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Original Paper

Integrating LCA, BIM, and Surrounding Trees for Carbon Neutrality in Steel and Concrete Frame Public Structures: A Case Study in Hangzhou

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Abstract

The construction industry is actively working to improve its operations' sustainability and reduce buildings' ecological impact on climate change. One approach involves integrating Building Information Modeling (BIM) with Life Cycle Assessment (LCA) to streamline data input, calculate environmental impacts, and optimize output data. This case study focuses on using the One-Click LCA plugin to explore LCA-BIM integration for sustainable construction.

The study examines the carbon emissions of steel and concrete frame public structures and assesses the role of surrounding trees in achieving carbon neutrality. Two innovative public buildings in China's Zhejiang province serve as the case study's subject. The One-Click LCA plugin in Revit is a quick and user-friendly tool, providing concrete and steel structure results and generating informative graphs for easy comparison.

The findings reveal that the A1-A3 material stage during the design phase contributes the most to emissions and biogenic carbon storage. By demonstrating the practical implementation of LCA-BIM integration using the One-Click LCA plugin, this case study contributes to the knowledge base on sustainable construction practices. The results can guide decision-making for architects, engineers, and construction professionals, empowering them to make informed choices that minimize carbon emissions and promote environmentally-friendly design strategies.

Keywords

Life Cycle Assessment (LCA), Building Information Modeling (BIM), One-Click LCA plugin, carbon *emissions, sustainable construction, carbon neutrality*

1. Introduction

Around 35% of worldwide energy consumption and 38% of the total CO2 emissions are attributed to buildings (Global, 2020). Consequently, the construction sector has been trying to improve the sustainability of its operations by adopting different building technologies and environmental assessment techniques to reduce the ecological effects of buildings on climate change.

Life Cycle Assessment (LCA) studies are increasingly conducted in the construction sector to evaluate the environmental consequences of building activities. LCA helps assess and compare the environmental impacts of different construction materials and stages of the building life cycle. The embodied phase, functional phase, and end-of-life phase all contribute to energy consumption and carbon emissions, with the embodied phase playing a crucial role in achieving energy efficiency and reducing emissions.

The integration of LCA and Building Information Modeling (BIM) can enhance sustainability in the built environment. By combining BIM with LCA, the design and evaluation of buildings become more efficient, saving time and effort. Various approaches have been proposed to integrate BIM and LCA, such as using third-party applications, importing LCA data into the BIM environment, or importing BIM data into professional LCA tools.

Autodesk Revit, a BIM software, can be integrated with additional 3rd party software like One-Click LCA. This integration allows designers and engineers to assess the environmental impact of design choices in real-time, considering factors such as carbon emissions, energy consumption, and resource depletion. The One-Click LCA plugin facilitates informed decision-making and optimization of designs for lower ecological footprints.

Furthermore, the presence of trees near construction projects should be considered for their carbon sequestration capacity and potential contribution to achieving carbon neutrality. Trees absorb CO2 through photosynthesis, which helps balance greenhouse gas emissions.

Overall, by prioritizing sustainability, adopting LCA practices, integrating BIM with LCA, and considering the role of trees, the construction sector can work towards reducing the ecological impact of buildings and achieving a more sustainable built environment.

2. Literature Review

2.1 BIM application for Sustainable Buildings

Building information modeling (BIM), which integrates building design and data digitally throughout its lifespan (Succar, 2009), has been proposed as a revolutionary technology that can transform the building industry (Peuportier et al., 2013). BIM can assist in compliance with green building rating systems (Wong & Kuan, 2014; Wong & Abe, 2014) and enhance the green building certification process (Jalaei & Jrade, 2014; Yahya et al., 2016). Aspects of sustainable building design, including orientation, massing, energy modeling, and materials, can be supported by BIM tools (Krygiel & Nies, 2008). According to studies, many green building rating systems may be directly evaluated using BIM, including LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), BEAM Plus (Building Environmental Assessment Method), Green Star Australia, and New Zealand Homestar.

In conclusion, BIM application for sustainable buildings offers immense potential to create environmentally conscious and energy-efficient structures. By integrating energy analysis, life cycle assessment, clash detection, facility management, and green building certifications into the BIM workflow, professionals can make data-driven decisions that minimize environmental impact, reduce energy consumption, and promote sustainable practices throughout the building’s lifecycle. BIM’s collaborative nature and information-rich models make it indispensable for sustainable building design and construction.

2.2 LCA Application for Sustainable Buildings

LCA evaluates the environmental impact of a product, process, or building throughout its whole life cycle (Papajohn et al., 2016; Zuo et al., 2017). It has been extensively studied in the building sector due to the high environmental impacts of this industry (Anand & Amor, 2017). Integrating LCA into green building rating systems is necessary to assess the building’s environmental impacts, such as carbon emissions (Bruce-Hyrks et al., 2018; Darko et al., 2019). However, the implementation of LCA in building environmental assessment remains a challenge (Jusselme et al., 2018) due to identified barriers such as complexity(Kiss et al., 2021), lack of knowledge of environmental impacts, complicated calculations, and cost (Bribián et al., 2009; Carmody et al., 2007; Roberts et al., 2020).

Previous research on LCA adoption for building environmental assessment focused on technical aspects and theoretical frameworks. Some studies developed simplified LCA frameworks for energy certifications (Bribián et al., 2009) or integrated LCA-LEED models for sustainability assessment (Alshamrani et al., 2014). Other studies developed building environmental performance analysis systems (Zhang et al., 2006) or methods to support the evaluation of construction materials using the LCA approach (Waldman et al., 2020). Another study by (Colangelo et al., 2021) assessed three different concrete compositions, and the results showed that recycled aggregate had a lower environmental effect than native aggregate.

In conclusion, LCA enables informed decision-making, supports sustainable material selection and design optimization, facilitates comparative analysis and benchmarking, assesses whole building performance, and aids in green building certification and compliance. By integrating LCA into the design and decision-making processes, professionals can create buildings that minimize environmental harm, reduce resource consumption, and contribute to a more sustainable built environment.

