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Embodied carbon emissions of buildings: Taking a step towards net zero buildings

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ABSTRACT

As global concerns about climate change and environmental sustainability escalate, the construction industry is shifting significantly towards eco-resilient and sustainable building practices. This paper comprehensively explores integrating Building Information Modelling (BIM) with eco-resilient principles to create a framework for designing and constructing sustainable buildings. This research introduced a practical approach for evaluating the embodied carbon from building construction, drawing insights from a residential building in Yangon City, Myanmar. The method developed in this study aims to assess the carbon footprints associated with distinct stages of the construction process, including raw material production and material transportation. Additionally, the proposed method compares the material embodied carbon, transportation embodied carbon, and total cost in the residential building, considering two cases of traditional and low-carbon materials. The results indicate that material embodied carbon contributes merely 84% to the overall, while material transportation makes up the remaining 16% for both cases. Utilising low-carbon materials yields remarkable reductions, with a 40% decrease in material embodied carbon and a 39% decrease in transportation carbon footprint compared to conventional materials. However, adopting low-carbon materials incurs a modest increase of approximately 6.7% in total cost. This study underscores the imperative of integrating low-carbon materials into the design of future passive buildings, advancing the pursuit of a net-zero strategy. This research underlines the potential for BIM-driven eco-resilient practices in mitigating carbon emissions and the need for continued innovation and collaboration in sustainable building design and construction.

1. Introduction

In recent decades, global warming has emerged as a significant challenge, and the primary driver of this phenomenon is greenhouse gases (GHGs) [1]. Among these gases, carbon dioxide (CO_2), primarily emitted through the combustion of fossil fuels like coal, oil, and natural gas, plays a crucial role in driving climate change [2]. The utilisation of renewable energy plays a pivotal role in reducing CO_2 emissions and concurrently brings about significant economic and socioeconomic advantages [3]. An increased incorporation of renewable energy will enhance the environment and lower the expenses associated with addressing environmental degradation

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challenges in urban areas [4].

The building construction industry stands as a significant player in energy consumption and CO_2 emissions on a global scale. The United Nations Environment Programme (2022) stated that building energy demand has experienced a notable rise of approximately 4% since 2020, reaching 135 exajoules (EJ), marking the most substantial increase observed in the past decade. Additionally, CO_2 emissions stemming from building operations have reached an unprecedented peak, with an increase of about 5% from 2020, surpassing the previous highest point recorded in 2019 by 2% [5].

As the economy expands and urbanisation progresses, there is a continuous rise in the number of residential buildings, leading to a notable influence on the associated carbon emissions. Comprehending the complete building process, such as extraction, manufacturing, transportation, construction, maintenance, and disposal, is crucial for mitigating CO_2 emissions. Buildings employ diverse materials that consume energy and emit CO_2 throughout their life cycle, collectively known as embodied energy and embodied carbon [6].

As a component of mitigation strategies, evaluating the embodied carbon of building materials stands out as a fundamental approach with the potential to significantly reduce carbon footprint. Opting for sustainable building materials can lead to approximately a 30% reduction in embodied CO_2 emissions over the lifespan of the building [7]. Strategies that involve substituting low-carbon materials, optimising material consumption, and emphasising locally sourced materials can positively contribute to carbon reduction. Implementing a cascaded strategy has been identified as potentially decreasing the average embodied carbon intensity by 28.8% [8].

Numerous tools and solutions have been introduced to decrease the emissions from buildings. Building Information Modelling (BIM) is a powerful tool with functionalities that enhance environmentally friendly and sustainable practices during eco-friendly structures' planning and construction stages. BIM offers numerous benefits, including disseminating sustainable knowledge among stakeholders, policymakers, and project managers and fostering the development of successful and high-quality green buildings [9]. Stojanovska-Georgievska et al.(2022) stated that transitioning to BIM as an innovative technology and methodology for managing construction across all stages necessitates a strategic plan [10]. Adopting digitalisation is essential for enhancing productivity in the building sector and introducing innovations to support infrastructure and urban development [10]. Nizam et al. (2018) stated that the BIM approach can create a decision-support system in the early design phase. This system encompasses crucial decisions such as selecting building materials, spatial configuration, construction methods, and building service systems [11]. Using BIM-based design, carbon emissions can be assessed before the construction phase commences. This approach enables pre-control low-carbon design and effective carbon management [12].

These technological innovations provide substantial options for emission reduction in design and planning with low costs. The early stages of design have proven to be particularly effective for implementing changes that yield significant results [13]. Additionally, it is widely recognised that decisions made during the initial stages of the design process considerably impact the performance and cost-effectiveness of buildings [14]. Due to its strategic approaches to managing construction projects and reducing carbon emissions, BIM plays a pivotal role in sustainable building practices; it becomes evident that innovative solutions like BIM are essential in addressing global challenges such as climate change.

Myanmar, a Southeast Asian country, faces the risks of unsustainable resource use and carbon emissions, primarily by constructing new infrastructure to accommodate an increased urban population. Despite being a developing country, Myanmar lags in adopting advanced technologies for green building practices, with the government not enforcing the use of BIM in the construction industry. This gap is exacerbated by a need for more experience and expertise in conducting comprehensive analyses of sustainable building practices in Myanmar. As per the Myanmar Climate Change Strategy (2018–2030), the planning approach for Myanmar should ensure that "residents in all townships and cities, especially those most at risk, are protected from heightened threats of both sudden and gradual natural disasters, and inhabit towns that are sustainable, inclusive, low-carbon, and resilient to climate impacts" as a specific sectoral objective [15]. This strategy could be implemented by addressing the reduction of carbon emissions associated with construction materials and processes so the stakeholders in the construction industry can make more informed decisions to mitigate their environmental carbon footprint and contribute to the country's sustainable development goals.

Understanding and quantifying the embodied emissions associated with the extraction, manufacturing, transportation, and construction of building materials are crucial steps towards achieving the ambitious goal of Net Zero Buildings, where the total carbon emissions associated with a building's lifecycle are minimised. The transition towards Net Zero Buildings requires dramatically changing how we conceptualise and approach building design, construction, and materials procurement. Consequently, there is a critical need for research focused on incorporating eco-friendly and sustainable building designs that emphasise carbon reduction, aiming to promote the integration of BIM technology and the utilisation of low-carbon materials in Myanmar.

This study aims to contribute to the existing body of knowledge on sustainable building practices by providing insights into the embodied carbon emissions of buildings in Myanmar. Ultimately, this research endeavours to bring a positive change within the construction sector, to leverage the advantages of the Building Information Modelling revolution, driving Myanmar towards a more sustainable and resilient built environment for future generations.

2. Literature review

2.1. Embodied carbon of the building

The literature shows that several researchers from various countries focused on embodied carbon emissions to achieve net zero from the construction industry. Different approaches, such as practical measurements, mass balance methodology [8], process-based analysis, and input-output analysis, are commonly utilised to gauge and assess carbon emissions [16].

The importance of structural forms and materials was identified in various studies of the embodied carbon assessment for buildings; on the other hand, research on reducing building embodied carbon has been concentrated on applying low-carbon materials and building design optimisation [17–19]. Akbarnezhad and Xiao (2017) stated that the relative influence of embodied carbon and operating carbon on the total life cycle carbon of buildings can vary considerably depending on the building's type, purpose, and elements like location, climate, fuel type, building orientation, and architectural aesthetics [20]. Su et al. (2020), Uddin et al. (2021), and Zhang et al. (2023) performed a Life Cycle Assessment for the selected case studies to identify carbon reduction by changing the type of construction materials [8], [21], [22]. Robati et al. (2021), Petrović, Eriksson, and Zhang (2023) and Robati and Oldfield (2022) investigated the reduction in embodied carbon due to the types of buildings such as timber, steel, wood, and concrete. They found that timber buildings can reduce carbon emissions more than concrete buildings [23–25].

