BIM-LCA Integration for Carbon Emission Assessment in Construction Industry: Systematic Review and Research Opportunities

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Abstract
A systematic literature review explored the integration between Building Information Modeling (BIM) and Life Cycle Assessment (LCA) for carbon emissions assessment in the construction industry to identify primary research studies published in English between 2017 and 2022 that focused on this integration. Data were extracted from the included studies and analyzed using qualitative synthesis approaches, including content and thematic analysis. The study found that integrating BIM and LCA provides numerous benefits for enhancing sustainability and reducing environmental impact in the construction industry, including improved building design and construction, optimization of building materials, and the ability to make informed decisions regarding carbon reduction. The review identified several commonly used BIM and LCA tools, explored a wide range of applications of BIM-LCA integration, and presented various case studies that demonstrated its benefits. However, the study also identified several limitations of BIM-LCA integration, including technical challenges and the need for more real-world projects, best practices for integration, and analysis of the barriers to adoption in Thailand's construction industry.

Keywords
Building Information Modeling (BIM), Life Cycle Assessment (LCA), BIM-LCA Integration, Carbon emission assessment, Carbon Reduction

1. Introduction

One of the major producers of CO_2 emissions worldwide is the building and construction sector (Bueno & Fabricio, 2018; Onat & Kucukvar, 2020). The World Green Building Council estimates that this industry is responsible for around 39% of the world's energy-related carbon emissions, substantially contributing to climate change. The building and construction sector must embrace sustainable building techniques and cutting-edge technology as the globe places a greater emphasis on lowering greenhouse gas emissions (Doan et al., 2017; Marrero et al., 2020). The manufacturing of building materials, the use of energy during the construction and operation of structures, and the transportation of workers and materials are all factors that contribute to the overall carbon emissions produced by the sector. There is potential for the construction sector to cut its carbon footprint via the adoption of innovative technology and environmentally responsible building practices. Carbon emissions have been the primary concern for the building and construction sector, particularly concerning the production of materials, energy consumption, transportation, waste management, and construction activities. (Mao et al., 2013). The rise in CO_2 is considered a factor in which climate change will severely affect humanity, including weather unpredictability, agricultural instability, and public health issues (Nema et al., 2012).

When it comes to addressing the challenges of cutting down on CO_2 emissions, innovations in building and construction technology may be crucial. Various tools and methods have been developed, including BIM and LCA (Teng et al., 2022). Building Information Modeling, often known as BIM, is a digital representation of a structure's structural and functional aspects used in building planning, construction, and operation. BIM allows for improved collaboration and communication between project stakeholders and provides valuable insights into the performance of buildings (Cerovsek, 2011; Ghaffarianhoseini et al., 2017). On the other hand, Life Cycle Assessment, often known as LCA, is a tool used to examine a product or service's effect on the environment during its entire life cycle, which includes the extraction of raw materials, manufacture, usage, and disposal. (Rebitzer et al., 2004). Integrating BIM and LCA can potentially revolutionize the way the construction industry assesses and reduces its carbon footprint. By modeling and simulating the performance of buildings with BIM and assessing the environmental impact of building materials and systems with LCA, the construction industry can make more informed decisions, which in turn leads to a reduction in carbon emissions (Tam et al., 2023).

The literature on BIM-LCA integration for carbon emissions assessment in the construction industry is expanding. Multiple studies have determined that BIM and LCA can be combined to provide a more comprehensive and accurate picture of carbon emissions in the building and construction industry. BIM is a technology that transfers information and allows interoperability between various design software tools. Moreover, it can be used to optimize material choices and reduce waste during construction, which can help reduce carbon emissions (Kamel & Memari, 2019). LCA has helped construction companies assess carbon emissions. ISO established LCA methodology standards in the second half of the 1990s. LCA quantifies a product's environmental impact using ISO 14040 framework. It considers the whole product life cycle, from procuring raw materials to recycling or disposal. Since 1990, the LCA technique has been extensively utilized in the construction industry to evaluate the effect that various building materials have on the environment throughout the life cycles of individual projects (Fava, 2006). Several studies have found that LCA can comprehensively understand the environmental impact (Tam et al., 2022).

Construction activities and environmental impacts are analyzed throughout a project's lifespan. The LCA-based method can identify and assess carbon emissions in various stages, from construction materials, transportation, equipment, and fuel and disposal impacts (Safari & AzariJafari, 2021; Yang et al., 2018). This information can be used to optimize building design and construction practices and reduce buildings' environmental impact. In addition, Life Cycle Assessments (LCAs) in the form of Environmental Product Declarations (EPDs) for building materials give information on the effect that building goods have on the environment. (Bovea et al., 2014). For instance, the EPDs available for insulation materials can provide architects and engineers with helpful information that can assist them in making educated choices regarding the types of materials that should be utilized to lessen the negative impact a building has on the surrounding environment (Soust-Verdaguer et al., 2022).