2.3 BIM-LCA Integration for Carbon Emission Reduction at the Design Stage

Integrating BIM with LCA at the design stage offers significant potential for reducing carbon emissions in construction projects. Since most sustainable decisions are made in the early design stages, including sustainable data in these stages is crucial for decision-making. Finding a means to use sustainable BIM-based tools even in the early design stages, when many of the building's system variables are not yet known, and offering quantitative performance estimates are the challenges (Ilhan & Yaman, 2016).

BIM software can now be integrated with sustainability databases, as in the case of the One-click software plugin. Still, in most cases, it may not be integrated with sustainability databases, necessitating the use of a team and requiring a significant amount of time and effort to import the data from an external source (Ilhan & Yaman, 2016).

The numerous uses of Life Cycle Assessment (LCA) in combining building materials components and the construction process were thoroughly examined (Ortiz et al., 2009). According to the study, whole-process construction and LCA of building materials components combination are ground-breaking methods that improve the building industry's sustainability over a structure's lifetime. Almost 90% of LCA case studies have been devoted to environmental impact analysis and decision-making assistance in the construction industry.

Although LCA is often applied retroactively for effect estimates (Peuportier et al., 2013), it may also help with building design (Basbagill et al., 2013) by encouraging design choices that are environment-centric (Khasreen et al., 2009). The LCA technique may measure a product's impact across its whole life cycle and identify the most significant components during the design phase (Guinée et al., 1993); nevertheless, it is frequently disregarded because of the challenging data and tool requirements (Ellram et al., 2008).

The emergence of BIM signifies a step toward integrating LCA into the construction industry, and this trend is expanding to include various engineering analysis techniques and construction business functions (Jung & Joo, 2011). To improve performance, it is crucial to identify and measure the BIM competencies necessary for developing BIM capabilities (Succar, 2009; Succar et al., 2013).

Prior research by (Wang et al., 2011) focused on advanced intelligent technologies, performance evaluation methodologies, and investment evaluation analysis. The integration of LCA within the BIM platform encompasses all three of these aspects and has the potential to support environmental assessments and conscious material choices during the design process (Ajayi et al., 2015; Wang et al., 2011).

However, there are several limitations to BIM-based LCA, such as the complexity of LCA tools and data input, as well as interoperability concerns between different software. Improvements in data exchange and LCA tool implementation in BIM software are still necessary (Ajayi et al., 2015; Fischer et al., 2004).

Present carbon emissions accounting methodologies need to account for early design phases for building elements. The challenge of acquiring building information during the early stages of schematic design is compensated for by BIM. Compared to older approaches, BIM-based sustainability software can deliver findings more quickly, but there may be inconsistencies in the results' accuracy because of errors in building information models (Azhar et al., 2011).

2.4 Carbon Neutrality Application of Sustainable Buildings

Applying sustainable buildings to achieve carbon neutrality is crucial to addressing climate change and promoting a low-carbon future. Carbon neutrality is the balance between the amount of carbon emissions produced and the amount of carbon removed or offset.

Planting trees around a building is a practical and widely recognized application for achieving carbon neutrality in the built environment. Trees play a vital role in carbon sequestration, helping to offset the carbon emissions associated with the building’s operations and embodied carbon. Trees absorb carbon dioxide (CO2) during photosynthesis and store it as carbon in their biomass. By planting trees around a building, the trees actively remove CO2 from the atmosphere, contributing to carbon sequestration. This helps offset the carbon emissions produced by the building, such as from energy consumption or embodied carbon in materials. (Nowak et al., 2013) explored the role of trees in storing and removing carbon dioxide (CO2) in urban environments. They also highlight the carbon sequestration potential of different tree species, indicating that certain tree types, such as oak and pine, have higher carbon storage capabilities than others. Additionally, the age and size of trees were identified as factors influencing their capacity to store carbon.

Planting trees around a building is a practical and tangible way to contribute to carbon neutrality. It helps sequester carbon, mitigate the urban heat island effect, conserve energy, enhance biodiversity, and provide numerous other environmental and well-being benefits. By incorporating tree planting into the design and planning of sustainable buildings, the path to achieving carbon neutrality becomes more attainable.

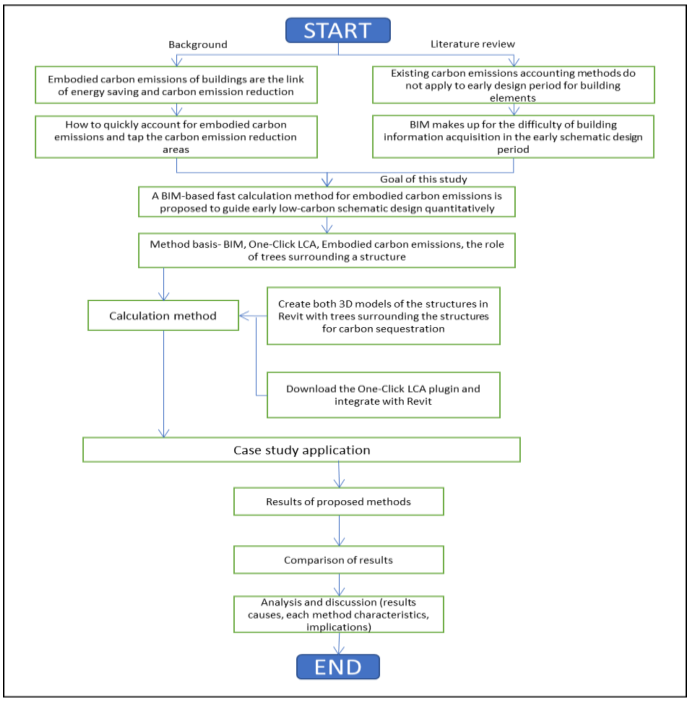


Figure 1. Paper Framework

3. Goal and Justification

To facilitate carbon emission optimization during the design phases of the construction of the structures, this study compares the carbon emissions of two public buildings—one constructed of concrete and the other of steel. Based on the construction area of both structures, a comparison is conducted between the outcomes of the two simulations. BIM software and LCA software will be used for this comparison. The framework of this study and how its goal will be attained are shown in **Figure 1** above.