Chen et al. (2022) examined the yearly cumulative energy and carbon emissions associated with China's ten most extensively utilised building materials. The findings revealed that cement, steel, and brick collectively contribute to over 70% of the energy and carbon footprint of the building materials. Zhang, Liu and Zhang (2020) investigated the carbon emissions and associated uncertainty of two high-rise residential buildings using different methods and identified that the operational phase was the larger contributor of the total embodied carbon [26]. Other researchers compared the embodied carbon in residential buildings that employed diverse structural forms and indicated that reinforced concrete structures were characterised by a higher carbon intensity than alternative structural forms [27].

Changing the building layout and compactness aids in the reduction of carbon footprints, and research is done to prove those points. Gan et al. (2019) introduced a comprehensive approach utilising simulation-based optimisation to optimise buildings' architectural layout and structural form designs to minimise operational and embodied carbon emissions [28]. Gauch et al. (2023) discovered that enhancing building compactness, opting for steel or timber instead of concrete frames, reducing the window-to-wall ratio, selecting appropriate glazing, and implementing mechanical ventilation with heat recovery are crucial measures for reducing embodied emissions and operational energy [29].

The studies mentioned above have highlighted the significance of structural forms and materials when evaluating the embodied carbon of buildings. Consequently, initiatives to mitigate building embodied carbon have focused on utilising low-carbon materials and optimising building design [17,18]. Numerous studies have undertaken comparisons of embodied carbon emission, construction costs and energy consumption. The methodology used in the research and findings are listed in Table 1.

2.2. Building Information Modelling, BIM

Building Information Modelling (BIM) stands out as a powerful tool equipped with capabilities that enhance environmental and sustainable practices during green building design and construction phases. BIM offers various advantages, providing sustainable knowledge exchange among stakeholders, policymakers, and project managers, ultimately contributing to the successful creation of high-quality green buildings [9]. Lu et al. (2017) proposed a taxonomy outlining the relationship between BIM and green buildings based on project phases, green attributes and BIM attributes. They found that the applications of BIM throughout the entire project lifecycle, including design, construction, operation, and retrofitting processes, and various functions such as energy analysis, emissions tracking, ventilation analysis, and also support for green building assessments [37].

During the design phase, paper-based communication often poses a significant challenge, as it necessitates a substantial amount of time and money to generate essential assessment data for a proposed design. This data includes cost estimates, energy-use analysis, structural details, and other crucial information. In the early stages of design, BIM can aid designers in leveraging existing construction data sets to enhance the default configuration for overall building performance. This allows designers to make informed decisions based on relevant data, leading to improved building performance outcomes [22]. Martins et al. (2020) stated that employing the BIM methodology during the early design phases can foster the creation of more sustainable projects with enhanced constructability. This is

Table 1
Research and findings on embodied carbon emission, construction costs and energy consumption.

Reference	Location	Methodology	Significant finding
[8]	China	Cradle-to-site system boundary for a dataset comprising 403 buildings in China	28.8% reduction in the embodied carbon intensity in substituting low-carbon materials.
[24]	Sweden	Life cycle assessment (LCA) focusing on greenhouse gas (GHG) emissions and Life cycle cost (LCC)	- Significantly reduce greenhouse gas emissions by constructing an entire building with wood - Construction costs for Cross Laminated Timber (CLT) elements in the foundation are nearly double those of concrete.
[13]	Iran	-NSGA-II for the energy performance -Dynamo for embodied carbon and material costs estimation	An average decrease of 24.92% in carbon emissions.
[30]	China	Carbon Emission Factor Method and Cost Accounting (variety method) for the entire life cycle of bamboo building materials	Reducing 40.10% in carbon emissions and 35.31% in costs
[29]	United Kingdom	"Cradle-to-completion" boundaries, excluding maintenance and end-of-life impacts.	Decreasing both embodied emissions and operational energy by Enhancing building compactness, window-to-wall ratio, glazing, and incorporating mechanical ventilation
[31]	China	Remote sensing techniques and building material flow analysis	The materials product stage forms 62% of the total; the building use stage accounts for 24% of the total, and during the construction, demolition, and end-of-life stages, it accounts for 14% of the total embodied carbon.
[25]	Australia	Monte Carlo simulations for mid-rise mass timber (MT) and post-tensioned concrete (PT) buildings.	Mass timber buildings hold lower whole lifecycle embodied carbon emissions than concrete buildings.
[32]	China	Cradle-to-site boundary to compare two primary building structures	-Over 70% of the embodied energy and carbon are cement, steel, and brick There are no apparent differences between steel-concrete buildings and brick-concrete buildings.
[33]	China	Evaluated process-based and subproject-based emissions, along with the costs for reinforced concrete framed (CF), block masonry (BM), and prefabricated masonry (PM) structures.	- Lowest emissions and costs in BM - Highest emissions and costs in CF. - Slightly higher emissions from the PM structure than the BM structure
[34]	Sri Lanka	Life cycle inventory analysis for 20 office buildings in Sri Lanka.	- Substructure, the highest embodied carbon, in low- and medium-rise buildings, while the upper floors in high-rise buildings
[22]	India	BIM process, Revit 2019 and Cost analysis by EDGE tool for the early design phase	2–3 times higher embodied carbon footprint in traditional design than a non-traditional design
[23]	Australia	A Carbon Value Engineering (CO_2VE) framework for cost and embodied carbon	-8% reduction in embodied carbon and a 10% capital cost saving in post-tensioned concrete structure - Reduction of embodied carbon by 13%–26% and costs 5%.in timber structure
[21]	China	Life cycle analysis for a passive building and comparison with a traditional building	on the operational stage, 17.4% and 22.7% lower in passive building than traditional building
[35]	China	A process-based inventory analysis method is used.	The carbon emissions associated with the primary building materials used in residential construction vary significantly depending on the structural forms of the buildings.
[28]	Hong Kong	integrated simulation-based approach to optimise architectural layout and structural designs to minimise operational and embodied carbon.	Reducing 30% of the building's operational carbon and 20% of the embodied carbon from construction materials.
[36]	United Kingdom	to identify cost and carbon-critical elements of two office buildings using BOQ and Pareto Principle	More than 70% of the cost and embodied carbon are from substructure, frame and services whereas, stairs and ramps, internal doors and fittings, furnishings, and equipment, which were the least expensive.
[7]	Spain	Three terraced houses were compared with a building possessing similar characteristics but constructed conventionally.	Selecting construction materials with low environmental impact has resulted in a reduction of CO_2 emissions by 27.28%.

attributed to the increased collaboration among project stakeholders and the utilisation of software tools like Autodesk Revit, Navisworks, Green Building Studio, and Tally [38]. BIM and its related applications have provided opportunities to support green building practices such as acoustic analysis, carbon emissions tracking, construction and demolition waste management, lighting analysis, operational energy use optimisation, and water consumption management [39,40].

Guo et al. (2021) and Uddin et al.(2021) performed the green building evaluation using BIM and offered an efficient and adaptable approach for assessing and optimising the performance of green buildings. This capability can further develop sustainable and environmentally friendly construction practices [22,41].

2.3. Evaluation of embodied carbon using BIM

Vincent J L Gan *et al.* (2019) performed a BIM-based integrated design approach geared towards optimising both the architectural design and structural form of buildings to minimise both the embodied carbon associated with the construction phase and the operational carbon across the entire life cycle of the structure. They resulted in approximately 30% reduction in carbon emissions related to energy use during the operational phase of building, along with a 21% decrease in the carbon footprint associated with construction materials [42]. Uddin et al. (2021) used the BIM tool, Revit 2019, to access the embodied energy and carbon footprint for local construction materials and found that utilisation of local construction materials not only leads to a considerable reduction in energy consumption but also results in a significant decrease in embodied energy and carbon footprint [22]. Ji et al. (2021) evaluated the contrast in carbon emissions from different building materials using BIM models. They examined how the distribution of material carbon emissions varies across different structural types in buildings [43]. Cavaliere et al. (2018) provided an assessment based on BIM for embodied environmental impacts in various stages of the design process, and they used the impacts as a decision-making tool to reach more sustainable solutions [39].

