



Lifecycle Carbon Footprint and Economic Feasibility of Net-Zero Buildings: A Multi-Dimensional BIM–Excel Framework for Sustainable Material Selection in Tropical Climates of Patna, India

Abstract: The building sector is a major contributor to global greenhouse gas emissions while rising focus on embodied carbon appears after net-zero buildings reach their energy needs. The research presents a framework that combines Building Information Modelling (BIM) with Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) and climate-responsive analysis to help choose materials for sustainable tropical ecosystem design. The framework uses BIM-based quantity extraction together with an Excel database that contains emission factors and cost parameters and climate performance indicators to support decision-making during the initial project stages. The framework proved effective through a residential case study which took place in Patna. The study shows that selecting the best materials can decrease embodied carbon between 30 and 35 percent which results in total emissions reduction from 400 to 420 kgCO₂e/m² down to 270 to 290 kgCO₂e/m². The study found that structural components made up almost 50 percent of all lifecycle emissions followed by wall systems as the second largest source. Sustainable construction materials increase first building expenses by 10 to 15 percent but lifecycle cost analysis shows total savings of 8 to 10 percent with a 5 to 8 year payback duration because operational energy expenses decrease. The climate performance index system enables architects to select materials which function best in hot-humid conditions, resulting in thermal efficiency improvements and cooling load reductions that reach 25 to 35 percent. The development of a multi-objective optimization model continues as it establishes a framework which designers and policymakers can use to assess three factors: carbon emissions and costs and climate performance. The proposed BIM–Excel framework offers a practical, scalable, and low-cost solution for sustainable building design, particularly in developing regions. The study advances net-zero building strategies while establishing policies for low-carbon construction in tropical climates through its environmental, economic, and climatic research dimensions.

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1. Introduction

The construction sector has experienced rapid expansion which has created serious environmental problems through increased energy usage and greenhouse gas emissions. The building sector accounts for nearly 40% of global carbon emissions which results from both operational energy use and the embodied carbon in construction materials. The concept of net-zero energy buildings (NZEBS) has become more popular because people want to



create sustainable solutions which will help them address climate change problems.([Fernandez et al. 2024](#))

Building performance assessments used to focus only on operational energy but recent studies show that organizations need to assess embodied carbon because operational emissions will decline through energy-efficient technologies. The manufacturing processes of cement and steel and concrete create substantial embodied emissions because these materials require high energy consumption during production. Net-zero targets need to include all lifecycle impacts which need to be evaluated through both operational and embodied emissions assessment.([Fernandez et al. 2024](#); [Baral et al. 2026](#))

Building Information Modelling (BIM) functions as a digital system that enables architects and engineers and construction workers to create precise digital models of building elements which they use to make decisions based on collected data. The Building Information Modeling system enables users to extract material quantities which they can connect to environmental databases thus making it an effective tool for conducting lifecycle assessments. The existing BIM-based LCA methods do not connect with economic assessments while they lack the ability to evaluate climate performance in tropical environments.([Lloyd-Jones et al. 2026](#))

The Patna tropical climate presents distinct challenges which include high temperatures and increased humidity levels and high demands for cooling systems. These conditions result in increased energy usage for operations, and they also impact the strength and functionality of materials. The material selection process in these areas needs to evaluate both the environmental effects and the materials ability to adapt to local climate conditions. Current research offers only a few

frameworks which combine lifecycle carbon assessment with economic viability evaluation and climate adaptability assessment into one cohesive system.

The Building Information Modeling-based Life Cycle Assessment framework proved its usefulness for sustainable building assessment through recent research studies which included the reference paper used in this work. These methods primarily assess environmental performance, but they lack complete integration of lifecycle costing and climate optimization processes. A more complete framework which contains multiple dimensions needs to exist to assist decision-making processes during the initial design phase.([Lloyd-Jones et al. 2026](#); [Ghaffari et al. 2026](#))

This research develops an integrated BIM-Excel framework which links carbon lifecycle evaluation with cost lifecycle evaluation and environmental assessment for choosing sustainable materials in tropical regions. The framework provides practical implementation through its scalable design which enables usage in actual projects throughout developing areas.