One-Click LCA is the preferred program because the One-Click LCA plugin enables integration with Autodesk Revit. The research stresses using BIM platforms coupled with LCA software to acquire findings simply and quickly, particularly at the design stage, to help in carbon optimization in the construction sector. Additionally, different BIM platforms interact with other LCA software, necessitating a deeper comprehension of the prerequisites for this combination to be helpful in the building industry.

4. Methodology

4.1 Foundation for the Methodology

This paper is based on LCA approaches integrated with a BIM platform that accounts for embodied carbon emissions from structures by utilizing a bill of quantities generated by the BIM platform Autodesk Revit.

4.1.1 Detailed Design of the Building

The essential components of a structure include its foundation, walls, columns, beams, slab, roof, doors, windows, stairs, steps, ramps, and decorative features. Significant construction components include the load-bearing framework, the outer structure, the finishing, and the accessories. In other words, a structure comprises six elements: a foundation, walls or columns, a floor, a staircase, a roof, doors, and windows. The majority of the detailed design is made up of a structure’s six main structural components.

4.1.2 Merits of BIM

The BIM software platform for this study is Autodesk Revit, which features a robust coding system. In the BIM model, each building material can be taken off using the “schedule” function, and the Revit software can produce a statistical bill of quantities for all the building materials.

4.1.3 Carbon Emission Factors

Each building material’s embodied carbon emissions are determined by multiplying its amounts by the relevant carbon emission footprint. The One-click LCA software will perform the calculations since it is coded with the carbon emission factor of various green building systems.

4.1.4 Embodied Carbon Emissions

Embodied carbon emissions of a building are the overall embodied carbon emissions of all the building materials, which roughly equals the embodied carbon emissions of all six parts of the structures.

4.1.5 Carbon Neutrality

Carbon neutrality refers to the state of achieving net-zero carbon dioxide (CO2) emissions. It is the balance between the amount of CO2 emitted into the atmosphere and the amount of CO2 removed from the atmosphere. The concept of carbon neutrality is based on recognizing that greenhouse gas emissions mainly contribute to climate change and global warming.

Organizations, governments, and individuals aim to minimize their carbon footprint by reducing their greenhouse gas emissions as much as possible to attain carbon neutrality. This includes adopting sustainable practices, improving energy efficiency, transitioning to renewable energy sources, and implementing emission reduction measures such as planting trees around a structure to help reduce carbon sequestration across various sectors.

The factors mentioned above provide a BIM-based method to compute the embodied carbon emissions of a building and attain carbon neutrality. Consequently, addressing the issue of optimizing the design through the calculation of the building’s embodied carbon emissions takes place during the detailed design phase.

4.2 Methodology Procedure

Essentially, there are two steps to be taken; the first step is to create two different models that allow the individual identification of each building element and the provision of a bill of materials for each element. The final step is to run the One-Click LCA software to obtain results of the building elements’ embodied carbon emissions by merging the building elements’ inventories with the database of carbon emission factors. **Figure 2** depicts this below.

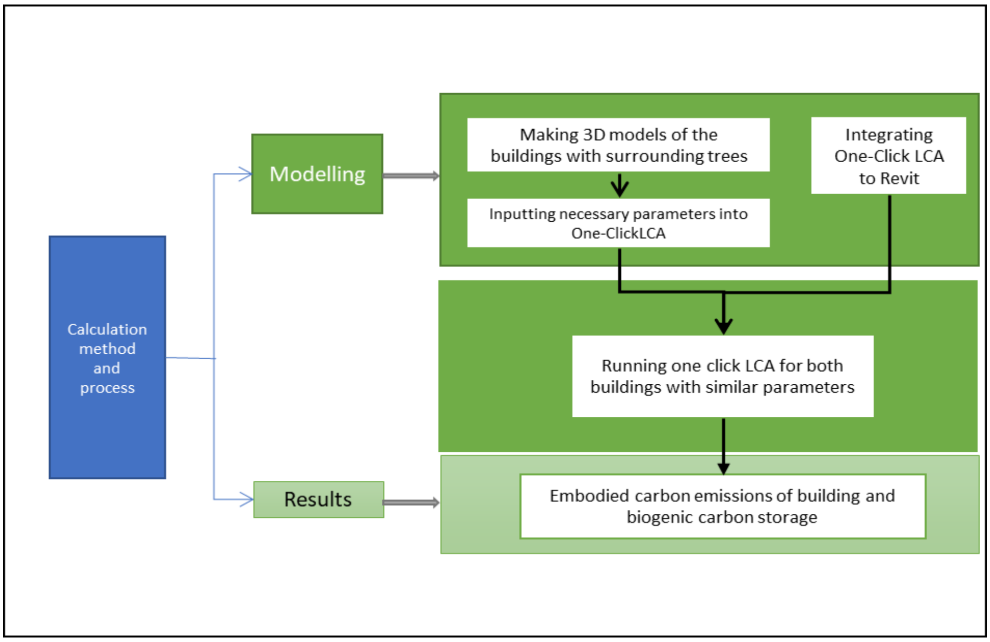


Figure 2. Methodology Process

4.3 Methodology Assumptions

Due to subsurface design depth, the initial stages of design are notably characterized by inaccuracy in the knowledge of the detailed design. However, detailed design knowledge is known in this study because detailed drawings with their specifications are readily accessible.

Certain materials in both structures have the same type, strength, or finishing to ensure consistency in the computations. For instance, the concrete grade is C20, the rebar grade is 400 MPa, and the wall type is 200 mm hollow concrete bricks and other similar materials.