Based on these literature reviews, the research on minimising the carbon footprints from construction materials will contribute to the sustainable development of Myanmar's construction industry. This study employs a standardised system boundary, methodology, and database to assess the embodied carbon of three-story buildings in Myanmar. The goal is to provide BIM-based models that are cost-effective and prioritised sustainability, thus introducing a new chapter for the newly constructed buildings in the country and holding value for developers and professionals in the industry and the occupants of the buildings.

3. Case Study

3.1. Functional unit and system boundary

de Simone Souza et al. (2021) stated that the functional unit is a crucial aspect in the life cycle assessment of a product or service. It describes the product or service being evaluated and is used to compare different products or services [44]. It helps to ensure accurate and meaningful comparisons during the life cycle assessment process [45]. When carrying out a life cycle emission assessment in architecture, the functional unit is usually defined as "one square meter" or "the total house"[46].

This research scope covered the entire building in the early design stage, from raw material production to material transportation stages. Focusing solely on the embodied carbon estimation in the production and transportation phases ensures a comprehensive understanding of the environmental impact of material extraction, manufacturing, and transportation processes, allowing for informed decision-making during the critical initial design stage.

For this study, "total house" is the functional unit adopted, and the system boundary encompasses the production and transportation phases of building materials. For the production phase, the quantities of all building materials were counted according to the architectural and structural models of Revit 2021. The embodied carbons of the materials due to the transportation phase were evaluated depending on the various transportation modes.

3.2. Estimation of total co_2 emission

The carbon emissions associated with buildings encompass direct emissions stemming from building energy consumption and indirect emissions, which involve the production of building materials, transportation of these materials, building construction and demolition, and other activities in non-construction processes [47].

This study considers the building construction process at the design stage. The carbon footprint of urban buildings is quantified by scrutinising two key components: the production of building materials and the transportation of these materials.

Wang et al. (2015) stated that the total emissions are derived by aggregating the values from each of these stages [1].

$$Q = Q_1 + Q_2 \tag{1}$$

Where, Q = the total amount of CO_2 emission from building construction; Q_1 = the amount of CO_2 emission from raw material production; Q_2 = the amount of CO_2 emission from material transportation. The units of Q, Q_1 and Q_2 are in kg.

3.2.1. CO_2 emission from raw material production

The CO_2 emissions originating from raw material production pertain to the carbon dioxide released during the extraction, processing, and manufacturing phases in mining and production facilities and other relevant production processes. The total CO_2 emissions from raw material production are a significant component of the embodied carbon footprint of a product or structure. The formula for quantifying CO_2 emissions from raw material production is outlined as follows:

$$Q_1 = \sum_{i=1}^{n} Q_{1i} = \sum_{i=1}^{n} (q_i \times u_i) \tag{2}$$

Q_1 = the total CO_2 emission from raw material production; Q_{1i} = the CO_2 emission from the production of material i, q_i = the coefficient of CO_2 emission from the production of material i, u_i = the quantity of material i, i = 1, 2, …, n, are the types of materials considered.The unit of Q_{1i} is kg, and the unit of u_i is kg. The emission factor q_i depends on the material type.

3.2.2. CO_2 emission from material transportation

Material transportation involves the transfer of materials from factories to construction sites through the use of vehicles. This phase uses various transportation modes such as trucks, ships, or trains. The distance travelled and the transportation methods employed significantly impact the overall carbon footprint. The calculation for CO_2 emissions from the transportation phase can be expressed as follows:

$$Q_2 = \sum_{i=1}^{n} Q_{2i} = \sum_{i=1}^{n} (u_i \times d_i \times c_i) \tag{3}$$

Where, Q_2 = the total amount of CO_2 emission from raw material transportation; Q_{2i} = the amount of CO_2 emission from the transportation of material i, u_i = the quantity of material i, d_i = the transport distance of material i, c_i = the coefficient of CO_2 emission for transferring material i. The unit of Q_{2i} is kg, and the unit of d_i is km.Emission factor c_i depends on the transportation method.

3.3. Research method

This research intends to assess the embodied carbon of a residential reinforced concrete building in Myanmar. Before evaluating the carbon footprint of a building during the materialisation stage, it is crucial to ascertain the quantity of building materials [48]. The outlined objective is conducted through four phases, explained as follows:

Phase 1: Incorporating the building information into a 3D model of the architectural and structural models based on the blueprints and taking off the total quantity of materials used in the proposed structure using Revit 2021 Software

Phase 2: Collecting data on both traditional and low-carbon materials within the local construction market

Phase 3: Evaluating the material embodied carbon, transportation embodied carbon and total embodied carbon on two options: traditional and low-carbon materials.

Phase 4: Estimating the total cost of the two options and comparing the results to decide on the most eco-resilient and sustainable building option

The flowchart of the methodology for this study is shown in Fig. 1.

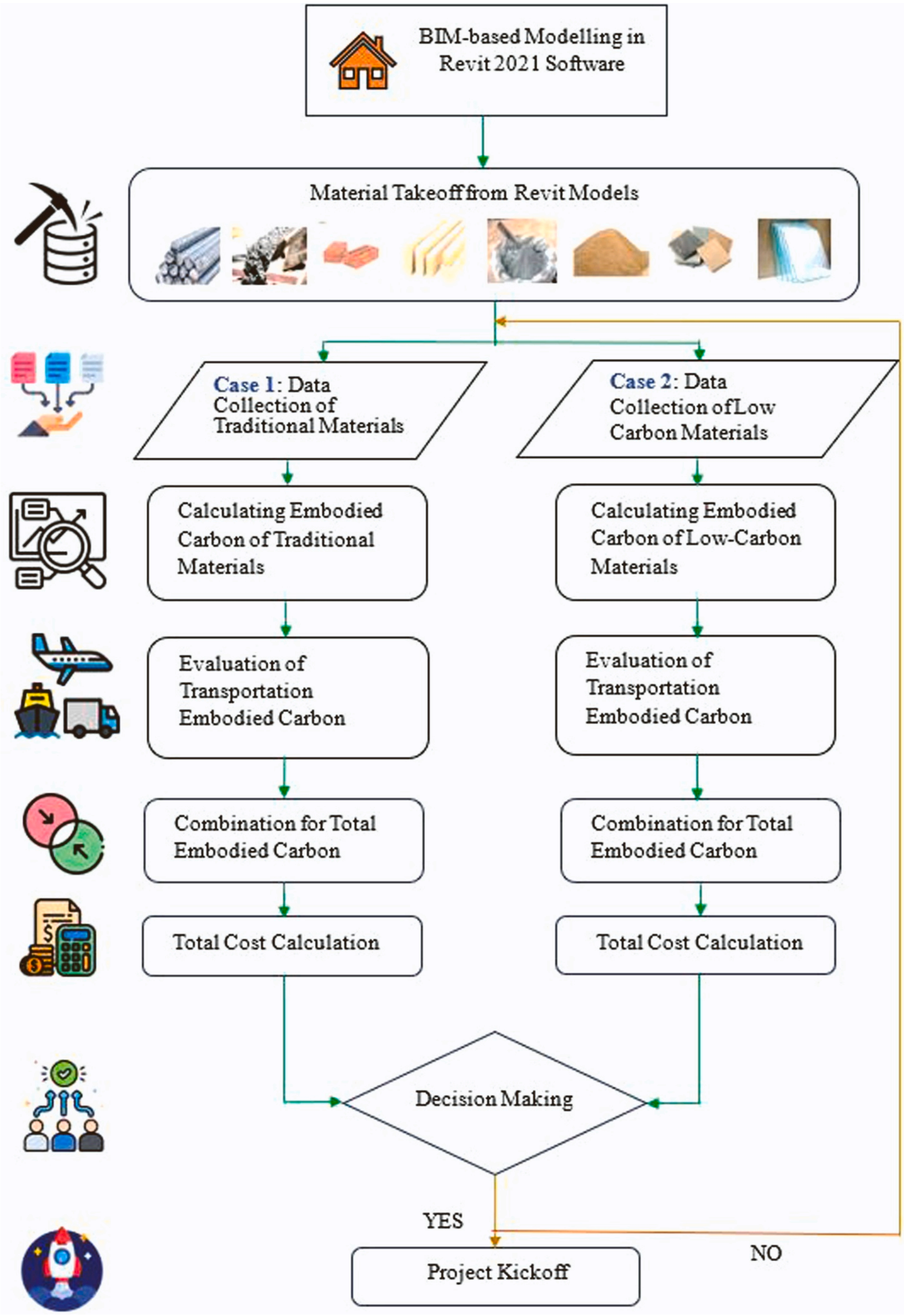


Fig. 1. A sustainable decision-making framework for the proposed buildings utilising Building Information Modelling (BIM).

