

SUSTAINABLE BUILDING PRACTICES: A REVIEW OF LCA AND BIM INTEGRATION FOR ENVIRONMENTAL IMPACT REDUCTION

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ABSTRACT

Life Cycle Assessment (LCA) and Building Information Modeling (BIM) are two powerful tools that, when integrated, offer a comprehensive framework for sustainable building design. BIM facilitates detailed modeling and visualization of building components, while LCA evaluates the environmental impact of materials, construction processes, and operational energy use throughout a building's lifecycle. The integration of LCA into BIM workflows enables stakeholders—architects, engineers, contractors, and sustainability consultants—to make data-driven, environmentally conscious decisions from early design stages to demolition and disposal. This review paper investigates the methodologies, software tools, and practical strategies used for BIM–LCA integration. It provides an overview of how this integration streamlines material selection, optimizes energy performance, reduces construction and operational waste, and minimizes a building's overall carbon footprint. A comparative analysis of current tools such as One Click LCA, Tally, SimaPro, and Revit-based plugins highlights their capabilities and limitations in real-world applications. Furthermore, the paper explores implementation challenges, including data compatibility, modeling complexity, and the lack of standardized protocols across software platforms and project teams. Through selected case studies, this review illustrates the tangible benefits of BIM–LCA integration in diverse project types and regions. These examples demonstrate improved sustainability outcomes and more efficient design-to-construction workflows, reinforcing the value of a holistic approach to environmental performance. The findings underscore the need for further research in automation, data interoperability, and dynamic LCA feedback during the design process. By addressing these gaps, the industry can move toward a more standardized, scalable approach to sustainable building. The study concludes by recommending enhancements in policy, education, and software development to fully realize the potential of BIM–LCA integration in transforming the construction sector toward low-carbon, high-performance buildings.

Keywords: *Building Information Modelling (BIM), Life Cycle Assessment (LCA), Sustainable Building Design, Environmental Impact Assessment, BIM–LCA Integration*

1. INTRODUCTION

Sustainable construction is widely considered a crucial approach for mitigating the environmental impact of buildings (Soust-Verdaguer et al., 2017) (Xue et al., 2021). There is a growing need within the construction sector for innovative approaches such as green building techniques, sustainable material practices and renewable energy systems to minimize energy consumption, greenhouse gas emissions and environmental footprints associated with building materials (M. Najjar et al., 2017). It's notable that constructing, operating and maintaining buildings and infrastructure consume a considerable amount of global resources, comprising both materials and energy and contribute directly and indirectly to 40% of global greenhouse gas emissions (Ma et al., 2024) (Kaghembega et al., 2023) (Lima et al., 2024). Assuring a sustainable future requires reducing environmental damage. By lowering greenhouse gas emissions, it lessens the impact of climate change, preserves natural resources like clean air and water and enhances public health by limiting pollution. Reducing environmental effect can also boost the economy by lowering expenses and increasing efficiency (M. Najjar et al., 2017) (Feng et al., 2023). In general, protecting the environment, advancing human health and fostering long-term economic stability all depend on lowering environmental damage (M. Najjar et al., 2017). There have been extensive scientific initiatives aimed at promoting sustainability through the adoption of techniques such as life cycle assessment (LCA) and building information modeling (BIM) (Soust-Verdaguer et al., 2017) (Xue et al., 2021). The integration of Building Information Modelling (BIM) and Life Cycle Assessment (LCA) is seen as valuable in guiding design decisions regarding the environmental and health effects of building materials and products materials (Kotula & Kamari, 2020) (Asare et al., 2020). Data and graphical representations of a building's materials and components are included in the BIM model (Feng et al., 2023). BIM offers designers, architects and engineers the necessary information to evaluate energy consumption and environmental impacts of construction materials from start to finish (M. Najjar et al., 2017) (Feng et al., 2023). Life cycle assessment (LCA) is an effective tool for assessing the environmental impact of a product or process and is utilized for benchmarking environmental performance across comparable products (Feng et al., 2023) (Chen et al., 2024). While uncertainty analysis is less commonly conducted in LCA which includes embedded energy and environmental impact assessments. It is gaining importance due to the increasing relevance of embedded life cycle phases in buildings (Schneider-Marin et al., 2020). This research aims to integrate Life Cycle Assessment (LCA) with Building Information Modelling (BIM) to promote sustainable building practices. It evaluates LCA's effectiveness in providing environmental data for BIM models, examines challenges and benefits of early-stage LCA application and explores CO2 reduction through alternative materials and optimized design features. The study focuses on eco-friendly materials like engineered wood, rammed earth, reclaimed wood, and recycled plastics, and analyzes the impact of design elements on a building's carbon footprint. The goal is to advance sustainable construction methods and reduce environmental impact.