4.4 Case Overview

The case study of the two innovative public buildings in China’s Zhejiang Province, characterized by hot summers and cold winters in Hangzhou, is presented in this paper. **Table 1** and **Table 2** provide the following fundamental construction information, and Figure 3 and **Figure 4** show the 3D models of the case buildings.

Table 1. Basic Building Data

Building Information	Details
Concrete building	
Building type	Multi-storey public building
Structure form	Concrete frame structure
Storey height	3.6m for both layers
Storeys	2
Total construction area	693m^2
Building base area	533m^2
Seismic fortification intensity	Seven degrees
Seismic grade	Four
Roof waterproof grade	I
Steel building	
Building type	Multi-storey public building
Structure form	Steel frame structure
Storey height	3.6 m first layer, 3.5 m second layer
Storeys	2
Total construction area	1361m^2
Building base area	1151m^2
Seismic fortification intensity	Seven degrees
Seismic grade	Four
Roof waterproof grade	I

Table 2. Vegetation Data

Vegetation information	Details
Concrete structure	
Vegetation area	260m^2
Tree species/Qty	Baldcypress/25
	Cedar-Red/15
	Gingko Biloba/20
	Oaktree/25
	Maple-Bigleaf/20
	Pine/15
Steel structure	
Vegetation area	300m^2
Tree species/Qty	Baldcypress/35
	Cedar-Red/20
	Ginkgo Biloba/30
	Oaktree/35
	Maple-Bigleaf/30
	Pine/25

The primary techniques employed in civil works for innovative public buildings are described below. The foundation of the building is composed of a reinforced concrete strip foundation and an isolated reinforced concrete foundation. Hollow brick non-load-bearing walls make up all interior and external partition walls, filler walls for frame columns, and other walls. The waterproof material comprises a roll of chlorinated polyethylene rubber 12mm thick and a 15mm thick polyurethane waterproof covering. Wood is used to make the internal doors. The beams, slabs, and columns are built from cast-in-situ reinforced concrete for the concrete structure and are made of steel I-sections for the steel structure. This study does not consider the building’s interior or exterior decoration.

Figure 3. Concrete Structure Case Model

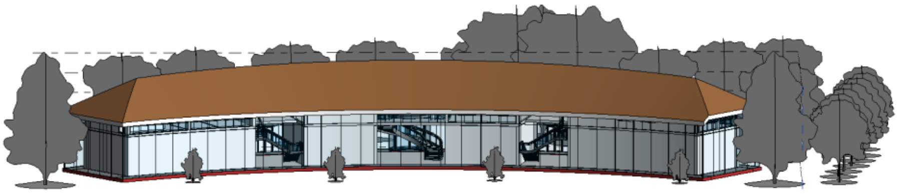


Figure 4. Steel Structure Case Model

5. Results and Discussion

5.1 Autodesk Revit Material Takeoff

After modeling, the quantities of each Building element may be established by completely utilizing the "schedule" function, as illustrated in **Table 3**. The following components, for instance, are frequently included in the comprehensive schedule of model-based exports from the Revit software: the family and type, category, name, physical geometric data (volume and area), created locations in the model, etc.

Table 3. Materials Take-Off Data

Concrete Structure Material Take-off				
Category	Family and Type	Name	Area	Volume
Columns	Columns Rectangular: 350x350mm	Concrete, Cast In Situ	203 m²	7.87 m³
Beam	Beam Rectangular: 250x600mm	Concrete, Cast In Situ	184 m²	2.8 m³
Slab	Floor: Tiles on concrete	Concrete, Cast-in-Place – C20	1,160 m²	85.43 m³
Wall	Basic interior and exterior wall	Brick, Plaster, Cement mortar	2,063 m²	136.93 m³
Window	Glass	Glass, Aluminium	568 m²	6.55 m³
Door	Interior and exterior door	Wood	152 m²	5.63 m³
Ceiling	Plain ceiling	Gypsum board	1,826 m²	52.09 m³
Roof	Basic Roof	Insulation, Purlins, Roof Tiles	1,383 m²	69.19 m³
Steel Structure Material Take-off				
Slab	Floor	Concrete	3,195 m²	272.12 m³
Wall	Basic interior wall	Brick, Plaster, Gypsum wallboard	4,087 m²	243.62 m³

Structural Columns	Universal Columns-UC305x305x97	Metal - Steel 43-275	240 m^2	1.6 m3
Structural Beam	Universal Beams: UB305x165x40 2	Metal - Steel 43-275	623 m2	2.69 m3
Door	Interior, Exterior	Wood, Glass	259 m^2	5.09 m^3
Window	Glass	Glass, Aluminium	458 m^2	15.65 m^3
Curtain Panels	System Panel: Glazed	Glass	713 m^2	18.13 m^3
Roof	Basic Roof	Insulation, Purlins, Roof Tiles	3,548 m^2	456.82 m^3

5.2 Embodied Carbon Emissions of the Building Based on One-Click LCA Software

After completing the models and inputting the necessary parameters for the software to run, it generated results of embodied carbon emission. In this case, PAS 2080 design stage carbon accounting tool was used.