Fig. 2. Location (a) Myanmar in Asia (b) Proposed Building in North Dagon Township Map Source: [49].

4. Case study

4.1. Description of the proposed building

The case study building is a three-storeyed residential building located at North Dagon Township of Yangon in Myanmar, as shown in Fig. 2. It is a reinforced concrete structure featuring three above-ground floors, and the gross floor area is 456 square meters. The architectural and structural plans from the Revit model are provided in Fig. 3.

4.2. Material take-off from Revit models

To determine the amount of building materials used, the BIM tool obtains the engineering quantity list to provide data for carbon footprint calculation [43]. The essential materials of the building, such as concrete, steel rebars, timber, brick, cement, sand, tiles and glass, are selected to compare the embodied carbon and the total construction cost. The quantities of the materials extracted from Revit 2021 models are shown in the following Table 2.

4.3. Carbon emission factors

Carbon emission factors are crucial in the carbon emission coefficient method, typically established through experiments. However, the values of these factors may vary depending on the specific goals and detection methods employed in different experiments [12]. Myanmar has no standard or guideline regarding carbon emission factors and embodied carbon calculation. Ding et al. (2020) also stated that in the absence of a regional database for carbon emission factors, one should apply the proximity principle when selecting data from nearby areas. Alternatively, the national database can be utilised as an alternative source of information [12]. Myanmar National Building Code states that before the national level standards and specifications are officially established, all building materials should conform to relevant references to the ASTM and IS [50].

Therefore, the emission factors and Global Warming Potential (GWP) for the materials are taken from the India Construction Materials Database, the EDGE green buildings certification platform, developed by the International Finance Corporation (IFC) to evaluate the embodied carbon of the building. Carbon emission factors for the construction materials is depicted in Table 3.

The transportation sector plays a crucial role in contributing to embodied carbon. George and Jacob (2018) assessed the embodied carbon of a building in India. Several key factors contribute to the transportation-related embodied carbon, such as modes of transportation, distance travelled, and type of energy used to power vehicles. The distance under consideration is round-trip, accounting for

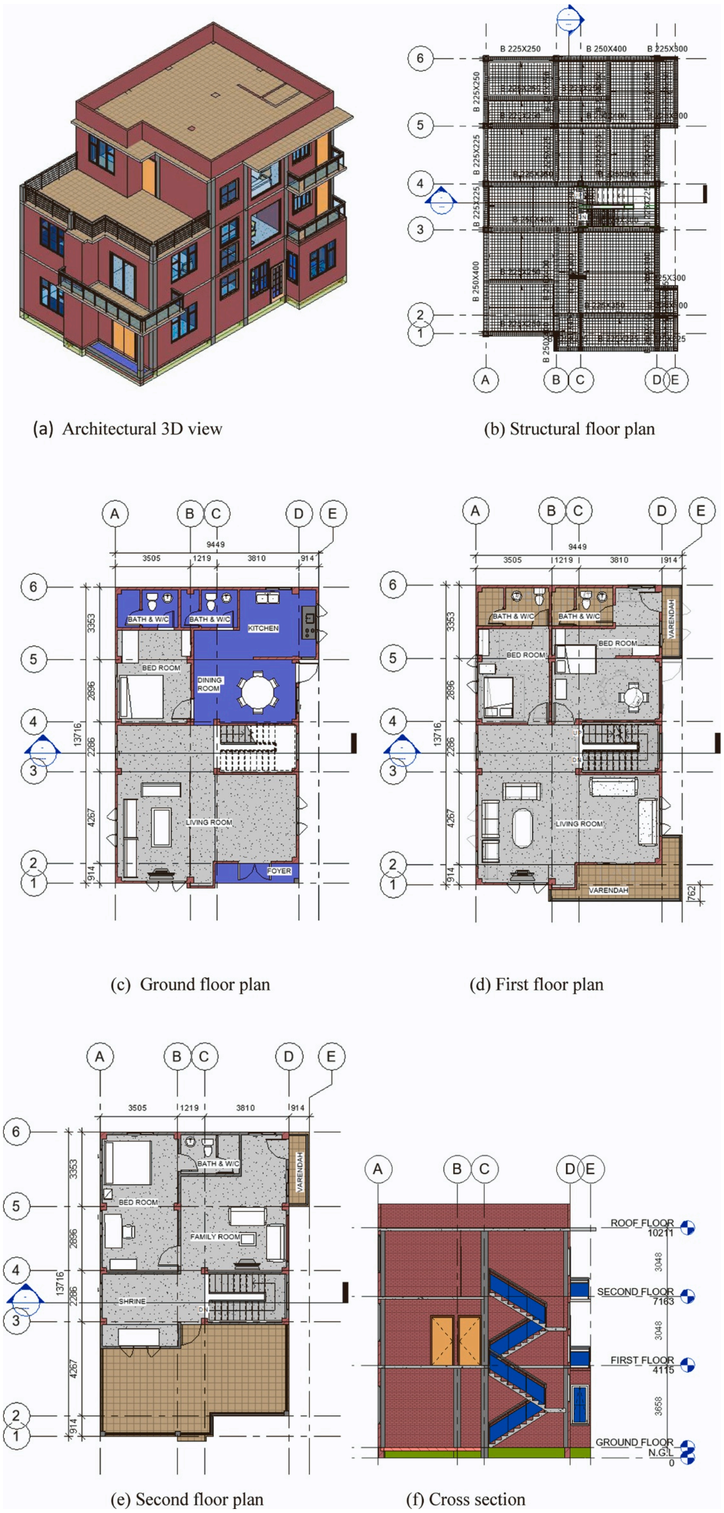


Fig. 3. Architectural and structural Revit models (all dimensions are in mm).

Table 2
Quantity of material take-off from Revit models.

Material type	Quantity	Unit
Steel 8 mm	39.1	m
10 mm	13882.68	m
12 mm	186.4	m
16 mm	4155.19	m
18 mm	965.54	m
Concrete	95.52	m^3
Timber: Doors and Window Frame	734	m
Door Panel and Flooring	623.59	m^2
Brick	113.18	m^3
Cement (For rendering and tiling)	32510.87	kg
Sand (For rendering and tiling)	46.03	m^3
Tiles	843.97	m^2
Glass	142.59	m^2

Table 3
Carbon emission factors from India Construction Materials Database [51].

Material type	GWP (kg CO_2 eq.)
Brick - Clamp kiln	0.57
Cement (ordinary Portland cement, OPC)	0.91
Cement-based terrazzo tile	0.51
Float glass	1.2
Kiln-dried timber	-0.43
Lightweight concrete block	0.37
Ready-mix concrete with ordinary Portland cement (OPC)	0.11
Sand	0.009
Steel reinforcement (steel rebar)	2.6
Timber window frame	2.4
Vinyl (PVC) flooring	2.1
Vitrified ceramic floor tiles	0.68
Wood laminate/multi-layer parquet flooring	2

the transportation from the manufacturing plant to the construction site and the return journey to the manufacturing plant [52]. The carbon emission coefficients for various modes of transport are in Table 4.

4.4. *Embodied carbon calculation*

In this study, the evaluation of the material embodied carbon, transportation embodied carbon, and total embodied carbon are conducted for two cases:

Case 1. Building using traditional materials

Case 2. Building using low-carbon materials.