Overall, BIM-LCA integration has the potential to considerably enhance carbon emissions assessment in the building and construction industry. It was mentioned that a multidisciplinary approach is necessary to minimize the environmental impacts of buildings, and the use of BIM can reduce the efforts of LCAs (Kamari et al., 2022; Xue et al., 2021). The integration process must address organizational and technical issues. The information necessary for the LCA analysis must comply with the study's objectives and scope, as well as the information structure established during the design stage (Rosen & Kishawy, 2012). The challenges and potential advancements of BIM and LCA integration include the data transformation between BIM and LCA platforms (Seyis, 2020). For example, there needs to be more standardization in the use of BIM for LCA, which can lead to inconsistent results.

Furthermore, the accuracy of the LCA findings is contingent upon the quality and completeness of the BIM model, which may be a difficulty for both the designers and the practitioners (Bueno & Fabricio, 2018). There is still a need for more research on the effectiveness of BIM-LCA integration in real-world projects, as well as more research on best practices for integrating BIM and LCA and barriers to adopting BIM-LCA integration in the construction industry, such as technical challenges and cultural resistance. There is still much work to be done to fully grasp the possibilities of this approach and create the best methods for putting it into action. Therefore, this paper aims to conduct a literature review to summarize and evaluate the current state of BIM-LCA integration in the building and construction industry, providing an overview of the existing literature, highlighting the main findings and conclusions from previous research studies, and identifying gaps or areas where further research is required to support the application of BIM-LCA integration in Thailand's construction industry. This study synthesizes multiple studies, combining the results of various research studies to provide a comprehensive picture of BIM-LCA integration. It also provides a complete, up-to-date summary of the current state and identifies future research directions; it also includes a barrier, limitations, and areas for improvement.

2. Methodology

This literature analysis was done to provide an all-encompassing overview of the BIM-LCA integration for carbon emissions assessment in the building sector. This study applied a systematic review to investigate the current state of research on the integration of BIM and LCA in the construction industry. A comprehensive search of academic databases and reviewed reference lists of relevant articles were conducted to identify primary research studies published in English between 2017 and 2022 that concentrated on using BIM and LCA in the building and construction industry. The search results were screened by title and abstract and included studies that met our inclusion criteria: primary research studies published in peer-reviewed journals or conference proceedings. Data were extracted from the included studies on study design, research objectives, BIM and LCA tools and methods, applications and case studies, and limitations and future research directions. In the process of analyzing the data, a qualitative synthesis approach was utilized, which included both content analysis and thematic analysis. Our findings are reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA guidelines) for systematic reviews. A narrative synthesis of the data, including a summary of the main themes and patterns that emerge from the analysis, was also provided in this paper.

This review conducted a comprehensive search of several databases, including Scopus, Web of Science, and Google Scholar, to identify relevant articles, reports, and studies by providing specific search terms to ensure their search was focused and relevant. The bibliometric analysis involves using quantitative methods to analyze scientific literature to understand knowledge production and dissemination patterns.

The title, keywords, and abstract criteria of topic areas about building information modeling, life cycle assessment, project life cycle assessment, CO_2 emission assessment, and construction project were used as a reference for collecting search results. The keywords were searched by using the terms which include TITLE-ABS-KEY: ["BIM-LCA integration" OR "carbon emissions assessment" OR "construction industry" OR "project life cycle"] and TITLE-ABS-KEY: ["building information modeling" AND "BIM" AND "life cycle assessment" AND "LCA"]. The inclusion criteria were used to select articles, reports, and studies for their review. The articles, reports, and studies were carefully reviewed and analyzed to identify the key findings, trends, and gaps in the literature. There were numerous publications on BIM-LCA integration from 2017 to 2022, with 1,764 articles found in the Scopus database on November 25, 2022. The results of 1,764 findings from the databases were exported to excel files. Following the review of the titles and abstracts, 620 articles were deemed ineligible for inclusion because they did not satisfy the inclusion criteria. Following an evaluation of the complete versions of the remaining 1,144 articles, a selection of 50 articles was made for the purpose of this review.

3. Results and Discussion

The integration of BIM and LCA has become increasingly popular in the construction industry, as it offers numerous benefits for improving sustainability and reducing environmental impact. The findings of bibliometric mapping were evaluated by country and keywords. The 32 included studies were published between 2017 and 2022 and were conducted in various countries, including China, the United States, the United Kingdom, Canada, Australia, etc. The studies used a range of research designs, including case studies, experiments, and surveys. The sample sizes of the studies ranged from single-building projects to large-scale industry surveys.