Table 4. Embodied Carbon Emission and Biogenic Cabon Storage Results for Concrete and Steel Structure

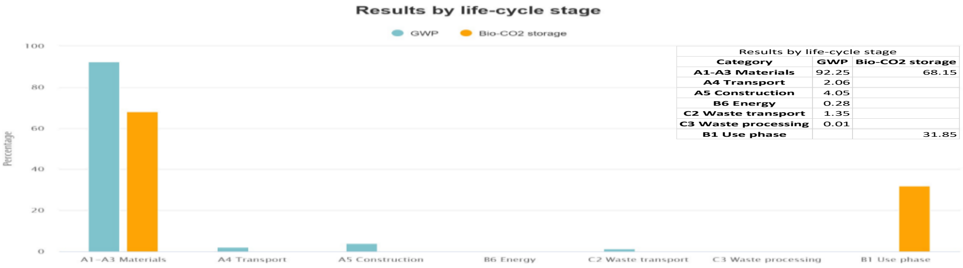
Section	**Result category**	**Global warming (tCo$_2$e)**		**Biogenic carbon storage (tCO$_2$e)**	
		Steel Structure	**Concrete Structure**	**Steel Structure**	**Concrete Structure**
A1-A3	Construction Materials	537.01	267.49	275.61	149.6
A4	Transportation to site	12.5	5.97		
A5	Construction/installation process	30.24	11.75		
B1-e	Vegetation withdrawal of carbon			92.18	69.93
B6	Energy consumption	0.81	0.81		
C1-C4	End of life	6.94	3.94		
	Total	**587.5**	**289.96**	**367.79**	**219.52**
	Total per gross area	**0.51**	**0.54**	**0.32**	**0.42**

Table 4 shows the two cases' total embodied carbon emissions and biogenic carbon storage, calculated using the One-click LCA software. Biogenic carbon storage is the process by which carbon dioxide (CO2) is removed from the atmosphere and stored in living organisms and organic matter, primarily through photosynthesis. In construction, Biogenic carbon storage in building materials refers to incorporating carbon dioxide (CO2) captured from the atmosphere into construction materials. This

approach aims to reduce carbon emissions associated with the construction industry and promote using sustainable and low-carbon materials.

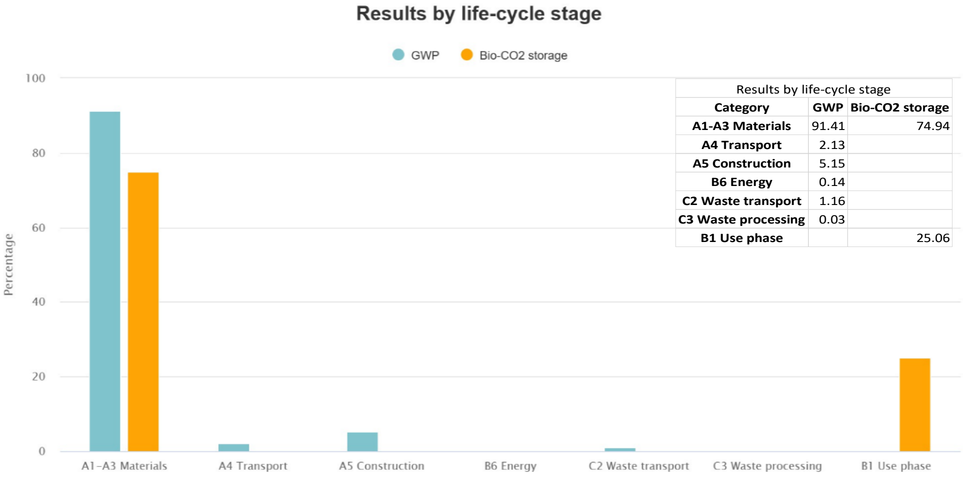
The table above shows that the total embodied carbon emission for the steel structure is 587.5 tons, the total carbon emission of 0.51 tons per gross internal floor area, and a total of 367.79 tons of biogenic carbon stored while the total embodied carbon emission for the concrete structure is 219.52 tons, total carbon emission of 0.54 tons per gross internal floor area and a total of 219.52 tons of biogenic carbon stored.

These results show that the steel structure has a higher carbon emission than the concrete structure, but the concrete structure has a more intense carbon emission per gross floor area. The results also show that the steel structure has better biogenic carbon storage, but the concrete structure has a better biogenic carbon storage capacity per gross floor area. These differences in embodied carbon emissions can be attributed to the gross area of both buildings, and this is shown in **Table 1**.



Results by life-cycle stage		
Category	**GWP**	**Bio-CO2 storage**
A1-A3 Materials	92.25	68.15
A4 Transport	2.06	
A5 Construction	4.05	
B6 Energy	0.28	
C2 Waste transport	1.35	
C3 Waste processing	0.01	
B1 Use phase		31.85

Figure 5. Concrete Structure Whole Life Cycle at the Design Stage



Results by life-cycle stage		
Category	**GWP**	**Bio-CO2 storage**
A1-A3 Materials	91.41	74.94
A4 Transport	2.13	
A5 Construction	5.15	
B6 Energy	0.14	
C2 Waste transport	1.16	
C3 Waste processing	0.03	
B1 Use phase		25.06

Figure 6. Steel Structure Whole Life Cycle Stage at the Design Stage

Figure 5 and **Figure 6** depict the outcomes of the life cycle assessment conducted during the design phase of the structures. The results for both structures exhibit similarities when considering the Global Warming Potential (GWP), indicating that most emissions occur during the A1-A3 stage of the life cycle. This stage accounts for approximately 92.25% of the total carbon emissions for the concrete structure and 91.41% for the steel structure. The stages with the most minor emissions in the life cycle are A5 construction, A4 transport, C2 waste transport, and C3 waste processing.

Additionally, the figures illustrate the biogenic carbon storage results for both structures. Similar patterns are observed, with the highest levels of biogenic carbon storage occurring during the A1-A3 materials stage. For the steel structure, this stage contributes 74.04% of the total 367.79 tons of biogenic carbon storage, while for the concrete structure, it accounts for 68.15% of the total 219.52 tons of biogenic carbon storage. The remaining biogenic carbon storage arises from the B1 usage stage, specifically under vegetation and removal, with 25.06% for the steel structure and 31.85% for the concrete structure.