4.4.1. *Material specification*

Most of the critical construction materials used in Myanmar are produced locally and are conveniently available in the construction market. Utilising locally available materials can reduce the amount of embodied carbon in transportation and can save costs. The specifications of the materials used for both cases are shown in Table 5.

4.4.2. *Transportation data*

The locally produced materials are transported by 10-wheel or 12-wheel trucks, and the transportation distances of all the materials

Table 4
Emission factor for transportation [52].

Mode of transport	Equivalent carbon emission per tonne-km (kg.CO_2eq/t km)
Truck (14 Wheel)	0.110
Truck (10 Wheel)	0.090
Freight train	0.035
Sea Freight	0.020

Table 5
Material specification data for Case 1 and Case 2.

Material type	Specification (Case 1)	Specification (Case 2)
Steel Rebar	HRB 400 (China)	HRB 400 (Local)
Concrete	Ready mix (Local)	Ready mix with fly ash (30% pozzolana) (Local)
Timber	Pyinkado and Teak (Local)	Pyinkado and Teak (Local)
Timber Flooring	Vinyl (Korea)	Woodblock (Local)
Brick	Brick - Clamp kiln (Local)	Lightweight concrete block (Local)
Cement	Ordinary Portland (Local)	Ordinary Portland (Local)
Sand	River (Local)	River (Local)
Tile	Ceramic floor tile (China)	Stone floor tile (Local)
Glass	Float glass (China)	Float glass (China)

are presented in the following Table 6.

4.5. Total cost estimation

Total Cost Estimation is a critical aspect of project management and financial planning, providing a comprehensive outlook on the anticipated expenses associated with a particular project or endeavour. In this study, total costs are estimated for both cases to compare the price of construction of the building using traditional materials and low-carbon materials. The cost estimations are evaluated based on the construction material market price at the Myanmar Builders Guide website.

5. Results

Case 1. Building using traditional material

The evaluation results of the embodied carbons for Case 1 are shown in Table 7. The material embodied carbon of brick is 106982 $kgCO_2eq$, the highest among all materials. The second most common material is steel rebar with 43843 $kgCO_2eq$, while sand occupies the least, and timbers' negative material embodied carbon suggests potential carbon sequestration. Brick stands out the most for transportation carbon footprints with 21732 $kgCO_2eq$, but glass contributes the lowest. The Total Embodied Carbon provides a holistic view, with brick having the highest total carbon footprint of 128714 $kgCO_2eq$.

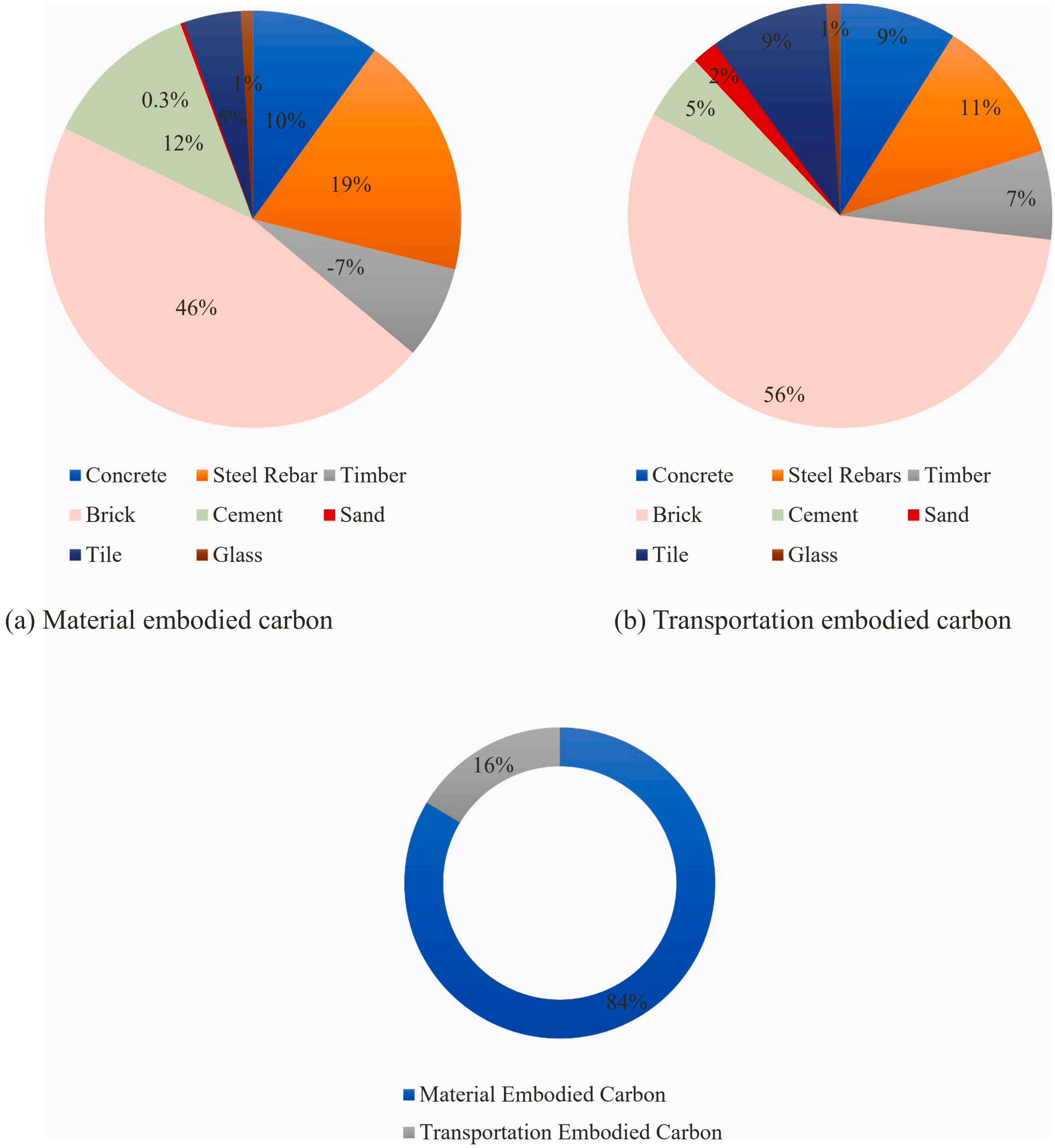
The proportions of each component in each embodied carbon emission for Case 1 are displayed in Fig. 4. Most of the material embodied carbon is contributed by brick at 46%, steel rebar stands second highest at 19%, and timber takes a small proportion of 0.3%. The result of the transportation embodied carbon shows that the brick contributes the most, with 56%, while the glass occupies only 1%. As the result of the % composition in total embodied carbon, materials contribute about 84%, and transportation takes place about

Table 6
Transportation Data for Case 1 and Case 2.

Material	Case 1			Case 2		
	Source location	Distance (km)	Transport type	Source location	Distance (km)	Transport type
Steel Rebar	China	1152	14wheel Truck	Local	22.4	14wheel Truck
Concrete	Local	14.4	10wheel Truck	Local	14.4	10wheel Truck
Timber	Local	208	10wheel Truck	Local	208	10wheel Truck
Timber Flooring	Korea	8360	Sea Freight	Local	208	10wheel Truck
	Local	9.6	10wheel Truck			
Brick	Local	72	10wheel Truck	Local	72	10wheel Truck
Cement	Local	528	14wheel Truck	Local	528	14wheel Truck
Sand	Local	16	10wheel Truck	Local	16	10wheel Truck
Tile	China	1152	14wheel Truck	Local	480	10wheel Truck
Glass	China	1152	10wheel Truck	China	1152	10wheel Truck

Table 7
Embodied Carbons Results for Case 1.