The literature review on the BIM-LCA integration for carbon emissions assessment in the construction industry revealed several key findings. BIM and LCA were found to have significant potential to be applied for reducing carbon emissions in the construction industry, and their integration was found to provide a more comprehensive picture of the carbon footprint of a building (Li, 2021). The research used a variety of BIM and LCA technologies and approaches to integrate BIM and LCA in the construction sector. Autodesk Revit, ArchiCAD, and Tekla Structures were among the most popular BIM software solutions. SimaPro, EcoInvent, Gabi, and One Click LCA were some of the most popular LCA applications. BIM and LCA were integrated into these studies using a variety of approaches, such as parametric modeling, simulation, and optimization, among others.

The studies explored various possible uses and applications of BIM-LCA integration in the construction industry, encompassing architectural design, construction planning, and existing facility administration. The studies also presented various case studies that demonstrated the benefits of BIM-LCA integration, such as decreased influence on the environment, increased quality of air within buildings, and lower energy usage (Dalla Mora et al., 2020). This means BIM and LCA have a significant relationship together. Improving stakeholder cooperation is one of the primary advantages that may be gained by merging BIM with LCA. Using a single, integrated platform to model the building or infrastructure project, all stakeholders can access and share data in real time, reducing the possibility of misunderstandings, errors, and delays. This can result in more efficient and cost-effective project management and improved sustainability outcomes (Huang et al., 2020).

Another benefit of BIM-LCA integration is an improved decision-making (Chan et al., 2022). Stakeholders may find ways to lessen the negative effects on the environment and boost the project's sustainability by conducting an environmental impact analysis. This can include optimizing the building design, selecting materials with lower environmental impact, and reducing energy consumption. Using objective data to inform decision-making, stakeholders can make more informed choices about resource use and environmental impact reduction (Motalebi et al., 2022; Sharif & Hammad, 2019).

The studies identified several limitations of BIM-LCA integration. Technical challenges, such as compatibility between BIM and LCA software and standardization in data formats, can make it challenging to implement BIM-LCA integration in the practice (Safari & AzariJafari, 2021). Table 1 summarizes previous research integrating various BIM-LCA integration techniques into construction projects. However, there is a need for more studies on the effectiveness of BIM-LCA integration in real-world projects and more research on the best practices for integrating BIM and LCA. Cultural resistance, including a lack of understanding of the benefits of BIM-LCA integration and a lack of incentives for adoption, can also be a barrier to implementation (Olanrewaju et al., 2022).

Moreover, there is a need for more research on the barriers to adopting BIM-LCA integration in the construction industry, including technical challenges and cultural resistance, and to develop best practices for BIM-LCA integration in the construction industry (Zimmermann et al., 2021). In the future, more studies should be conducted on the information sharing between BIM and LCA throughout various project lifecycle phases. This would help expand the BIM-enabled LCA to an enormous scope of sustainable construction by including other sustainability metrics or scenarios, such as renewable energy sources, interior comfort, resource consumption, etc. (Llatas et al., 2020).

Table 1. BIM-LCA integration into construction project: Summary from previous research

Type of building/ References	BIM authoring tool	LCA Tool	Method of data exchange and format	Information shared from BIM to LCA platform	Contribution	Challenges and limitations
Multi-story office building in Brazil (Najjar et al., 2017)	Autodesk Revit	Green Building Studio/ Tally/ GaBi	Direct link/ Revit plug-in/ Parametric modeling/ Simulation	Geometry/ Material data/ Energy performance/ MEP system/ Maintenance/ Replacement schedules	Incorporation of BIM and LCA methodologies in the early stages of construction project design	Insufficient BIM database
Residential building in China (Yang et al., 2018)	Autodesk Revit 2015 (LOD300) MagiCAD	eBalance software/ Chinese Life Cycle Database/ Designbuilder (Version 4.5.0.148)	Exporting data/ gbXML file/ Parametric modeling/ Simulation	Geometry/ Material data/ Energy performance/ MEP system/ Maintenance/ Replacement schedules	Improved environmental performance/ Building energy simulation/ Optimized building performance	Limited interoperability between BIM and LCA tools/ Need for specialized expertise
Single-family house in Belgium (Santos et al., 2019)	Information Delivery Manual (IDM)/ Model View Definition (MVD)	IFC4 schema/ EPDs/ Ecoinvent database	Exporting data/ IFC file/ gbXML file/ Direct link/ Parametric modeling	Geometry/ Material data/ Equipment and systems data/ Maintenance/ Replacement schedules	Improved environmental performance/ Cost savings	Limited availability of LCA data/ Limited interoperability between BIM and LCA tools
Hospital Building in China (Lu & Wang, 2019)	Autodesk Revit 2017 (LOD 300)/ Glondon GTJ2018	Green Building Studio	Direct link/ Simulation	Geometry/ Material data/ Energy performance/ MEP system/ Maintenance/ Replacement schedules	Improved environmental performance/ Optimized building performance	Limited interoperability between BIM and LCA tools