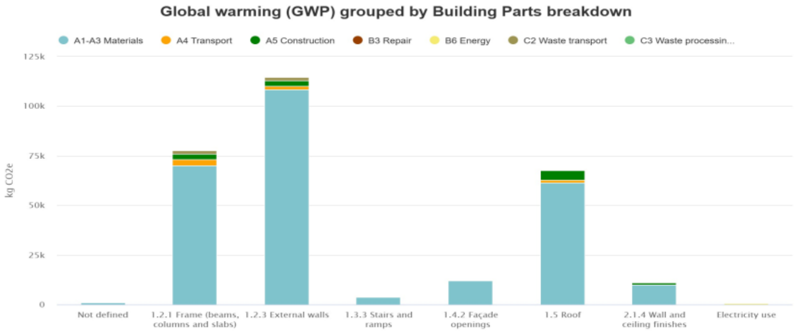


Figure 7. Embodied Carbon Emission by Building Parts (Concrete Structure)

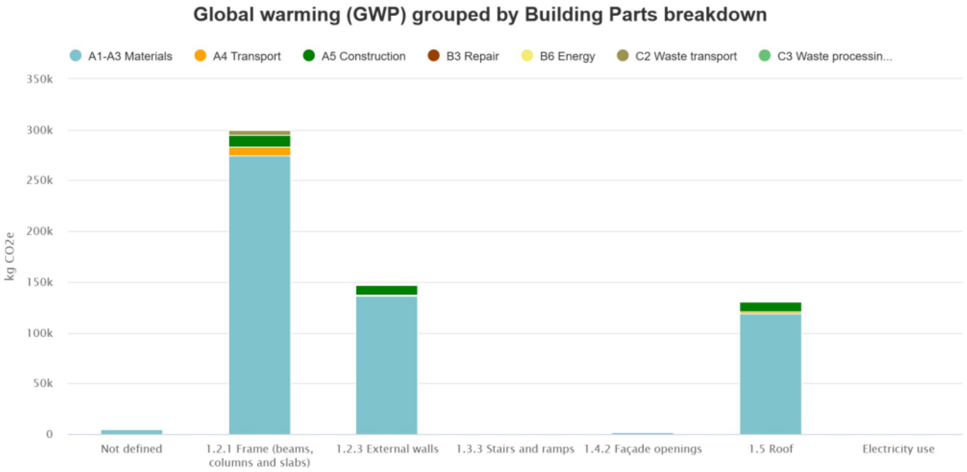


Figure 8. Embodied Carbon Emissions by Building Parts (Steel Structure)

Figure 7 and **Figure 8** provide a visual representation of the total carbon emissions throughout the entire life cycle of the two structures, specifically focusing on different building components at the design stage. The figures demonstrate that the A1-A3 material stage significantly influences carbon emissions in all the components analyzed.

In the concrete structure, the external walls, frame (beam, column, and slab), and roof components exhibit the highest emissions, respectively. Similarly, the frame, exterior walls, and roof components contribute the highest emissions in the steel structure. These components are primarily associated with the construction materials used.

Following the A1-A3 stage, the A5 construction and A4 transport stages represent the subsequent contributors to carbon emissions in the various building components. The C2 waste transport stage also plays a role, although to a lesser extent.

Regarding specific components, the concrete structure shows that wall and ceiling finishes, façade openings, and stairs and ramps have minor carbon emissions, respectively. On the other hand, in the steel structure, the façade opening is the component with the lowest carbon emissions.

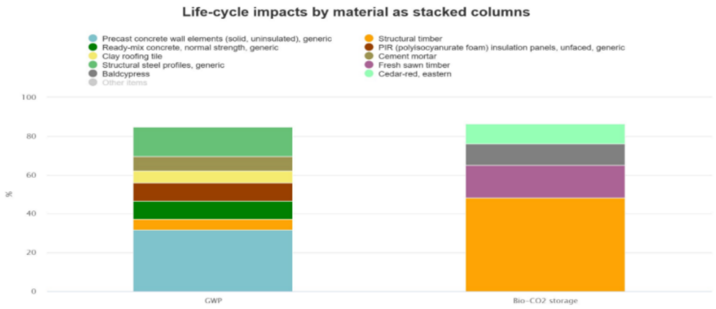


Figure 9. Life Cycle Impacts by Materials (Concrete Structure)

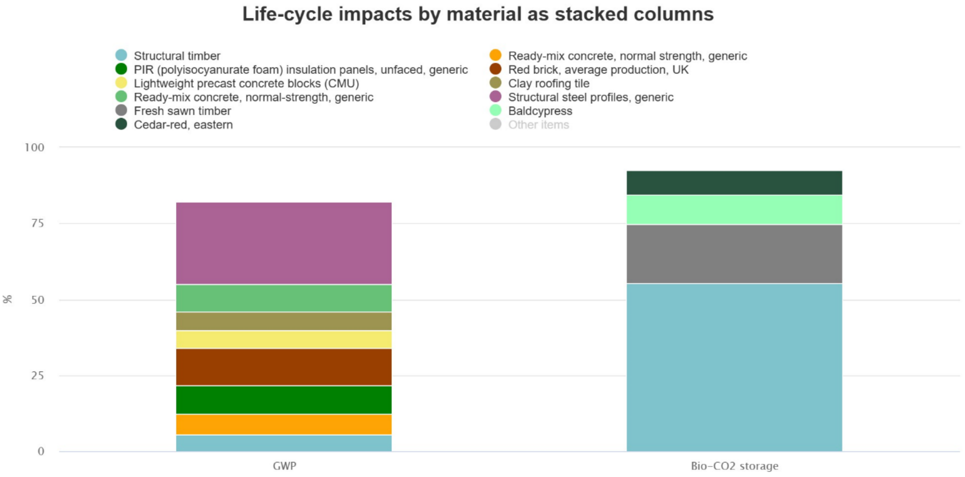


Figure 10. Life Cycle Impacts by Materials (Steel Structure)

Figure 9 and **Figure 10** present a breakdown of the sources of carbon emissions and biogenic carbon storage originating from different materials. The materials with the highest carbon emissions in the concrete structure are precast concrete, structural steel profiles, and ready-mix concrete. These three materials collectively contribute to over 56% of the total carbon emissions. On the other hand, the materials with the lowest carbon emissions are PIR (polyisocyanurate foam) insulation, cement mortar, structural timber, and clay roof tiles.