2. METHODOLOGY

The methodological approach of this study is organized into three key stages, as depicted in Figure 1. The first stage involved developing a search string tailored to capture publications relevant to the study's scope, aim and objectives. To achieve this, a search string was designed specifically to retrieve scholarly materials related to "BIM and LCA analysis". The constructed search syntax was as follows: "BIM oriented*" OR "LCA of building" OR "Carbon reduction BIM*" OR "LCA to reduce GHG" OR "Building materials Low carbon" OR "Low carbon emission". This search was conducted using two major scholarly databases: "Google Scholar" and "Scopus" which yielded 189 publications on May 15, 2024. Subsequently, various exclusion criteria were applied to filter out materials that were outside the study's scope mentioned in the Figure 1. This study adopts a structured narrative review approach. While a systematic literature search and screening process were applied to ensure comprehensive coverage, the study does not claim to follow a full systematic review protocol such as PRISMA.

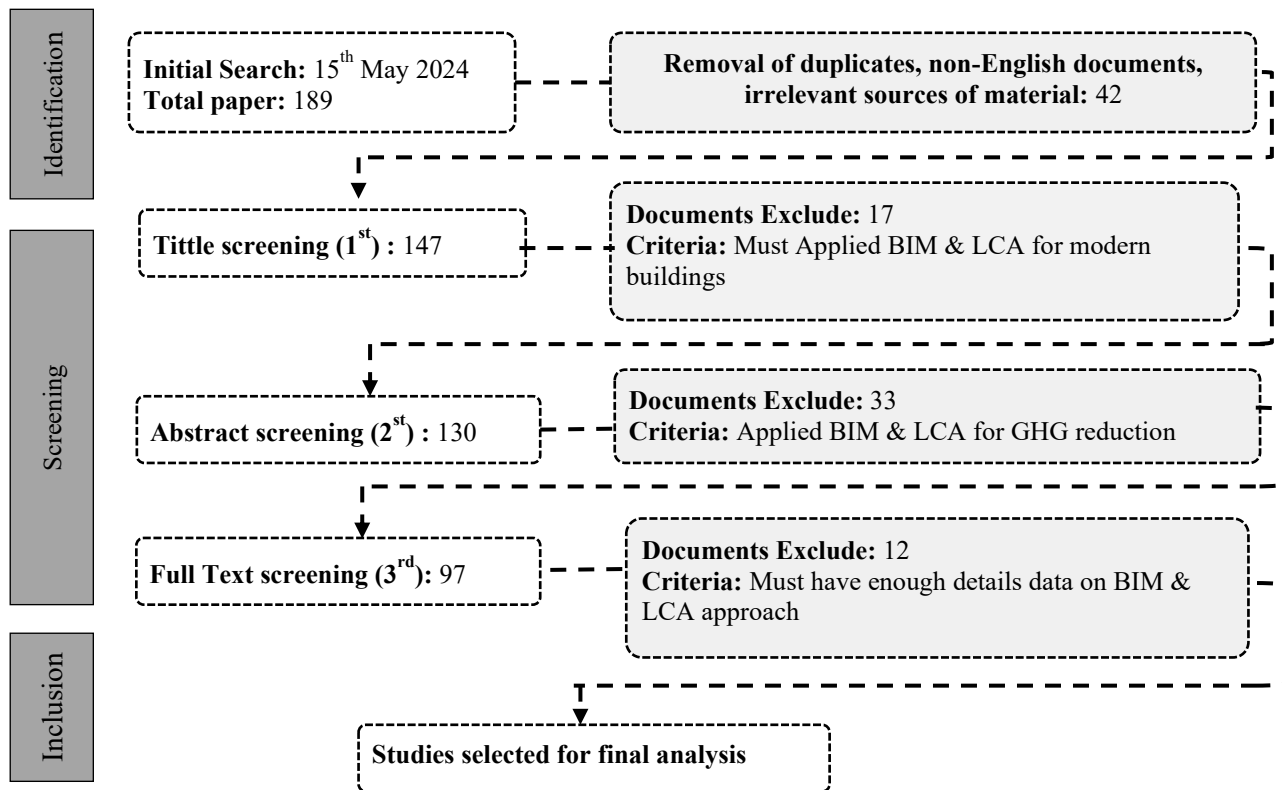


Figure 1: Methodology of the study

3. INTEGRATION OF BIM AND LCA IN SUSTAINABLE BUILDING PRACTICES

Life Cycle Assessment (LCA) serves as a method to assess the environmental impact of a product or process throughout its complete life cycle (M. Najjar et al., 2017) (Theißen et al., 2022). The International Organization for Standardization (ISO) has developed a series of standards for Life Cycle Assessment (LCA), known as ISO 14040 to ISO 14044 (M. Najjar et al., 2017) (Schneider-Marín et al., 2020) (Hollberg et al., 2020) (Kaghembega et al., 2023) (Su et al., 2020) (Marrero et al., 2020). The comprehensive examination of a building's entire life cycle encompasses stages such as raw material extraction, processing, production, transportation, distribution, usage, refurbishment, maintenance, recycling and eventual disposal (M. Najjar et al., 2017) (Hollberg et al., 2020) (Basbagill et al., 2013) (Su et al., 2020) (Marrero et al., 2020). The basic framework for assessment consists of four primary steps: defining goals and scope, conducting a life cycle inventory analysis, performing a life cycle impact assessment, and interpreting the results (Schneider-Marín et al., 2020) (Hollberg et al., 2020) (Su et al., 2020). LCA methodology applies three levels of classification tools to simplify LCA analysis at the scale of building (M. Najjar et al., 2017). BIM is a shared knowledge resource providing reliable facility information for decision-making throughout its lifecycle from design to demolition (Feng et al., 2023) (Kylili et al., 2016) (Ragheb, 2011). It is increasingly used worldwide in AEC to improve design, construction and maintenance processes (Alecrim et al., 2020) (Soust-Verdaguer et al., 2017) (Omrany et al., 2023). BIM models employ object-oriented representations to depict building elements, departing from the flat, line-based approach of traditional CAD drawings (Omrany et al., 2023) (Dupuis et al., 2020). The AIA defines Level of Development (LOD) as the detailed data in a model element with five levels (LOD 100 to 500) outlining required graphic and data standards (Dupuis et al., 2020) (Ragheb, 2011). It enables better stakeholder communication and collaboration, saving time, reducing costs and waste, preventing errors and improving living and working conditions (M. Najjar et al., 2017) (Alecrim et al., 2020). Combining BIM and LCA supports sustainability by streamlining data, improving feedback and aiding decisions on energy use and environmental impact (M. Najjar et al., 2017) (Feng

et al., 2023). A review of BIM and LCA studies reveals common themes forming a standardized framework with a flowchart showing their integration based on existing literature.

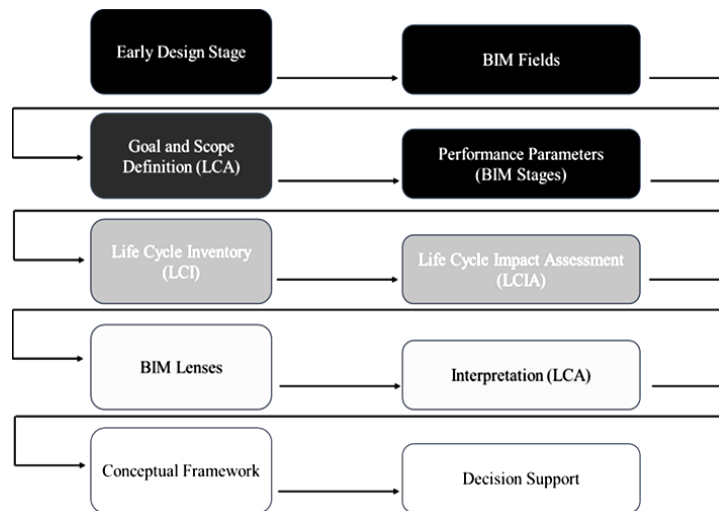


Figure 2: Flow chart of framework

The flowchart in Figure 2 provides a clear visual representation of how BIM and LCA integration works, detailing each step and their interactions as possible (Dupuis et al., 2020) (M. Najjar et al., 2017) (Feng et al., 2023) (Kylili et al., 2016) (Ma et al., 2024) (Wang et al., 2011) (Yangyang & Gong, 2021) (Asare et al., 2020) (Not, 2023) (Su et al., 2020) (Marrero et al., 2020).