Type of building/ References	BIM authoring tool	LCA Tool	Method of data exchange and format	Information shared from BIM to LCA platform	Contribution	Challenges and limitations
Multi-apartment building in Germany (Yayla et al., 2021)	Simplified BIM models belonging to SBS database	GaBi	Direct link/ Simulation	Geometry/ Material data/ Energy performance/ MEP system	Improved collaboration and communication/ Enhanced stakeholder engagement	Limited availability of LCA data and specific energy consumption/ Time and resource constraints
Guangdong Inkstone Culture Museum in China (Cheng et al., 2020)	Autodesk Revit/	Design-builder software	Exporting data/ gbXML file/ Direct link/ Simulation	Geometry/ Material data/ Energy performance/ MEP system/ Maintenance/ Replacement schedules	Improved environmental performance/ Optimized building performance	Need for future enhancement of the compatibility of multiple BIM systems
The historical heritage of the city of Matera, Italy: Palazzo del Sedile (Selicati et al., 2020)	Design-builder Model	SimaPro v.8.5.2.0/ EPDs/ EnergyPlus™/ Ecoinvent3, ELCD and Industry data 2.0	Data exchange platforms/ Simulation	Geometry/ Materials data/ Energy performance/ Equipment and systems data/ Maintenance/ Replacement schedules	Improved environmental performance/ Optimized building performance/ Enhanced stakeholder engagement	Limited availability of LCA data/Integration of social and economic factors
Residential apartment complex in the territory in India. (Kurian et al., 2021)	Autodesk Revit Architecture 2018	GaBi database/ EPDs/ Ecoinvent databases through One Click LCA software/ ICE database	Parametric modeling/ Direct link	Geometry/ Materials data/ Energy performance/ Equipment and systems data/ Maintenance/ Replacement schedules	Improved environmental performance	Limited availability of LCA data
Educational institutions in Peru (Vázquez-Rowe et al., 2021)	BIM3D model/ Comparative Monte Carlo (MC) simulation	Peru LCA, the Peruvian LCA database	Manual Export/ Direct link/ Simulation	Geometry/ Materials data/ Equipment/ Fuel/Energy/ Maintenance/ Replacement schedules	Improved environmental performance/ Optimized building performance/ Enhanced stakeholder engagement	Lack of standardized methods and tools/ Limited interoperability between BIM and LCA tools/ Integration of economic factors
Urban Transformation in Istanbul, Turkey (Yayla et al., 2021)	Autodesk Revit	Green Building Studio	Manual Export/ Direct link/ Simulation	Visualization/ Spatial data/ Building geometry data/ Building envelope characteristics	Improved environmental performance/ Cost savings/ Optimized building performance/ Enhanced stakeholder engagement	Lack of standardized methods and tools/ Time and resource constraints
Real-life prefabricated building in Hong Kong (Xu et al., 2022)	Autodesk Revit	SimaPro	BIMToSimaPro/ The Industry Foundation Class (IFC) data format	Geometry/ Materials data/ Energy performance/ MEP system/ Maintenance/ Replacement schedules	Improved environmental performance	Limited interoperability between BIM and LCA tools

In addition, content analysis of BIM-LCA integration involves examining the specific data and information used in integrating BIM and LCA and analyzing how this data is organized, evaluated, and communicated. A thorough content analysis can gain insights into the strengths and limitations of the approach and opportunities for further improvement. This section will explore the critical components of BIM-LCA integration, including BIM content, LCA methodology, environmental impact categories, data sources, and limitations, and provide a detailed analysis below.

3.1 The overview of BIM-LCA integration

Several building and construction case studies have successfully integrated BIM and LCA (Asare et al., 2020; Najjar et al., 2017; Obrecht et al., 2020a). The literature demonstrates the potential of BIM-LCA integration for reducing carbon emissions and provides valuable insights into the implementation's key benefits and challenges (Potrč Obrecht et al., 2020). The authors propose a BIM-based LCA approach to enhance the sustainability of the buildings (Hollberg et al., 2020; Obrecht et al., 2020b; Soust-Verdaguer et al., 2017; Xue et al., 2021), as well as three methods for linking BIM and LCA, which include the quantification of materials, the incorporation of environmental information into BIM software, and the creation of an automated process that combines various data and software. However, the case studies also highlight some challenges of implementing BIM-LCA integration in the construction industry (Safari & AzariJafari, 2021). The need for compatibility between BIM and LCA software and standardization in data formats can make it challenging to integrate the two technologies in practice. BIM offers information for storing multi-disciplinary data and automating and connecting the many phases of the design process. Nevertheless, it has a few drawbacks, such as the fact that the entire life cycle effects of the construction materials must be entered manually, interoperability problems, and the possibility of human mistakes (David Mineer, 2016).

