCA integration holds promise for advancing sustainable building practices, significant improvements are needed. These include developing standardized methods for integration, enhancing interoperability between tools, and creating comprehensive case studies to support robust LCA applications. By addressing these challenges, the construction industry can better leverage BIM and LCA to manage and reduce the environmental impacts of buildings effectively.

#### 4.1 Existing Solution 2/Resolution 2 - Standardizing wbLCA Benchmarking method facilitated by statistical method

Benchmarking methodology in the construction sector is a process comprised of consecutive steps of collecting and analyzing performance data of comparable buildings for evaluating and comparing their performance. These benchmarks provide important guidelines that permit knowledge concerning economic value and even issues of sustainability concerning an asset and facilitate sustainable building practice. They should be established using appropriate information from sources such as statistics, surveys, and regulatory requirements. In this regard, designers play an important role in reducing global greenhouse gas emissions by implementing LCA in their projects. Optimization during early design phases of building is vital as these decisions significantly impact a building's environmental performance. Benchmarks thus offer guidance from the outset, ensuring sustainable practices are integrated from the beginning. Current wbLCA benchmarks have limitations, such as their inability to guide design on either the elemental or material level. The greater proportion of current benchmarks focus on the building in general, and therefore, no direct link between total building target values and component-level benchmarks is available. Current benchmarks lack standard parameters and methodology, and thus, comparison between studies is difficult. The context and assessment goals influence the type of benchmarking values, such as limit, reference, best-practice, target, absolute, and relative values, and each is intended for various reasons such as to provide minimum compliance or compare to industry standard. Benchmark models for wbLCA in building structures can be derived using top-down and bottom-up strategies. The bottom-up models, which are preferred for wbLCA, compare individual building parameters to obtain energy use and environmental impact. The methodology is holistic and is crucial for successful benchmarking. For example, in Switzerland, impact for building is bottom-up estimated through materials and operation energy requirements for residential building. The top-down, however, is to specify building life cycle reductions. The dual approach is where component-specific and global ecosystem benchmarks are incorporated, and building performance is given an integrated perspective. The graduated approach is built progressively, and improvement in data collection leads to refinement in benchmarks to better building design for the environment.

### 5. FRAMEWORK DEVELOPMENT FOR OPEN-BIM BASED WBLCA BENCHMARKING

To achieve the goals of this study and address the research questions, a comprehensive framework for openBIM enabled wbLCA benchmarking is introduced. This proposed framework is designed to ensure a consistent and reliable approach for deriving consistent reproducible benchmark values for buildings. The intention of this research is to establish references and best practice values for benchmarking. Going forward the proposed openBIM framework is divided into two interrelated modules namely Module A and Module B as discussed below:

#### 5.1 Module A: Standardizing openBIM Enabled wbLCA Framework

The first module of the proposed framework provides necessary components of openBIM enabled wbLCA, focusing on standardizing the wbLCA process and the data related to materials, energy (Hosseini

Gourabpasi et al., 2025), and water for environmental performance indicators. The components required to establish a standardized openBIM enabled wbLCA framework is visually represented in Figure 3.

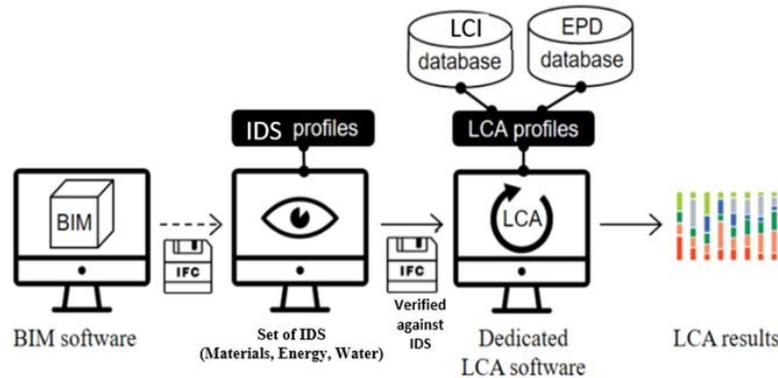


Figure 3: Standardizing openBIM Enabled wbLCA Framework

The main components of this openBIM framework consist of IFC, IDS and LCA profiles. The integration of BIM and LCA begins with the export of a IFC file from any BIM authoring tool, which contains detailed building information. This IFC file is then verified against specific Information Delivery Specifications (IDS) developed for materials, energy, and water. The contents of BIM model are checked resulting in a validated .ifc file which contains all the necessary information required for wbLCA. The verified data is subsequently imported into dedicated LCA software, which uses Life Cycle Inventory (LCI) and Environmental Product Declaration (EPD) databases to generate comprehensive LCA profiles. In the next phase, the LCA software generates detailed reports of these assessments.