1.1 Research Objectives

1. The primary objective of this study is to develop and validate a multi-dimensional framework for evaluating the lifecycle sustainability of buildings using BIM and Excel integration. The specific objectives are as follows:
2. The study aims to measure the building component carbon emissions through standardized assessment methods which determine the lifecycle carbon footprint.
3. The study examines the total lifecycle costs of different material options through an analysis of their initial costs, maintenance expenses,



replacement costs and operational expenditures.

4. The research framework will be tested through a residential building case study in Patna which will evaluate results against established benchmarks.

2. Literature Review

The growing need to reduce climate change impacts has resulted in multiple studies which explore sustainable building design methods which seek to decrease carbon emissions from constructed spaces. The construction industry exists as a major source of global greenhouse gas emissions because it emits both operational carbon and embedded carbon throughout its processes. Research has shifted from its initial focus on operational energy use to show that embodied carbon becomes more vital as building energy efficiency increases. The building industry uses Lifecycle Assessment (LCA) as its primary method to measure environmental effects which building structures create. EN 15978 standards present an organized method for organizations to evaluate emissions throughout all phases of their product lifecycle starting from material creation to building installation and building operation until final product disposal. Multiple research studies utilized LCA methods to assess how different environmental factors impact both residential and commercial building systems which resulted in embodied carbon values that usually fell within the range of 300 to 500 kgCO₂e/m² based on building design and material choices. The research reference study showed that structural systems which include slabs and reinforced concrete elements produce most of their emissions through these components which account for more than 50% of total embodied carbon emissions.(Megiso et al. 2026)

Building Information Modelling (BIM) has found application in Life Cycle Assessment

(LCA) because it automates the extraction of material quantities while connecting with environmental databases which leads to better assessment outcomes. Researchers have increasingly explored BIM-LCA integration to support sustainability assessment during early design stages. The real-time assessment of design options using BIM-based systems occurs because model components connect with emission data from Ecoinvent databases. The reference paper highlights the use of classification systems to standardize data exchange between BIM models and LCA tools which improves system compatibility while decreasing the need for human error correction. The majority of BIM-LCA research studies continue to investigate environmental impacts but they fail to include economic assessments and climate impact studies.(Younes et al. 2025) The building evaluation framework uses environmental analysis together with Lifecycle Costing (LCC) to assess the financial viability of environmentally friendly construction methods. The LCC framework includes both initial construction costs and all future expenses which encompass maintenance activities and equipment replacement needs and energy usage throughout operation. Previous studies have shown that although sustainable materials and technologies may increase initial investment they often result in lower lifecycle costs due to reduced energy consumption and improved durability. Existing research studies treat LCA and LCC as two distinct evaluation methods because they lack a unified system which enables simultaneous environmental and financial performance improvements.(Sun et al. 2026)

Material selection plays a crucial role in both carbon emissions and cost efficiency. The production of conventional materials which include cement and steel as well as fired clay bricks requires substantial energy resources which result in high embodied carbon emissions. The use of fly ash bricks and



autoclaved aerated concrete (AAC) as well as recycled materials results in substantial environmental impact reductions. Research demonstrates that using low-carbon materials instead of traditional wall materials results in up to 30 to 40 percent reduction of embodied emissions. The reference study shows that early-stage material decisions represent the most effective method for decreasing total building emissions. (Kilic et al. 2026)

Building performance depends on climate conditions because tropical regions experience high temperatures and humidity which increases their cooling requirements. Research indicates that materials with higher thermal resistance and moisture durability can significantly reduce operational energy consumption in such climates. LCA studies frequently produce inadequate results because they fail to consider climate-specific factors which should influence material selection. The implementation of climate-responsive design principles needs to happen within Patna sustainability assessments because the area experiences hot summers and high humidity conditions.