4. IMPLEMENTATION OF BIM–LCA INTEGRATION

4.1 Tools & Technology

Integrating BIM and LCA is a structured process using advanced technologies to boost sustainability in construction (M. Najjar et al., 2017). Initially, a detailed BIM model is created using software like Autodesk Revit (Not, 2023) (Marrero et al., 2020) (Veselka et al., 2019), ArchiCAD (Lee et al., 2015) (Mazur & Olenchuk, 2023b) (Naneva et al., 2020), DProfiler (Basbagill et al., 2013) (Soust-Verdaguer et al., 2017) or VectorWorks Architect (Kumar & Mani, 2022) encompassing all relevant building components and materials. This BIM model is then linked with LCA software such as One Click LCA, SimaPro, or GaBi etc (Chandrasekaran & Dvarionienė, 2022) (Mazur & Olenchuk, 2023). A substantial number of LCA tools are well-known to the authors. Nearly 11 different types of LCA tools are referenced in 87 articles. Upon calculating the familiarity percentages of the LCA tools, a graph and a pie chart have been generated to illustrate the results, as shown in Figure 3.

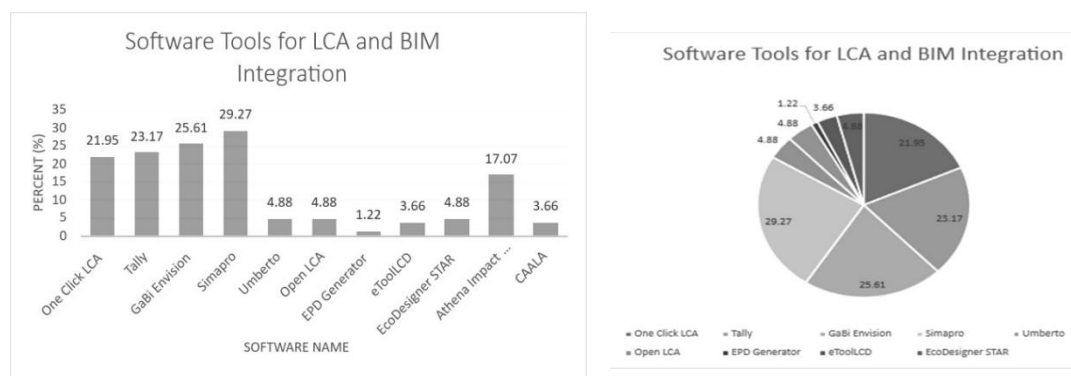


Figure 3: Percentage of common LCA tools

The integration is typically facilitated through standardized data exchange formats like Industry Foundation Classes (IFC) or gbXML, which allow seamless data transfer between BIM and LCA tools (Asare et al., 2020) (Lu et al., 2021) (Lee et al., 2015). Also NavisWorks, a project review tool used for clash detection, 4D simulation, and model integration in construction projects (Kumar & Mani, 2022), Excel, used for performing mathematical operations on material quantities and integrating data from various software sources (Basbagill et al., 2013) (Marrero et al., 2020) (Soust-Verdaguer et al., 2017) (Nilsen & Bohne, 2019), CostLab: An online facility operations reference database that calculates maintenance, repair, and replacement (MRR) costs for building components (Basbagill et al., 2013), ModelCenter: A sensitivity analysis software that integrates DProfiler and Excel into a unified environment (Basbagill et al., 2013) are employed to assess the importance of each individual factor. GBS (Green Building Studio) used to demonstrate BIM-based LCA and energy analysis for SBD (sustainable building design) (Asare et al., 2020) (Marrero et al., 2020) (Soust-Verdaguer et al., 2017) (Kaghembega et al., 2023). Ecosoft, BLAST, QUEST, TRACE, DOE2, Ecotect, IES, EnergyPlus, Design builder and Exotic mentioned as other energy analysis tools available, offering alternatives to GBS (M. K. Najjar et al., 2022) (Asare et al., 2020) (Soust-Verdaguer et al., 2017) (Soust-Verdaguer et al., 2017) (Kaghembega et al., 2023) (Lu et al., 2021). There are some specific integrations and studies:

- DProfiler linked to eQuest within a BIM environment (Marrero et al., 2020).
- BIM combined with LEED and BREEAM assessments (Marrero et al., 2020) (Mirzaie & Menzies, 2016) (Soust-Verdaguer et al., 2017) (Nilsen & Bohne, 2019) (Lee et al., 2015).
- Revit combined with IES Virtual Environment (Marrero et al., 2020).
- Graphisoft ArchiCAD linked to the BREEAM material database (Marrero et al., 2020).