The proposed framework in this study adopts and adapts a standardized process for material quantity labeling and model checking, as proposed by (Bowick et al., 2022) as shown in Figure 4. This mapping involves Unifomat Level 3 with Masterformat Level 4 and Uniclass 15 labeling. This mapping allows for direct integration of these classifications into the IFC. By mapping these elements, the framework facilitates the standardization of the wbLCA process and establish reliable benchmarks, thereby enhancing sustainable building practices.

The proposed openBIM Enabled wbLCA Framework significantly enhances the utility of data by extending its application to the LCA use case. It achieves this by minimizing errors during data extraction and mapping processes, ensuring that the information is both accurate and reliable. Additionally, the framework employs IDS profiles to meticulously verify the availability of the necessary information required for comprehensive analysis. This verification step is crucial as it ensures that all relevant data is present and correctly formatted, thereby facilitating a more efficient and effective LCA process. By integrating these mechanisms, the framework not only streamlines data management but also supports more informed decision-making and sustainability assessments in projects.

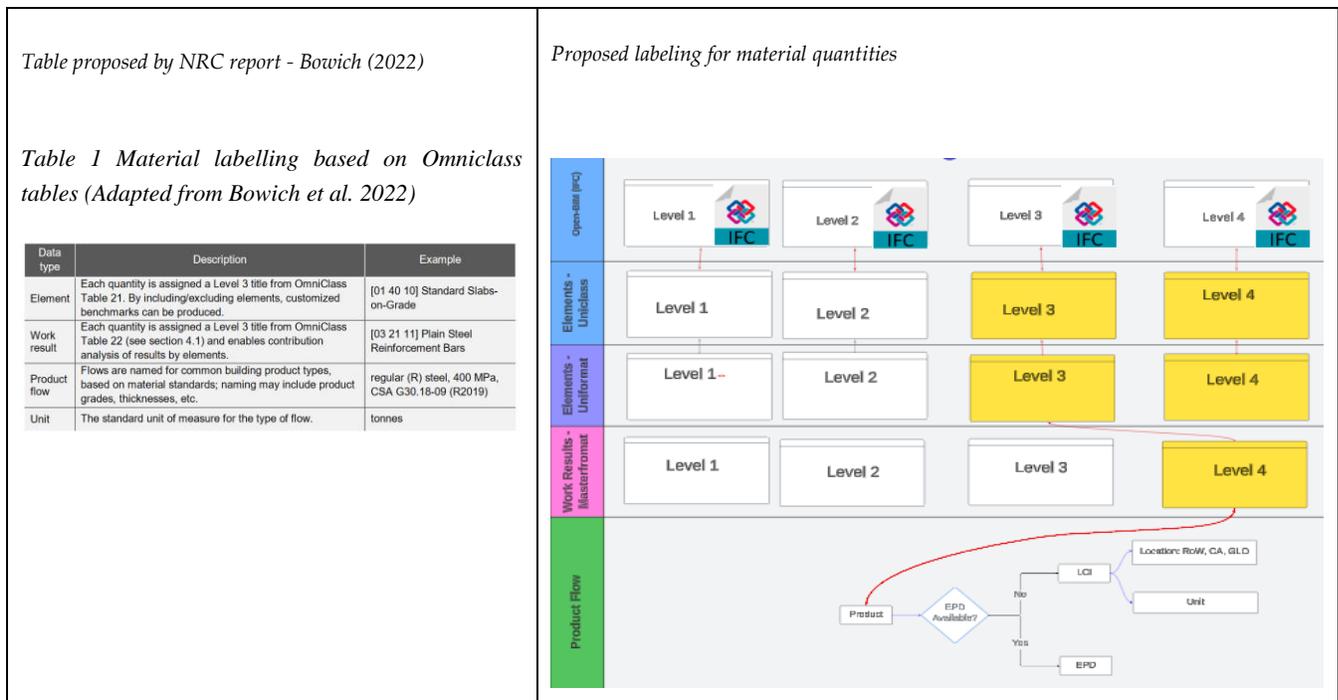


Figure 4: Proposed labeling for material quantities

## 5.2 Module B: Standardizing wbLCA Benchmarking

This module focuses on wbLCA benchmarking based on Global Warming Potential (GWP). It aims to standardize the information necessary to derive benchmark values, requiring a comprehensive dataset and an adequate sample size of buildings.