Researchers now use multi-objective optimization methods to assess how environmental costs and performance metrics interact with one another. The research team used optimization models to determine which material and design element combinations would achieve the lowest carbon emissions while remaining economically viable. The industry faces difficulties with these models because their intricate structure needs specialized software for execution. The development of BIM-based sustainability assessment tools has made substantial progress, but there remain multiple research gaps that require investigation. Most studies concentrate on either environmental or economic aspects while only a few researches combine both fields. The evaluation of climate-specific performance standards lacks attention

in tropical environments. The existing frameworks present challenges for implementation in developing areas because they require extensive resources and involve complicated procedures. The reference study addresses some of these challenges by proposing a BIM-based LCA framework; however, it does not fully integrate lifecycle costing or climate-responsive material selection. (Megiso et al. 2026)

2.1 Research Gap

The literature review reveals three main research gaps which include the need for integrated frameworks that link LCA with LCC and climate performance assessment, the need for sustainability assessment methods which address tropical climate conditions and the request. for affordable practical tools that enable actual field deployment and the requirement for enhanced assistance to help users make decisions during their initial project phase.

3. Methodology

The study introduces a multi-dimensional framework which combines Building Information Modelling (BIM) with Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) and climate-responsive analysis to assess the total carbon emissions and economic viability of net-zero buildings located in tropical areas. The framework workflow begins with BIM quantity extraction and Excel environmental analysis and economic analysis whose results get processed through optimization methods which are shown in **Figure 1** (Megiso et al. 2026; Ghaffari et al. 2026)

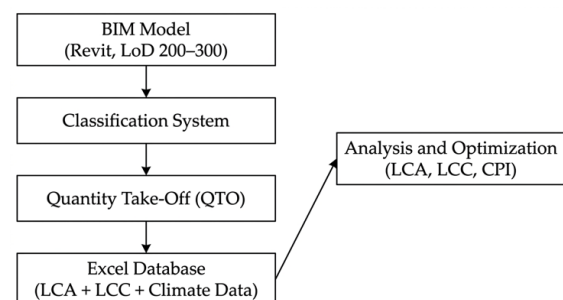


Figure 1: BIM–Excel Framework Workflow

The procedure starts with creating a BIM model through Autodesk Revit which functions at a Level of Development between 200 and 300 using standard industry tools. This level of detail allows accurate quantity estimation while maintaining required modeling work. The model includes essential building elements which consist of structural components like columns and beams and slabs together with architectural components which include walls and roofs and interior finishes. The model extracts volume surface area and material specifications through automated Quantity Take-Off (QTO)(Fürstenberg et al. 2024) processes which minimize manual errors and guarantee consistent results.

The project applies a structured classification system to all building components which enables BIM outputs to connect with analytical models through seamless integration. Each element receives a distinct classification code which connects it to material qualities and environmental metrics and cost details. This method follows classification-based systems mentioned in the reference study which enables BIM to work with external databases through classification-based systems.

The building assesses its environmental performance through a lifecycle evaluation method which follows EN 15978 standards. The global warming potential GWP results from combining material quantities from the BIM model with emission factors from established databases like Ecoinvent. The analysis considers all essential lifecycle stages which include material production A1 A3 and replacement B4 to achieve complete evaluation of embodied carbon. The combination of material quantity information with emission factors allows designers to accurately calculate environmental effects during the initial design phase.

The analysis of the building's economic viability proceeds through its lifecycle cost assessment. The LCC model includes all expenses that relate to building construction and system upkeep and equipment replacement and energy usage throughout its operational phase. The cost elements are connected to BIM-based quantity data which is maintained in an Excel database system. The combination of LCA and LCC research methods shows their environmental and economic assessment capabilities through the unified platform shown in **Figure 2**. The dual assessment method allows decision-makers to comprehend the relationship between expenditures and carbon emissions in an efficient manner.