3.2 Benefits of integrating BIM and LCA

BIM and LCA are two significant techniques increasingly utilized in designing, constructing, and managing buildings and construction. Integrating these two approaches can bring many benefits to building projects, such as better decision-making, improved sustainability, increased efficiency, improved communication, and better documentation. Because of the BIM-LCA integration, architects, engineers, and contractors are now able to evaluate a variety of design alternatives, consider the ramifications of those alternatives with regard to the environmental impacts and cost implications, and then arrive at well-informed judgments. Integrating LCA with BIM makes it possible to identify opportunities for reducing the environmental impact of a building and to make design changes to improve sustainability. BIM provides a centralized and collaborative platform for managing building design data, making it easier for all project team members to access and share information. Then LCA offers a comprehensive evaluation of the environmental impact that a building has throughout its entire life cycle. Integrating LCA into the BIM process streamlines the LCA analysis process, reducing the time and cost associated with producing separate LCA reports. Finally, integrating BIM and LCA provides a more holistic and comprehensive approach to building design, construction, and operation, resulting in more sustainable, efficient, and cost-effective buildings (Asare et al., 2020; Azizoglu & Seyis, 2020; Potrč Obrecht et al., 2020)

3.3 Challenges and limitations of BIM-LCA integration

While BIM-LCA integration can bring many benefits to building projects, several challenges and limitations must be overcome to realize the full potential of this approach. Some key challenges and limitations include the following: First, data quality and accuracy are crucial for both processes; inaccurate data can lead to incorrect LCA results and limit the usefulness of the integration. Second, integrating data between BIM and LCA tools requires a seamless exchange of data, which can only be challenging with proper tool design. Third, a lack of standardization in data and methods can make it difficult to compare results and limit the consistency of the environmental impact assessment. Fourth, integrating BIM and LCA requires high technical expertise, which can hinder adoption for some organizations. Fifth, integrating BIM and LCA can be time-consuming and costly, making it difficult for some organizations to justify the investment. Finally, data security and privacy concerns may limit the willingness of some organizations to participate in the integration process. Despite these challenges, integrating BIM and LCA is critical for creating more sustainable, efficient, and cost-effective buildings. Overcoming these challenges and limitations can lead to a more holistic and comprehensive approach to building design, construction, and operation (Genova, 2018; Obrecht et al., 2020a).

3.4 The research gap in BIM-LCA integration

Despite the rapid growth and increasing importance of BIM-LCA integration, there are still significant research gaps in this field. Some of the key research gaps include (Obrecht et al., 2020b; Theißen et al., 2020; Xue et al., 2021):

1. Integration of multiple LCA methods: While BIM-LCA integration has made significant progress in recent years, there is still a need for better ways to integrate different LCA methods and tools and to standardize the data and results generated by these tools.

2. Improved data quality and accuracy: The quality and accuracy of the data generated by BIM-LCA integration are critical to the correctness and dependability of the findings. However, there is still a need for better methods to ensure this data's quality and accuracy and mitigate the impact of data gaps and uncertainties on the results.
3. Integration with other sustainability assessment tools: BIM-LCA integration is just one of many tools used to assess the sustainability of buildings. There is a need for greater integration of BIM, LCA, and other sustainability assessment tools, such as Energy Performance Assessment (EPA) and Building Performance Simulation (BPS), to provide a more thorough perspective of the environmental impact of buildings.
4. Standardization and interoperability: To ensure that the results of BIM-LCA integration are consistent, reliable, and meaningful, there is a need for greater standardization and interoperability in the methods and tools used for data analysis and reporting.
5. Improved user-friendliness: While BIM-LCA integration has become more accessible in recent years, there is still a need for better methods for making the integration process more user-friendly, especially for non-expert users.

The research gaps in the field of BIM-LCA integration highlight the need for continued research and development in this area. By addressing these gaps, organizations can continue to make the integration process more effective, efficient, and reliable and make better-informed decisions about the environmental impact of their buildings.

3.5 The future of BIM-LCA integration and opportunities for further research and development.

BIM and LCA are evolving fields with many opportunities for further research and development. Integration of BIM and LCA has excellent potential, and there are numerous opportunities for further research and development in this area. By utilizing the most recent technologies and methodologies, organizations can continue to make the integration process more effective, efficient, and reliable and make more informed decisions regarding the environmental impact of buildings.