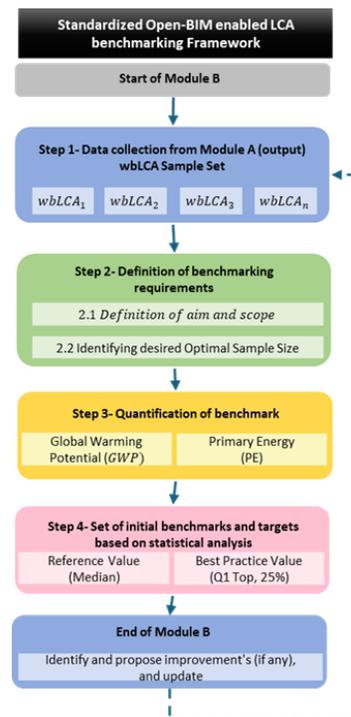


Figure 5: Standardized openBIM wbLCA benchmarking framework

Module B utilizes a modified graduated approach for wbLCA benchmarking, as shown in Figure 5. The approach is begun by data collection, where Module A outputs are aggregated to produce a wbLCA sample dataset. The process is followed by determining benchmarking needs, such as determining goal and objectives and selecting the optimal sample size for sound statistical benchmarks. The result is quantitative benchmarking, where leading metrics such as GWP and Primary Energy (PE) are used to specify benchmarks. Initial data and benchmarks are derived through statistical inference, using tools such as Monte Carlo Simulation to establish reference and best practice values. Module B concludes by proposing improvement according to the benchmarking outputs, revising structure, and setting up new goals for improvement. The synergy between the Module A and B presents a robust and standard procedure for conducting wbLCA and determining benchmarks, for building sustainability and for enabling wbLCA outputs to compare between studies.

## **6. DISCUSSION AND CONCLUSIONS**

The proposed framework offers several key benefits. By standardizing the wbLCA process and the information used, the framework ensures consistency and reliability in the results. This standardization is crucial for making informed decisions based on the LCA outcomes. The use of an IFC file and IDS profile ensures that data is exchanged and understood in different software tools and platforms, which creates the platform for interoperability. Verification of IFC files against IDS profiles and the use of LCI and EPD databases not only assure LCA analysis on accurate and reliable data, they also help deliver the most precise results. The standardized processes for material quantity labeling and model checking enhance the framework's effectiveness by verifying the materials modeled in BIM. These processes then cross-reference the materials with the Life Cycle Inventory (LCI) database through LCA. This connection ensures that accurate and relevant data is used for LCA calculations, streamlining the integration between BIM models and LCA, and resulting in more precise environmental impact assessments. In conclusion, the integration of building information modeling and life cycle assessment is crucial for enhancing the environmental performance of buildings. Given the significant contribution of the built environment to global GHG emissions, both existing and new buildings require urgent mitigation strategies and sustainable construction practices. The proposed framework addresses key challenges by predefining Levels of Development (LOD) requirements, using IFC for data translation, ensuring accurate data capture and reliable integration of BIM and LCA. Future research should focus on developing flexible LCA methodologies and building lifecycle assessments that encompass all stages, including planning, design, construction, and operation.

Additionally, the implementation of the proposed approach through case studies is required to validate its feasibility and calibrate its application in real-life scenarios, ultimately to improve building sustainability. In short, standardizing benchmarking and combining BIM and LCA is crucial to advance building sustainability. As the built environment is responsible for having a considerable amount of GHG emissions, current and future structures have to adopt green building practices and mitigation strategies urgently. The proposed framework addresses key challenges by predefining Levels of Development (LOD) requirements, using IFC for data translation, and adopting a dual-approach to benchmarking, ensuring accurate data capture and reliable integration of BIM and LCA. Standardizing and improving the quality and reliability of wbLCA is achieved by establishing a link with openBIM for interoperability. The integration of global sustainability targets with detailed component-specific benchmarks through the combination of top-down and bottom-up models provides a holistic view into building performance. The proposed framework also stresses the importance of an adequate sample size based on desired precision and confidence levels pertaining to standardized specifications, such as Omniclass tables. This approach ensures reliable benchmarking and encourages sustainable building practices. The proposed framework in study employs a modified graduated approach. This allows the identification of best practice values and reference values applicable to residential and office buildings in the Canadian building domain; hence, it helps them to do reliable comparisons. This also helps the openBIM framework to intend to support the users with the basis for informed decision-making for governments and industry stakeholders. Adopting improved wbLCA benchmarking techniques highlighted in this study would take a strong leap towards reducing the environmental impact of the built environment and fosters a more sustainable and environmentally conscious construction industry.

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