A summary of these tools and technologies is provided in table 2.

Table 2: Summary of BIM-LCA Tools & Technology

Tool/Technology	Description	Examples / Software
BIM Software	Platforms to create detailed building models with materials	Autodesk Revit, ArchiCAD, VectorWorks
LCA Software	Tools for environmental impact assessment	One Click LCA, SimaPro, GaBi, Tally
Data Exchange Formats	Standards enabling data transfer between BIM and LCA	IFC, gbXML, ifcXML, COBie
APIs	Interfaces enabling automated data exchange	Autodesk Forge API, Rhino Compute
Cloud Computing	Platforms supporting large data handling and collaboration	Trimble Connect
Additional Tools	For cost estimation, simulation, and sensitivity analysis	NavisWorks, Excel, CostLab, ModelCenter
Energy Analysis Tools	Specialized software for building energy use analysis	GBS (Green Building Studio), DOE2, IES, EnergyPlus

4.2 Challenges and Barriers

BIM-LCA integration faces challenges like software incompatibility, complex urban conditions, unpredictable occupant behavior (Omrany et al., 2023) and the need for a stronger BIM database with real-time visualization for effective LCA application (M. Najjar et al., 2017) (Soust-Verdaguer et al., 2017) (Dupuis et al., 2020). Early-stage LCA is difficult due to fragmented design decisions, as designers focus on different priorities and late changes often raise environmental impacts (Kaghembega et al., 2023) (Basbagill et al., 2013). The challenges and barriers can be documented as follows in table 3.

Table 3: Summary of BIM-LCA Challenges & Barriers

Category	Challenges	Description
Technical	Software Interoperability	Compatibility issues between different BIM and LCA software due to varying data formats and standards (Omrany et al., 2023) (Obrecht et al., 2020).
	Complexity	LCA's detailed data requirements and modeling complexity can hinder adoption especially in smaller projects (Kaghembega et al., 2023).
	Real-time Visualization	Need for enhanced BIM databases with real-time visualization to improve LCA application throughout the lifecycle (M. Najjar et al., 2017) (Soust-Verdaguer et al., 2017) (Dupuis et al., 2020).
Data-related	Data Integration	Difficulty in seamless integration of LCA data into BIM models due to inconsistent formats and standards (Soust-Verdaguer et al., 2017) (Obrecht et al., 2020).
	Data Quality and Accuracy	Ensuring high-quality, accurate data to avoid errors and improve reliability of environmental assessments (M. Najjar et al., 2017) (Omrany et al., 2023) (Kaghembega et al., 2023) (Basbagill et al., 2013) (Obrecht et al., 2020).
	Data Security and Privacy	Concerns about data privacy and security limiting data sharing and collaboration (Kaghembega et al., 2023) (Basbagill et al., 2013) (Obrecht et al., 2020).
Organizational	Time and Cost	High time and financial investments required for BIM-LCA integration can discourage implementation (M. Najjar et al., 2017) (Omrany et al., 2023).
	Technical Expertise	Lack of skilled professionals able to manage BIM-LCA workflows effectively (Omrany et al., 2023) (Obrecht et al., 2020).

4.3 Case study

From case study mentioned in the papers, we compile a table that includes the following information: building type, building properties (gross area, number of stories, whether the building is real or hypothetical), the BIM tool used, the LCA tool employed, and the techniques applied.