Based on the results of the literature review and case studies presented in this paper, the following recommendations for future research on the topic of BIM-LCA integration for carbon emissions assessment in the construction industry are made:

1. Further development of BIM-LCA integration software: To fully realize the potential of BIM-LCA integration, it is important to continue to develop compatible software that can communicate between BIM and LCA platforms. This will enable more accurate and efficient analysis of building design and construction decisions in terms of their impact on the environment.
2. Standardization of data formats: The need for more standardization in data formats presents a challenge for BIM-LCA integration. Industry organizations and standards bodies are recommended to collaborate to develop and implement standard data formats for BIM-LCA integration.
3. Increased use of BIM-LCA integration in practice: Despite the potential benefits of BIM-LCA integration, there is limited evidence of its use in practice. It is recommended that industry stakeholders encourage and support the adoption of BIM-LCA integration in the construction industry by providing education and training and developing best practice guidance.
4. Further case studies and comparative analysis: The case studies presented in this manuscript provide valuable insights into the potential of BIM-LCA integration for reducing carbon emissions in the construction industry. However, more case studies are needed to better understand the benefits and challenges of BIM-LCA integration in different contexts and to provide a more comprehensive understanding of the potential of BIM-LCA integration for reducing carbon emissions.
5. Investigation of the impact of BIM-LCA integration on other sustainability indicators: This review has focused on the potential of BIM-LCA integration for reducing carbon emissions. Nevertheless, it is also vital to explore the influence of BIM-LCA integration on other sustainability metrics, including resource usage, water consumption, and waste production, to give a complete knowledge of the environmental impact of building design and construction choices.

These recommendations provide a framework for future research on the issue of BIM-LCA integration for carbon emissions assessment in Thailand's construction industry. Hopefully, this review will contribute to the ongoing development of strategies and methods to lower the number of carbon emissions produced by the building and construction sectors.

4. Conclusion

Integrating BIM and LCA can play a significant role in reducing carbon emissions in the construction industry. The results of the literature review suggest that BIM-LCA integration can provide valuable insights into the environmental impact of building design and construction and help to reduce the carbon emission of the building and construction industry.

The benefits of BIM-LCA integration include optimizing building design to reduce energy use and the carbon footprint of building materials and to evaluate the environmental impact of a building over its entire life cycle, from material extraction to demolition. This can help identify opportunities to reduce a building's carbon footprint, optimize material choices, and inform design, construction, and operation decisions. Moreover, BIM-LCA integration can help promote sustainable building practices and reduce the environmental impact of the construction industry.

However, there are still significant research gaps in this field, but progress has yet to be made in recent years. Several challenges and limitations need to be overcome to realize the full potential of this approach, including the need for compatibility between BIM and LCA software and the need for standardization in data exchange and formats. BIM-LCA integration is a cross-disciplinary field that requires collaboration between architects, engineers, sustainability professionals, and others. There is a need for more advanced methods for analyzing and interpreting the data generated by the integration, including the development of more sophisticated LCA algorithms and models. By utilizing the most recent technologies and methodologies, organizations can continue to make the integration process more effective, efficient, and reliable, as well as make more informed decisions regarding the environmental impact of buildings, and professionals can analyze the environmental impact of different design and material choices.

The key findings and insights from this research provide valuable guidance for those considering the implementation of BIM-LCA integration in Thailand's construction industry and highlight the need for further research to get ready for this technology. Adopting and implementing BIM-LCA integration in Thailand may need help, such as a need for more awareness and knowledge among stakeholders, limited availability of local data and tools, and the need for collaboration and coordination among different parties involved in the building design and construction process. There are also possibilities for BIM-LCA integration to contribute to Thailand's sustainable construction development.

References

Asare, K. A. B., Ruikar, K. D., Zanni, M., & Soetanto, R. (2020). BIM-based LCA and energy analysis for optimised sustainable building design in Ghana [Article]. *SN Applied Sciences, 2*(11), Article 1855. https://doi.org/10.1007/s42452-020-03682-2

Azizoglu, B., & Seyis, S. (2020). Analyzing the benefits and challenges of building information modelling and life cycle assessment integration. Advances in Building Information Modeling: First Eurasian BIM Forum, EBF 2019, Istanbul, Turkey, May 31, 2019, Revised Selected Papers 1,

Bovea, M. D., Ibáñez-Forés, V., & Agustí-Juan, I. (2014). Environmental product declaration (EPD) labelling of construction and building materials. In *Eco-efficient construction and building materials* (pp. 125-150). Elsevier.

Bueno, C., & Fabricio, M. M. (2018). Comparative analysis between a complete LCA study and results from a BIM-LCA plug-in. *Automation in construction, 90*, 188-200.

Cerovsek, T. (2011). A review and outlook for a 'Building Information Model'(BIM): A multi-standpoint framework for technological development. *Advanced engineering informatics, 25*(2), 224-244.

Chan, M., Masrom, M. A. N., & Yasin, S. S. (2022). Selection of low-carbon building materials in construction projects: Construction professionals' perspectives. *Buildings, 12*(4), 486.