Regarding biogenic carbon storage in the concrete structure, the materials with the highest storage capacity are structural timber and fresh-sawn timber, primarily utilized in the roof component to help offset the carbon emissions of the structure. The Cedar-Red and Baldcypress trees are also among the biogenic carbon storage materials. These and other tree species are intentionally planted around the structure to aid in mitigating carbon emissions. This can be seen in **Figure 11** and **Figure 12** below.

Similarly, the materials with the highest carbon emissions in the steel structure are structural steel profiles, red bricks, PIR (polyisocyanurate foam) insulation, and ready-mix concrete. These four materials contribute to over 57% of the total carbon emissions. Conversely, the steel structure's materials with the lowest carbon emissions are clay roof tiles, lightweight precast concrete, and structural timber.

Biogenic carbon storage in the steel structure is similar to that of the concrete structure. This is because the same type of roof was used on both structures to have neutrality in the results obtained from the carbon emission calculation. The materials with the highest storage capacity are structural timber and fresh-sawn timber. These materials were used for biogenic carbon storage capacity, as seen in the results below.

The comparison between the two biogenic carbon storage graphs suggests that the vegetation in the concrete structure is more effective in storing carbon than the steel structure. This is primarily because the concrete structure has a higher density of trees per square meter, which helps compensate for the more significant carbon emissions the concrete material produces. Both structures utilize the same tree species, including Maple-Bigleaf, Baldcypress, Cedar-Red-Juniperus, Oak-Chestnut, and Pine-Pinus Nigra. Interestingly, the softwoods, specifically Cedar-Red-Juniperus and Baldcypress, demonstrate faster biogenic carbon storage than the hardwoods. These two tree species are the only ones reflected in the biogenic carbon storage results.

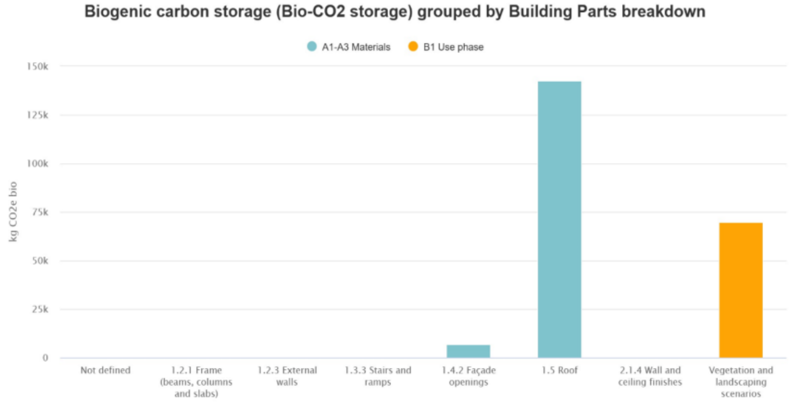


Figure 11. Biogenic Carbon Storage by Building Part (Concrete Structure)

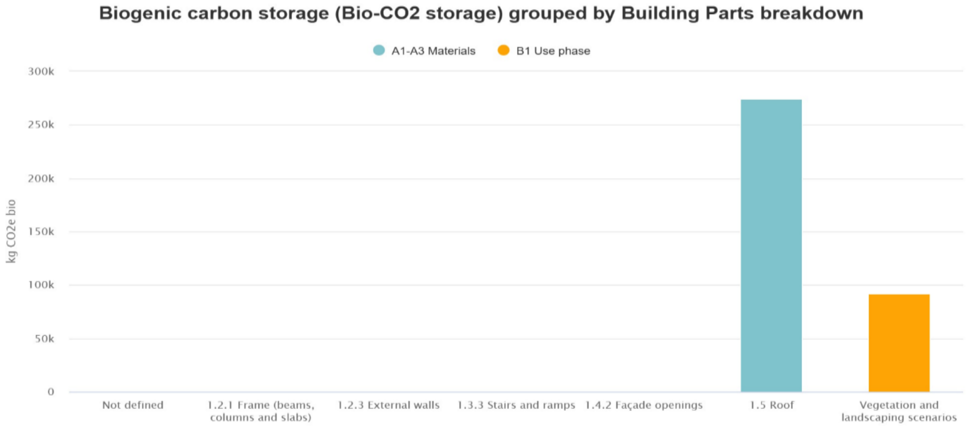


Figure 12. Biogenic Carbon Storage by Building part (Steel Structure)

5.3 Discussion

5.3.1 The Design Perspective

The goals of evaluating building embodied carbon emissions are to identify potential reasons for reducing carbon emissions and to use that information to provide real-time design guidance. According to the evaluation of the two example buildings, the fundamental goal would be to identify alternate materials for the roof component other than structural steel since it is the component that significantly contributes to the carbon emissions in both buildings. To lower the carbon emissions in the wall component of the concrete structure, an environmentally friendly aggregate may be utilized in the block-making process. Implementing measures to regulate and optimize carbon emissions from the inception of the design as early as practical requires an assessment of the effectiveness of embodied carbon emissions at the design stage.

When adequately designed and constructed, a steel frame structure is more sustainable than a concrete frame structure. However, it’s important to recognize that the sustainability of any structure depends on various factors, such as design, construction methods, and maintenance practices. The study employed generic materials from the Revit software to ensure impartial results. Interestingly, the steel structure in the study exhibited higher overall carbon emissions, which may be attributed to the difference in the area of the two buildings. However, the concrete building displayed higher carbon emission intensity when considering carbon emissions per square meter.