	Material embodied carbon [$kgCO_2$ eq]	Transportation embodied carbon [$kgCO_2$ eq]	Total embodied carbon [$kgCO_2$ eq]
Concrete	23115.84	3470.34	26586.18
Steel Rebars	43842.72	4300.36	48143.08
Timber	-16691.52	2629.27	-14062.25
Brick	106981.25	21731.93	128713.18
Cement	28252.22	1987.81	30240.03
Sand	618.05	750.28	1368.33
Tiles	10330.19	3486.77	13816.96
Glass	2130.00	407.40	2537.40
Total	198578.76	38764.16	237342.92



(a) Material embodied carbon

(b) Transportation embodied carbon

(c) Total embodied carbon

Fig. 4. Percent composition of materials in embodied carbon for Case 1.

Table 8
Embodied carbons results for Case 2.

	Material embodied carbon [kgCO_2 eq]	Transportation embodied carbon [kgCO_2 eq]	Total embodied carbon [kgCO_2 eq]
Concrete	17652.10	2817.39	20469.49
Steel Rebar	43842.72	83.62	43926.34
Timber	-15811	2528.52	-13282.26
Brick	43028	13515.67	56544.07
Cement	28252.22	1987.81	30240.03
Sand	618.05	750.28	1368.33
Tile	850.72	1452.82	2303.54
Glass	2130.00	407.40	2537.40
Total	120563.43	23543.51	144106.94

16% of the total.

Case 2. Building using low-carbon material

To reduce the amount of embodied carbon used in this residential building, selecting low-carbon materials and transportation methods is crucial because they significantly affect carbon emission potential [21]. Also, the availability of those materials, the type of the vehicles, and transport distance in marine, motorway and airway transportation methods should be considered. In this research, most of the low-carbon materials selected are local products; thus, the embodied carbon of each material is significantly reduced.

Based on material embodied carbon results, steel rebars and bricks have nearly equal amounts of material embodied carbon, with 43843 kgCO_2eq and 43028 kgCO_2eq, respectively, being the highest. In comparison, sand has the lowest carbon emission of 618 kgCO_2eq. In the findings of transportation embodied carbon, brick stands out the most, with 13516 kgCO_2eq, whereas steel rebar has the lowest carbon emission. Therefore, brick has the greatest total embodied carbon, and sand has the least carbon footprint Table 8.

The contribution of the materials for building using low-carbon materials is shown in the following figure. Steel rebar and brick are dominant contributors to material carbon footprint with portions of 29% and 28%, respectively, whereas sand distributes only 0.5%, showing a minimum among all materials. Brick also stands out as the highest in transportation-embodied carbon, making up around 57%, as shown in Fig. 5. Steel rebar has the lowest transportation carbon footprint, although it accounts for the most in material carbon footprint. Steel contributes a comparatively smaller amount at just 0.3% of the overall, the minimum due to a reduction in transportation by replacing local products. For the result of the % composition in total embodied carbon, despite the significant reduction in the total amount, the proportion of contribution is the same as using traditional materials, with 84% and 16% contributions to materials and transportation, respectively.

5.1. Comparison of the two cases

According to the results of the embodied carbon for the two cases, the results are discussed and compared to identify the sustainability of the building.

5.1.1. Comparison of material embodied carbon

Low-carbon materials generally exhibit reduced embodied carbon compared to traditional materials across the various construction elements. Brick shows a significantly reduced amount of more than 50% in Case 2. Despite having a negative value for Traditional material, timber contributes lower embodied carbon in the low-carbon materials scenario. The notable reductions in material embodied carbon are observed for concrete and tiles. The comparison emphasises the potential environmental benefits of adopting low-carbon materials in construction practices, as shown in Fig. 6.

5.1.2. Comparison of transportation embodied carbon

Due to replacement with locally available materials, significant reductions in transportation embodied carbon are observed in concrete, steel rebar, brick, and tile. However, steel rebar sharply decreases from 4300 kgCO_2eq to 84kgCO_2eq, a 98% reduction in embodied carbon (Fig. 7). The percentage of reducing carbon emissions depicts about 19%, 38%, and 58% for concrete, brick, and tile, respectively. Transportation embodied carbon remains the same for cement, sand and glass in both cases. Timber shows a slight increase due to the change in material volume. The comparison highlights the potential for substantial reductions in carbon emissions

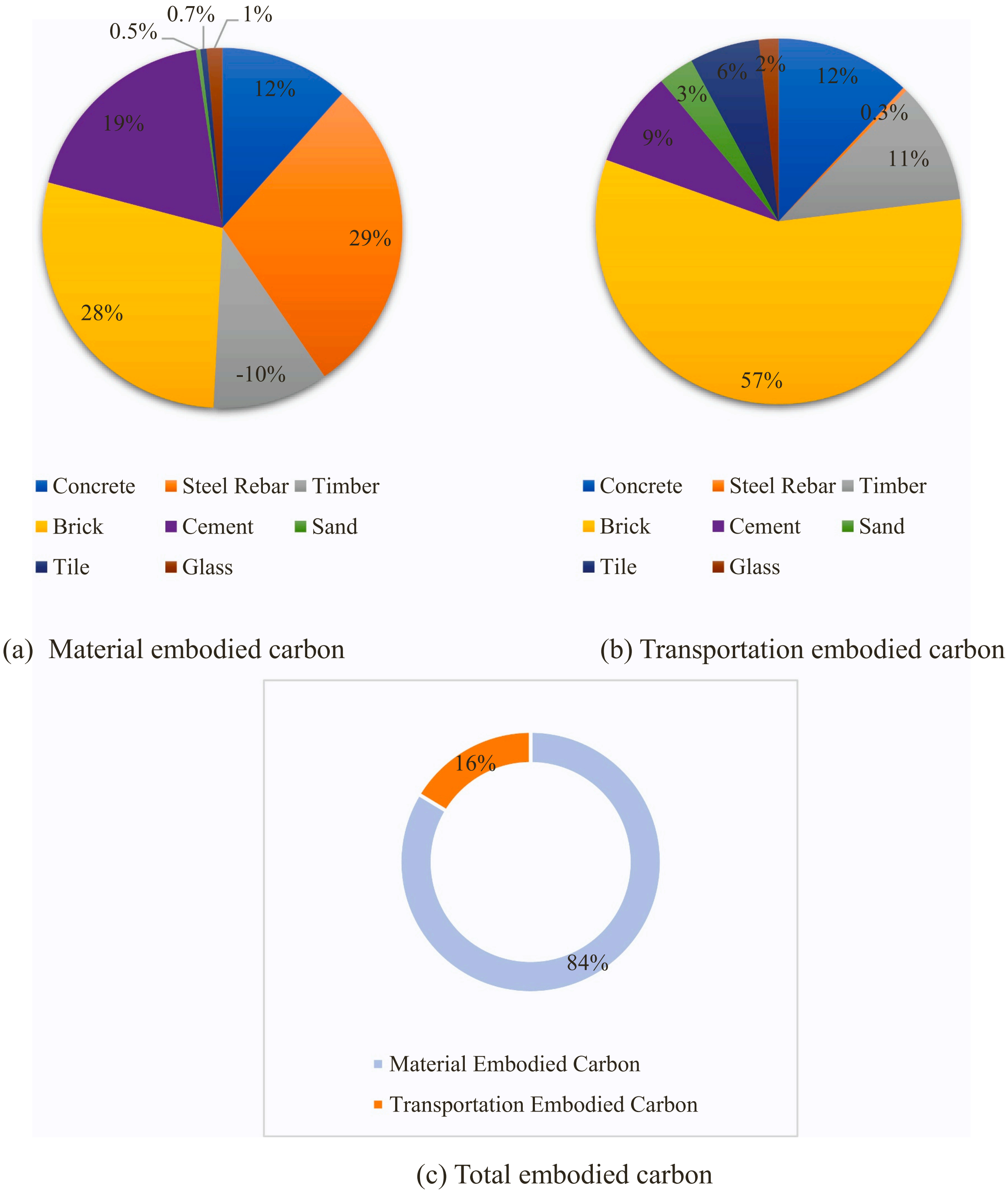


Fig. 5. Percent composition of materials in embodied carbon for Case 2.