Cheng, B., Li, J., Tam, V. W., Yang, M., & Chen, D. (2020). A BIM-LCA approach for estimating the greenhouse gas emissions of large-scale public buildings: a case study. *Sustainability, 12*(2), 685.

Dalla Mora, T., Bolzonello, E., Cavalliere, C., & Peron, F. (2020). Key parameters featuring bim-lca integration in buildings: A practical review of the current trends. *Sustainability, 12*(17), 7182.

David Mineer. (2016). *Pros & Cons of Using a BIM Model for your Next Project – Construction Monitor. Pros & Cons of Using a BIM Model for Your Next Project – Construction Monitor*. Retrieved 15 Februray from https://www.constructionmonitor.com/blog/2015/12/03/pros-cons-of-using-a-bim-model-for-your-next-project/

Doan, D. T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Ghaffarianhoseini, A., & Tookey, J. (2017). A critical comparison of green building rating systems. *Building and Environment, 123*, 243-260.

Fava, J. A. (2006). Will the next 10 years be as productive in advancing life cycle approaches as the last 15 years? *The International Journal of Life Cycle Assessment, 11*(1), 6-8.

Genova, G. (2018). *BIM-based LCA throughout the Design Process with a Dynamic Approach* ETH Zurich].

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., & Raahemifar, K. (2017). Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews, 75*, 1046-1053.

Hollberg, A., Genova, G., & Habert, G. (2020). Evaluation of BIM-based LCA results for building design. *Automation in construction, 109*, 102972.

Huang, B., Gao, X., Xu, X., Song, J., Geng, Y., Sarkis, J., Fishman, T., Kua, H., & Nakatani, J. (2020). A life cycle thinking framework to mitigate the environmental impact of building materials. *One Earth, 3*(5), 564-573.

Kamari, A., Kotula, B. M., & Schultz, C. P. L. (2022). A BIM-based LCA tool for sustainable building design during the early design stage. *Smart and Sustainable Built Environment*.

Kamel, E., & Memari, A. M. (2019). Review of BIM's application in energy simulation: Tools, issues, and solutions. *Automation in construction, 97*, 164-180.

Kurian, R., Kulkarni, K. S., Ramani, P. V., Meena, C. S., Kumar, A., & Cozzolino, R. (2021). Estimation of carbon footprint of residential building in warm humid climate of India through BIM. *Energies, 14*(14), 4237.

Li, L. (2021). Integrating climate change impact in new building design process: A review of building life cycle carbon emission assessment methodologies. *Cleaner Engineering and Technology, 5*, 100286.

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.

Lu, K., & Wang, H. (2019). Estimation of Building's Life Cycle Carbon Emissions Based on Life Cycle Assessment and Building Information Modeling: A Case Study of a Hospital Building in China. *Journal of Geoscience and Environment Protection*.

Mao, C., Shen, Q., Shen, L., & Tang, L. (2013). Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects. *Energy and Buildings, 66*, 165-176.

Marrero, M., Wojtasiewicz, M., Martínez-Rocamora, A., Solís, G., & Alba-Rodríguez, M. D. (2020). BIM-LCA integration for the environmental impact assessment of the urbanization process [Review]. *Sustainability (Switzerland), 12*(10), Article 4196. https://doi.org/10.3390/su12104196

Motalebi, M., Rashidi, A., & Nasiri, M. M. (2022). Optimization and BIM-based lifecycle assessment integration for energy efficiency retrofit of buildings. *Journal of Building Engineering, 49*, 104022.

Najjar, M., Figueiredo, K., Palumbo, M., & Haddad, A. (2017). Integration of BIM and LCA: Evaluating the environmental impacts of building materials at an early stage of designing a typical office building. *Journal of Building Engineering, 14*, 115-126.

Nema, P., Nema, S., & Roy, P. (2012). An overview of global climate changing in current scenario and mitigation action. *Renewable and Sustainable Energy Reviews, 16*(4), 2329-2336.

Obrecht, T. P., Röck, M., Hoxha, E., & Passer, A. (2020a). BIM and LCA integration: A systematic literature review [Review]. *Sustainability (Switzerland), 12*(14), Article 5534. https://doi.org/10.3390/su12145534

Obrecht, T. P., Röck, M., Hoxha, E., & Passer, A. (2020b). The challenge of integrating Life Cycle Assessment in the building design process - A systematic literature review of BIM-LCA workflows.

Olanrewaju, O. I., Kineber, A. F., Chileshe, N., & Edwards, D. J. (2022). Modelling the relationship between Building Information Modelling (BIM) implementation barriers, usage and awareness on building project lifecycle. *Building and Environment, 207*, 108556.