Table 4: Summary of BIM-LCA Case Study

No	Building type	Location	Building properties			Used BIM tool	Used tools & techniques	LCA & Reference
			Gross Area (m ²)	Story	Real/non real			
1.	Office building	Chicago, USA	137,078 square meters	60	real	Autodesk Revit	Tally	(Ma et al., 2024)
2	Mixed structure Villa	Xining, China	450 square meters	3	real	Autodesk Revit	Tally	(Yangyang & Gong, 2021)
3	Residential	Denmark	5,500 square meters	5	real	Autodesk Revit	Visual Studio and C# programming language the Revit API	(Kotula & Kamari, 2020)
4	Residential	Porto, Portuga	150 square meters	1	real	Autodesk Revit	Dynamo	(Carvalho et al., 2021)
5	Residential building	the City of Kelowna,	2940 ft2	2	real	Autodesk Revit	simulation software HOT2000	(Feng et al., 2023)

		British Columbia						
6	Office building	Brazil	3424 m2	Multi	real	Autodesk Revit	Open LCA	(M. K. Najjar et al., 2022)
7	Residential building	Switzerland	1149.5 m ²	3	real	Autodesk Revit	Dynamo	(Röck et al., 2018)
8	Office building	Switzerland		3	real	Autodesk Revit	Dynamo	(Hollberg et al., 2020)
9	Office building	Brazil	2730 m2	multi	real	Autodesk Revit	Tally	(M. Najjar et al., 2017)
10	Office building	Chicago, USA	137,078 square meters	60	real	Autodesk Revit	Tally	(Not, 2023)
11	Residential building	Huai'an City, Jiangsu Province, China	16,650 square meters	27	real	Autodesk Revit	GBS	(Su et al., 2020)
12	Office building	Netherlands	1,900 m ²	2	real	Autodesk Revit	Tally and ATHENA tools	(Santos et al., 2020)
13	Residential building	Islamabad, Pakistan	540 m2	4	real	Autodesk Revit	One Click LCA and Gabi	(Behm, 2008)
14	Office building	Busan, South Korea	5313.90 m2	18	real	Autodesk Revit		(Lee et al., 2015)
15	Commercial building	Gazipur, Bangladesh	4729.375 square feet	6	real	Autodesk Revit	One Click LCA	(Zahin et al., 2024)
16	Commercial building	Kuala Lumpur, Malaysia	17,280 m ²	10	real	ArchiCAD	Eco-designer STAR	(Ali et al., 2020)
17	Residential building	Seville, Spain	1638.65 m2	5	real	Autodesk Revit	Revit Application Programming Interface (API)	(Llatas et al., 2022)
18	Residential building	Québec, Canada		4	real	Autodesk Revit	OpenLCA	(Rezaei et al., 2019)[
19	Residential building	Beijing, China	5410.16 m2	11	real	Autodesk Revit	GTJ construction measurement	(Zhan et al., 2023)
20	Hospital Building	Chuzhou City, China's Anhui Province	6367 m2	4	real	Autodesk Revit	Green Building Studio	(Lu et al., 2019)
21	Office building		2228 m2	4	non real	Autodesk Revit	LCA database (ÖKOBAUDA T)	(Theißen et al., 2020)
22	Single-family home	Porto, Portugal	90 m2	1	real	Autodesk Revit	Tally.	(Carvalho et al., 2020)
23	Residential building	Winterthur, Switzerland's Lokstadt	31,559 m2.	10	real	Revit	Dynamo	(Naneva et al., 2020)

5. ENVIRONMENTAL EFFECTS

Integrating BIM and LCA reduces buildings environmental impact and supports sustainable construction and climate action (Schneider-Marín et al., 2020). Mitigation can cut GHG emissions by up to 29% in materialization, 16% in operation, and 21% at end-of-life; early assessment reduces overall impact (Behm, 2008). Alternative building parameters can reduce carbon emissions by 13.9% compared to traditional design (Ali et al., 2020). Reinforced concrete causes about 49.64% of construction-phase emissions, while HVAC systems account for 53.63% of operational-phase emissions (Lu et al., 2019). The reduction of the environmental impact of buildings can be categorized into four distinct groups:

- **Material Selection:** Selecting sustainable materials is key, as production causes 44-64% of environmental impact. Concrete leads with 55% of global warming potential and 64% acidification. Masonry follows with 45% and 53%, respectively., while openings and glazing have minimal impact. Operational energy, mainly electricity (55%) and heating (32%), is also significant (Yangyang & Gong, 2021). Concrete dominates the building's carbon footprint at 83% (1.37E+06 kg CO₂e), followed by metals and insulation at 7% and 8%, respectively. Using wood can reduce this impact by 7% (Kotula & Kamari, 2020). Najjar et al. found steel and cement have high environmental impacts, while wood and aluminum are better for ecosystem quality and resource use (M. K. Najjar et al., 2022). Using sustainable materials reduces CO₂ emissions by 132.68 tons, a 6.72% life-cycle reduction (Zahin et al., 2024).
- **Energy Efficiency:** Energy use during building operation greatly affects environmental impact, with global warming potential (GWP) at 42%, acidification and eutrophication at 15% each. Exterior walls and foundations contribute ~30%. Material impacts and operational energy make up 60-90% of total impact, with concrete and wood responsible for 65% of material impacts. Domestic heating accounts for over 80% of energy use (Feng et al., 2023). Comparing modern (Type A) and typical (Type B) materials shows similar energy mixes (~97% electricity), with Type A costing more and using more energy for HVAC (46%), lighting (23%), and miscellaneous equipment (31%). Manufacturing of both types causes major environmental harm, including ozone depletion (M. Najjar et al., 2017). Overall, product manufacturing and operational energy dominate impacts across categories like mass, GWP, acidification, and non-renewable energy use.
- **Waste Reduction:** Efficient material use and waste management can minimize waste, with 99% of non-hazardous waste being recyclable. Recycling prevents 1.4× more emissions and saves 85× more energy than disposal (Llatas et al., 2022).
- **Carbon Footprint:** Reducing the overall carbon footprint by considering embodied carbon in materials and optimizing energy performance. Concrete (91% of building mass) contributes 74% to global warming, 53% to acidification, 74% to eutrophication, 74% to smog, and 68% to non-renewable energy use. Steel (9% mass) adds 26% to global warming and 32% to non-renewable energy. Reducing embodied carbon and improving energy performance lowers the overall carbon footprint (Ma et al., 2024). An LCA analysis shows Global Warming Potential (GWP) as the highest impact category at 38.75%, followed by Acidification Potential (AP) and Eutrophication Potential (EP) at 11.66% each. Ozone Depletion Potential (ODP) accounts for 6.46%, Particulate Matter Formation Potential (POCP) 8.15% and Cumulative Energy Demand (ENR) also 11.66% (Carvalho et al., 2021).

6. LIMITATIONS AND RECOMMENDATIONS

6.1 Limitations of the Research

Despite progress, BIM-LCA integration faces key gaps in Multiple LCA Methods Integration, data quality and accuracy, Greater integration of BIM, LCA and other sustainability assessment tools like EPA and BPS, standardization and interoperability in data analysis and reporting methods and user-friendliness for non-expert users. Addressing these will enhance reliability and support better environmental decisions.

6.2 Recommendations

- Develop compatible BIM-LCA software for accurate, real-time environmental analysis.
- Standardize data formats to improve interoperability.
- Conduct further case studies across different building types and regions.
- Promote BIM-LCA education and training through best practice guidelines.
- Expand research to include other sustainability metrics like water use and waste.

7. CONCLUSIONS

This study highlights the transformative potential of integrating Building Information Modeling (BIM) and Life Cycle Assessment (LCA) to promote sustainable construction practices. Through comprehensive analysis of tools, frameworks, and case studies, it is evident that BIM-LCA integration enables more informed design decisions by providing accurate, data-driven insights into a building's environmental performance. The findings emphasize the importance of early-stage assessment, sustainable material selection, energy efficiency, and waste reduction in minimizing the carbon footprint of buildings. Despite significant progress, challenges such as data interoperability, tool compatibility, and usability for non-experts remain. Addressing these gaps through standardized formats, enhanced software solutions, and wider education and training will improve the reliability and effectiveness of BIM-LCA workflows. Ultimately, this integration supports climate action goals by enabling stakeholders to design and deliver buildings that are environmentally responsible, economically viable, and socially beneficial throughout their life cycle.

Declaration of Use of AI

The authors declare that AI-assisted tools (such as ChatGPT) were used only for language refinement, paraphrasing and improving the clarity and readability of the manuscript. All technical ideas, conceptual developments, modeling procedures, analysis interpretations and research findings were fully conceived, executed and verified by the authors. The authors carefully reviewed, edited and validated all AI-generated text to ensure accuracy, originality and compliance with academic and ethical standards. No AI tools were used for data generation, analysis, experimental design or drawing scientific conclusions. The use of AI was limited to editorial support and the authors maintained full oversight and responsibility for the entire content of the work.

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