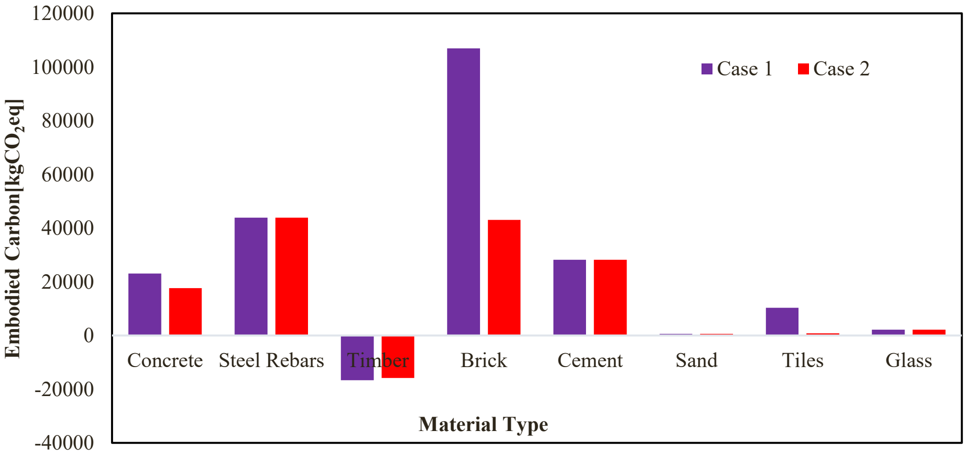


Fig. 6. Comparison of material embodied carbon.

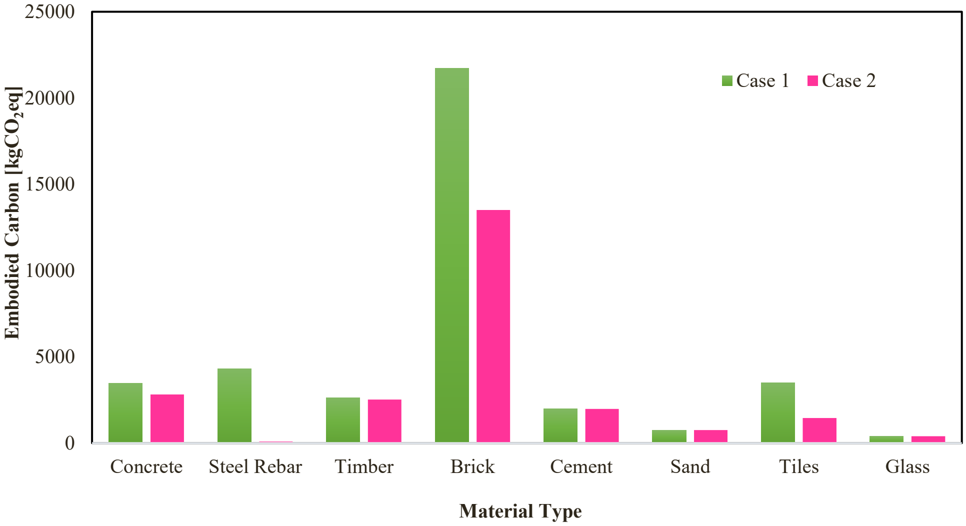


Fig. 7. Comparison of transportation embodied carbon [$kgCO_2eq$].

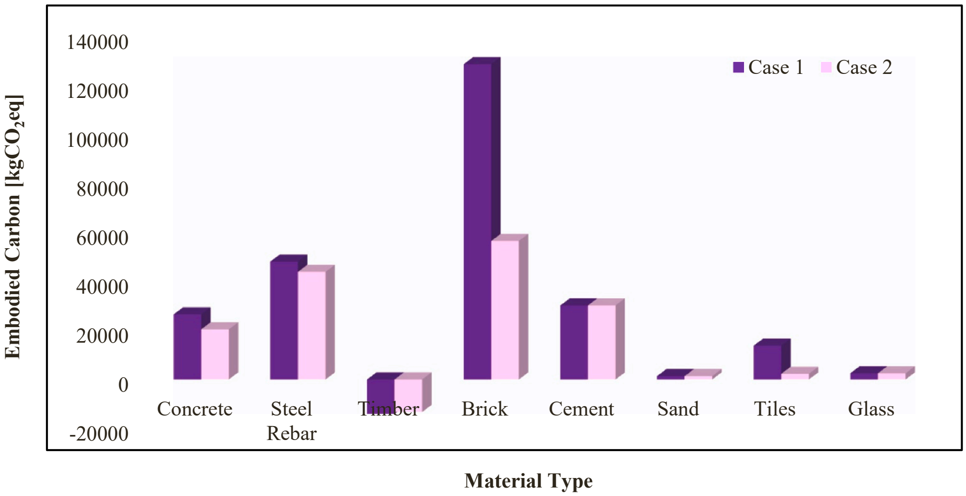


Fig. 8. Comparison of total embodied carbon in material composition [$kgCO_2eq$].

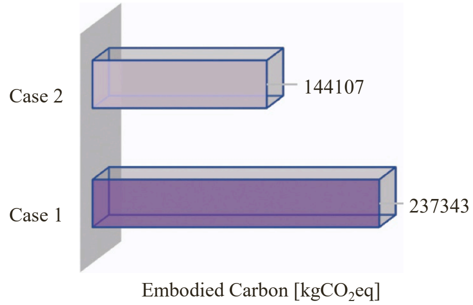


Fig. 9. Comparison of total embodied carbon.

Table 9
Total cost estimation.

Material type	Cost in USD (Case 1)	Cost in USD (Case 2)
Concrete	5454	9988
Steel Rebar	49167	43254
Timber	10298	18172
Brick	4264	5129
Cement	3063	3063
Sand	232	232
Tiles	10277	8643
Glass	2378	2378
Total	85134	90860

associated with transportation when using low-carbon or locally available material, contributing to more sustainable construction practices. Additionally, the benefits will be most significant if low-carbon material is locally available.

5.1.3. Comparison of total embodied carbon

The total embodied carbon of each material is significantly reduced for Case 2 compared to Case 1. A significant reduction in brick and tile indicates more sustainable practices in the early design stage, sharply decreasing 56% and 83% of the embodied carbon using low-carbon materials rather than traditional ones. There are slight reductions in total embodied carbon for low-carbon materials in concrete and steel rebar, but the decrease percentages are 23% and 9%, respectively. Cement, sand and glass exhibit consistent values, implying no material replacement between the two cases, as shown in Fig. 8. Timber results in a marginal decrease in total embodied carbon for Case 2, showing slight effects on reducing carbon even though the local material is used. The comparison underscores the potential for significant overall reductions in carbon emissions through using low-carbon materials in construction, contributing to a more environmentally sustainable approach.

In comparing the total amount of embodied carbon in both cases, using traditional materials in construction takes up the carbon of 237343 kgCO$_2$eq and using low carbon materials distributes the carbon amount in 144107 kgCO$_2$eq, showing 39% less than Case 1, so this effect benefits the most in developing the sustainable building as shown in Fig. 9.

5.2. Comparison of the total cost

The total costs of the studied building for the two proposed cases are estimated, and the costs for each material are presented in the following table. Based on the total cost comparison, using low-carbon materials is essential to spend more; however, in this study, there is only a 6.7% increase in the total cost for developing low-environmental impact buildings. The total cost for low-carbon materials is higher than traditional materials, indicating that implementing low-carbon practices may initially involve higher upfront costs; however, the environmental impact due to carbon emission is significantly reduced Table 9.

6. Discussion

This study develops and demonstrates a BIM-based method for evaluating embodied carbon and cost estimation for the case study of a residential building in Myanmar. Two cases, such as using traditional and low-carbon materials, are investigated, and then the results are compared to identify the benefits of sustainable building design. This research provides a way to make a preliminary determination of the most cost-effective sustainable designs within a low carbon emission regime in the early stages of building design.