Onat, N. C., & Kucukvar, M. (2020). Carbon footprint of construction industry: A global review and supply chain analysis. *Renewable and Sustainable Energy Reviews, 124*, 109783.

Potrč Obrecht, T., Röck, M., Hoxha, E., & Passer, A. (2020). BIM and LCA Integration: A Systematic Literature Review. *Sustainability, 12*(14), 5534. https://www.mdpi.com/2071-1050/12/14/5534

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W.-P., Suh, S., Weidema, B. P., & Pennington, D. W. (2004). Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment international, 30*(5), 701-720.

Rosen, M. A., & Kishawy, H. A. (2012). Sustainable manufacturing and design: Concepts, practices and needs. *Sustainability, 4*(2), 154-174.

Safari, K., & AzariJafari, H. (2021). Challenges and opportunities for integrating BIM and LCA: Methodological choices and framework development. *Sustainable Cities and Society, 67*, 102728.

Santos, R., Costa, A. A., Silvestre, J. D., & Pyl, L. (2019, 2019/07/01/). Integration of LCA and LCC analysis within a BIM-based environment. *Automation in construction, 103*, 127-149. https://doi.org/https://doi.org/10.1016/j.autcon.2019.02.011

Selicati, V., Cardinale, N., & Dassisti, M. (2020). Evaluation of the sustainability of energy retrofit interventions on the historical heritage: A case study in the city of Matera, Italy. *International Journal of Heat and Technology, 38*(1), 17-27.

Seyis, S. (2020). Mixed method review for integrating building information modeling and life-cycle assessments. *Building and Environment, 173*, 106703.

Sharif, S. A., & Hammad, A. (2019). Simulation-based multi-objective optimization of institutional building renovation considering energy consumption, life-cycle cost and life-cycle assessment. *Journal of Building Engineering, 21*, 429-445.

Soust-Verdaguer, B., Llatas, C., & García-Martínez, A. (2017). Critical review of bim-based LCA method to buildings. *Energy and Buildings, 136*, 110-120.

Soust-Verdaguer, B., Palumbo, E., Llatas, C., Acevedo, A., Hoxha, E., & Passer, A. (2022). Environmental Product Declarations (EPDs) of construction products in Spain: Current status and future challenges. IOP Conference Series: Earth and Environmental Science,

Tam, V. W., Zhou, Y., Illankoon, C., & Le, K. N. (2022). A critical review on BIM and LCA integration using the ISO 14040 framework. *Building and Environment, 213*, 108865.

Tam, V. W. Y., Zhou, Y., Shen, L., & Le, K. N. (2023, January 20th). Optimal BIM and LCA integration approach for embodied environmental impact assessment. *Journal of Cleaner Production, 385*, 135605. https://doi.org/https://doi.org/10.1016/j.jclepro.2022.135605

Teng, Y., Xu, J., Pan, W., & Zhang, Y. (2022). A systematic review of the integration of building information modeling into life cycle assessment. *Building and Environment*, 109260.

Theißen, S., Höper, J., Drzymalla, J., Wimmer, R., Markova, S., Meins-Becker, A., & Lambertz, M. (2020). Using open BIM and IFC to enable a comprehensive consideration of building services within a whole-building LCA. *Sustainability, 12*(14), 5644.

Vázquez-Rowe, I., Córdova-Arias, C., Brioso, X., & Santa-Cruz, S. (2021). A method to include life cycle assessment results in choosing by advantage (Cba) multicriteria decision analysis. A case study for seismic retrofit in peruvian primary schools. *Sustainability, 13*(15), 8139.

Xu, J., Teng, Y., Pan, W., & Zhang, Y. (2022). BIM-integrated LCA to automate embodied carbon assessment of prefabricated buildings. *Journal of Cleaner Production, 374*, 133894.

Xue, K., Hossain, M. U., Liu, M., Ma, M., Zhang, Y., Hu, M., Chen, X., & Cao, G. (2021). BIM integrated LCA for promoting circular economy towards sustainable construction: an analytical review. *Sustainability, 13*(3), 1310.

Yang, X., Hu, M., Wu, J., & Zhao, B. (2018). Building-information-modeling enabled life cycle assessment, a case study on carbon footprint accounting for a residential building in China. *Journal of Cleaner Production, 183*, 729-743.

Yayla, A., Kayakutlu, G., & Kayalica, M. O. (2021). Life Cycle Assessment with BIM Towards Sustainable Energy Policy-Making: The Case of Urban Transformation in Istanbul. *International Journal of Sustainable Construction Engineering and Technology, 12*(3), 142-154.

Zimmermann, R. K., Bruhn, S., & Birgisdóttir, H. (2021). BIM-Based Life Cycle Assessment of Buildings—An Investigation of Industry Practice and Needs. *Sustainability, 13*(10), 5455.

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