Careful planning, thoughtful material selection, and effective construction management are essential to enhance the sustainability of both concrete and steel frame structures. By incorporating sustainable design principles, such as optimizing energy efficiency, utilizing recycled or low-carbon materials, and implementing renewable resource systems, the carbon emissions of both types of structures can be significantly reduced.

Moreover, employing construction techniques that minimize waste, improve resource efficiency, and promote environmentally friendly practices can contribute to the project’s sustainability. Regular maintenance and monitoring throughout the structure's life cycle are also crucial to ensure sustainability.

Integrating biogenic carbon storage into the design process aids in promoting carbon sequestration and supporting sustainability objectives. Designers can incorporate vegetation like trees, green roofs, living walls, and urban gardens, fostering the presence of photosynthesizing plants that absorb carbon dioxide (CO_2) from the air and store carbon in their biomass.

The selection of tree species is crucial, considering their compatibility with local climate, soil conditions, and desired growth rates. Due to their growth characteristics and biomass density, certain tree species exhibit higher carbon sequestration rates. By carefully choosing suitable species, designers can optimize the potential for biogenic carbon storage.

Overall, the embodied carbon emission calculation needs are paired with the relevant parameters at the design stage, and the calculations align the carbon emission reduction viewpoints with the design practices.

5.3.2 Comparison with Related Studies

The BIM life cycle research now focuses mainly on three variables. Using BIM as a technology to extract the building information and life cycle engineering figures necessary for life cycle assessment has been the subject of extensive research and should be noted. For instance, (Wiberg et al., 2014) calculated embodied carbon emissions based on length, area, and volume involving transferring data from Revit to Excel. His results showed that the PV panels, external walls, and foundations were the most significant contributors to the emissions, with an emission value of 7.2 kgCO2eq/m^2 per year. (Iddon & Firth, 2013) stated that the embodied carbon dioxide accounted for 49.3 tons or 22.3% of total CO2e, with the significant contributions to the embodied CO2e total being emitted from the external wall and openings elements, and (Peng, 2016) used the number of materials from the 3D model that was constructed to calculate carbon emissions.

The study revealed that the concrete structure's external walls, frame (beam, column, and slab), and roof components contributed the highest emissions. Together, these three components accounted for more than 89% of the total carbon emission, amounting to 289.96 tons. Similarly, the steel structure's frame, external walls, and roof components contributed the most to emissions, accounting for over 98% of the total carbon emission of 587.5 tons. These components are primarily influenced by the construction materials utilized.

The vast majority of these studies employ building quantity information. With the development of BIM technology, it is now possible to utilize the engineering numbers that are extracted not only directly in studies about the environmental effect but also as the foundation for further investigation and application to other applications (Jrade & Abdulla, 2012; Shadram et al., 2016). Transferring these research methods or findings to other studies is difficult because the plurality of BIM-based studies are case studies. In addition, BIM is commonly used both during construction and at the early design stage to enhance the dependability of design choices. As a result, an evaluation is still tricky and time-consuming (Cheng et al., 2020; Jun et al., 2015; Roeck et al., 2018; Shrivastava & Chini, 2012). Information on the degree of assessment needs must be produced to conduct life-cycle assessments more quickly and efficiently. Similarly, most BIM-LCA studies are one-time post-evaluations instead of integrated continuous assessments throughout the building design. This is the current trend for BIM development in the early design phase (Basbagill et al., 2013).

(Müller et al., 2019) provides an overview of the potential for biogenic carbon storage in construction materials, focusing on wood-based products, bio-based materials, and carbonation in concrete. It discusses the benefits, challenges, and prospects of incorporating biogenic carbon storage into the construction industry. He also stated that Wood has significant potential for biogenic carbon storage due to its ability to sequester carbon dioxide during tree growth. Wood-based construction materials, such as cross-laminated timber (CLT) and engineered wood products, offer opportunities for carbon storage throughout their life cycle.

The research findings indicated that incorporating wood elements, such as structural timber and fresh-sawn timber, contributed to the structures' biogenic carbon storage and overall carbon neutrality. Additionally, the presence of surrounding trees such as Baldcypress and Cedar-Red further enhanced carbon sequestration and played a beneficial role in mitigating carbon emissions.

The implementation of the conventional inventory analysis technique that employs material as the calculation unit is not restricted when the One-click LCA software plugin in Revit is used. Therefore, using the One-Click LCA program to create inventories of the building components, it can quickly compute the embodied carbon emissions. Then, due to the multiplicity of building parts, the evaluation is sped up and made more straightforward by rapidly matching the model's building elements with those in the database of carbon emission factors. In addition to the case, other projects can also use the One-Click LCA method. Furthermore, this strategy concentrates on the design stage but can also be used at later stages of construction.

6. Conclusion

The study highlights the importance of integrating LCA and BIM to promote sustainable construction practices. Using the One-Click LCA plugin, the research on a case study focusing on the carbon emissions of steel and concrete frame public structures was taken.

The findings reveal that steel and concrete frames contribute significantly to carbon emissions in the embodied carbon emission phase. However, incorporating surrounding trees plays a vital role in achieving carbon neutrality by offsetting these emissions through carbon sequestration.

The study emphasizes the need to consider the environmental impact of construction materials and methods early in the detailed design process. It suggests that designers and stakeholders should prioritize sustainable alternatives, such as incorporating trees surrounding the structure and utilizing biogenic carbon storage materials, to reduce carbon emissions.

Furthermore, integrating BIM and LCA provides a valuable tool for assessing and optimizing the environmental performance of building structures. It allows for evaluating different design scenarios and identifying strategies to minimize carbon emissions and achieve carbon neutrality.

The One-Click LCA approach is recommended as it is consistent with design procedures and possesses high dependability properties, such as high precision and consistency, and high efficiency. It also has an easy-to-use interface and a feedback feature for designing carbon emission reductions that are highly sensitive. The recommended approach may be used to determine the embedded carbon emissions in detailed designs quickly, enhance building designs, and optimize the potential for buildings to save energy and cut carbon emissions.

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