Among the eight materials selected to evaluate the embodied carbon (EC) for two cases, brick is the highest in material and transportation embodied carbons. After brick, steel rebars have the second highest EC and concrete and cement have higher EC than others. To validate the research findings, the relevant literature on carbon emissions from traditional building structures is referenced for comparison. This performance was better compared with that of the previous study. Cang et al. (2020) investigated the estimation of embodied carbon emission in residential buildings and found that materials such as bricks and building blocks, steel and commercial concrete have high carbon emissions for brick concrete buildings [35]. Cang et al. (2020), Andersson et al. (2018) and Kumanayake and Luo (2018) concluded that approximately 80% of the environmental impact is collectively attributed to steel, concrete, cement mortar, and masonry materials [35,53,54]. This study shows that the composition of EC for concrete, steel rebar, cement, and brick is 87% of the total value.

When all other building requirements are fulfilled, selecting an economical and rational low-carbon building structure becomes imperative in reducing carbon emissions. For Case 2 of this study, reducing total embodied carbon (TEC) is investigated in two ways: replacing concrete, timber, brick, and tile with low-carbon materials and substituting steel rebar with locally available materials instead of imported products. For the floor tile, the result shows an 83% reduction due to replacing imported traditional material with low-carbon material, which is also a local product, so reducing embodied carbon is the highest among all materials due to both low-carbon and local product effects. Using lightweight concrete blocks can decrease carbon emissions by 56% compared to brick, and other replacing materials such as concrete and timber depict the depletion of the total embodied carbon in the proportions of 23% and 5.5%, respectively. The TEC of steel rebar reduces by about 9% since it is replaced with local products, and the low carbon effect is not considered; thus, only transportation EC is changed. Despite having a negative value for traditional material, timber demonstrates its capacity to contribute positively to carbon sequestration efforts in the low-carbon materials scenario, and these emissions contribute to climate change.

Based on the results, it can be identified that using local products with low-carbon materials can significantly reduce the carbon footprint of the building. According to the comparison of the two cases, Case 2, using low-carbon materials for the proposed residential building in Myanmar, can reduce 39% of the total embodied carbon compared to Case 1, using traditional materials.

Comparing the study results with other research, George and Jacob (2018) implemented reduction strategies in various materials for a building in India during the design phase of the building, which resulted in a 13% decrease in the initial embodied carbon emissions [52]. Cang et al. (2020) found that using low-carbon materials significantly reduces embodied carbon compared to local products. When all other building requirements are fulfilled, selecting an economical and rational low-carbon building structure becomes imperative in reducing carbon emissions [35]. Petrović, Eriksson, and Zhang (2023) investigated the carbon accounting of a wooden single-family house and stated that wooden products exhibit negative emissions stored throughout their service life. Moreover, these products offer advantages beyond their end-of-life, especially when considering their second life. The biogenic carbon stored in wooden materials can notably diminish embodied carbon [24]. Hence, the results are relevant to the previous literature on embodied carbon evaluation.

The study contributes that assessing the embodied carbon during the initial design phase proves instrumental in minimising both the embodied carbon footprint and overall project costs. This is achieved through strategic adjustments and the judicious selection of construction materials. Uddin et al. (2021) conducted a BIM-based green building analysis for a two-storeyed house in India and stated that considering the sustainable design during the initial design stage will be beneficial as project teams can identify and link various sustainable factors without requiring extensive financial resources, time, and other assets [22]. Cang et al. (2020) and Nikolić Topalović et al. (2018) found that accurately quantifying and predicting embodied carbon emissions (ECEs) during the schematic design phase is an effective strategy for mitigating and reducing ECEs directly from their origin [35,55].

This study is based on the application of the BIM tool, REVIT 2021, to identify the quantity of materials by changing the input of the various locally accessible construction materials. This approach aims to streamline the evaluation of alternative design options customised to the specific context's unique characteristics. However, Fonseca Arenas and Shafique (2023) investigated numerous constraints arising from the absence of comprehensive green applications within BIM software. Consequently, it becomes imperative to establish precise outcomes that can serve as effective benchmarks. These results are crucial for guiding interested parties in making informed decisions about incorporating these technologies, investing resources, and drawing valuable insights for future projects utilising (BIM) tools [9]. Establishing practices for integrating, organising, and automating a sustainable construction environment within the BIM framework is crucial.

Regarding the total cost in this study, the building using low-carbon materials increases slightly by about 6.7% than using traditional materials. In contrast, Xu et al. (2023) found a noticeable decrease in carbon emissions by 40.10% and a reduction in costs by 35.31%, underscoring the apparent effectiveness of the optimisation strategy [30]. Decision-making in construction projects should consider material selection and transportation methods to minimise environmental impact [56,57]. It's crucial to consider the long-term environmental benefits and potential cost savings associated with low-carbon practices when evaluating the overall value of such materials. Therefore, it's essential to prioritise and allocate resources to aspects that have a more significant influence on overall carbon emissions and sustainability goals [58,59]. Identifying elements that can be disregarded in the decision-making process during the early stages of design is crucial, especially when their contribution to total Embodied Carbon and the cost is nearly negligible [36].

The approaches for diminishing CO_2 emissions in the construction industry involve implementing regulations and policies, assessing environmental impacts, embracing low-carbon technologies, and limiting energy consumption [6]. Policymakers play a pivotal role in advancing the adoption of BIM technology within the Architecture, Engineering, and Construction (AEC) industry. They should actively endorse and facilitate the utilisation of BIM technology, ensuring its widespread integration. Moreover, policymakers are encouraged to mandate the development of sustainable building designs, emphasising effective strategies for environmental responsibility. Promoting and enforcing these practices can contribute significantly to fostering environmentally conscious and sustainable approaches within the AEC sector.

7. Conclusion

This study presents a comprehensive examination of embodied carbon evaluation and cost estimation using Building Information Modelling (BIM) for sustainable building practices, focusing on a residential building case study in Myanmar. By investigating two scenarios - one utilising traditional materials and the other employing low-carbon alternatives, significant insights have been gained into the potential benefits of sustainable design in reducing environmental impact and overall project costs.

The findings reveal that adopting low-carbon materials and strategic optimisation strategies can substantially reduce embodied carbon emissions. Specifically, implementing the optimisation strategy resulted in a remarkable 39% decrease in carbon emissions. However, the project expenses increase slightly by 6.7%, highlighting the tangible impact of adopting sustainable practices. The increase in capital cost could be negligence compared to the reduction in carbon emission; thus, using low-carbon materials in the construction industry dramatically benefits from developing net zero buildings.

Moreover, comparisons with existing literature and previous studies underscore the relevance and significance of this research in the broader context of sustainable construction practices. By leveraging BIM technology and integrating eco-friendly design principles, stakeholders in the construction industry can make informed decisions that prioritise environmental responsibility while simultaneously achieving cost-efficiency.

Moving forward to the net zero buildings, the following are recommended:

- The embodied carbon assessment should be conducted during the initial design phase to minimise the embodied carbon footprint and overall project costs.
- In selecting construction materials, the priority should be on the locally available low-carbon products to reduce the effects of material and transportation embodied carbon.

For future studies,

- The life cycle assessment of the building should be investigated for timber, steel and concrete structures since this study only focuses on the design stage.
- Brick stands out as the highest embodied carbon among the materials in this study, and further research on changing the walling system should be conducted.
- The embodied carbon evaluation of the existing building should be studied to find ways to reduce carbon emissions.

Policymakers, industry professionals, and researchers must continue advocating for the widespread adoption of BIM technology and sustainable building practices. We can pave the way towards a more resilient, environmentally conscious built environment by concerted efforts to promote regulatory frameworks, facilitate knowledge exchange, and incentivise sustainable development.

This study contributes to the ongoing discourse surrounding sustainable construction, offering practical insights and recommendations for advancing towards a greener, more sustainable future in the construction industry in Myanmar and globally.

CRediT authorship contribution statement

Muhammad Shafique: Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Nwe Ni Myint:** Writing – original draft, Visualization, Validation, Software, Resources, Investigation, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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