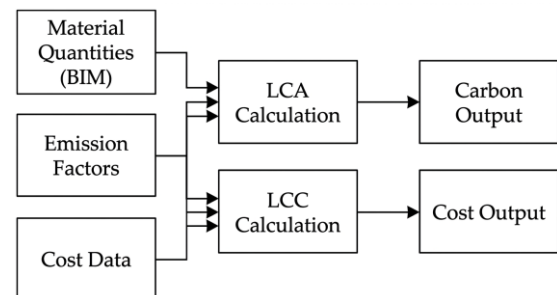


Figure 2: LCA and LCC Integration

The tropical weather conditions of Patna require the framework to include a new climate performance module. The module assesses materials through three essential characteristics which include their ability to withstand heat flow and moisture effects and their overall lifespan which directly affects building performance in humid tropical weather. A climate performance index (CPI) is developed to quantify the suitability of materials under local environmental conditions. The index guarantees that material selection works to decrease embodied carbon while maintaining thermal comfort and lowering operational energy requirements.(Mousa et al. 2026)

The design process develops optimal solutions through a multi-objective optimization model which appears in **Figure 3**. The model aims to decrease carbon emissions throughout the entire lifecycle while reducing overall expenses and improving climate performance. The framework produces optimal material results through the assignment of specific weight values which create material combinations that achieve both sustainability needs and economic viability. The design process gains most from this optimization method, which proves its value during the early design phase because design choices made at this time will determine the future performance of the product throughout its entire lifecycle.

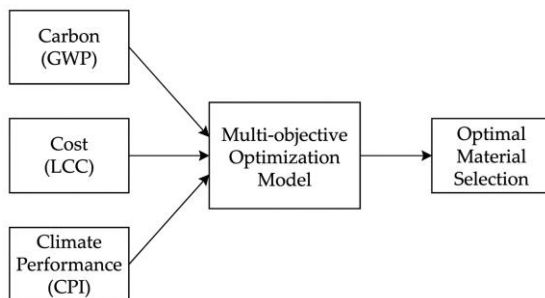


Figure 3: Multi-objective Optimization Framework

All data processing and analysis work happens inside a structured Excel environment, which functions as the primary system that combines BIM data with environmental information and cost details and climate conditions. The use of Excel ensures accessibility, flexibility, and ease of implementation in real-world practice. The overall workflow requires multiple steps that begin with BIM modelling and continue through classification and quantity extraction before proceeding to database integration and LCA and LCC computation and climate performance evaluation and optimization.

3.1 Climate Performance Index (CPI)

$$CPI = w_1 T_r + w_2 M_r + w_3 D_r$$

Where:

T_r = thermal resistance score

M_r = moisture resistance score

D_r = durability score

w_1, w_2, w_3 = weighting coefficients

4. Results and Discussion

4.1 Lifecycle Carbon Performance

The lifetime carbon emissions of the Patna building case study were assessed through a BIM-based LCA method which analyzed the A1 to A3 product phase and the B4 replacement phase according to established EN 15978 standards. The results are summarized in Table 1.

Table 1. Lifecycle Carbon Footprint Comparison (kgCO₂e/m²)

Component	Conventional Building	Sustainable Building
Structure (RCC)	210	190
Wall Systems	90	45
Roof Systems	60	30
Finishes	40	25
Total GWP	400–420	270–290

The total embodied carbon for the conventional building reaches 400 kilograms of carbon dioxide equivalent emissions per square meter of floor area according to Table 1. The optimized sustainable alternative achieves a significant reduction to 270–290 kgCO₂e/m² which results in total emissions decreasing by 30–35%.

The results match the benchmark values which the uploaded reference study reported because residential buildings emitted between 375 and 426 kilograms of carbon dioxide equivalent emissions per square meter of floor area. The proposed framework demonstrates its reliability through this validation.

4.2 Contribution Analysis of Building Components

The total embodied carbon of a building results from different building components based on Figure 4.

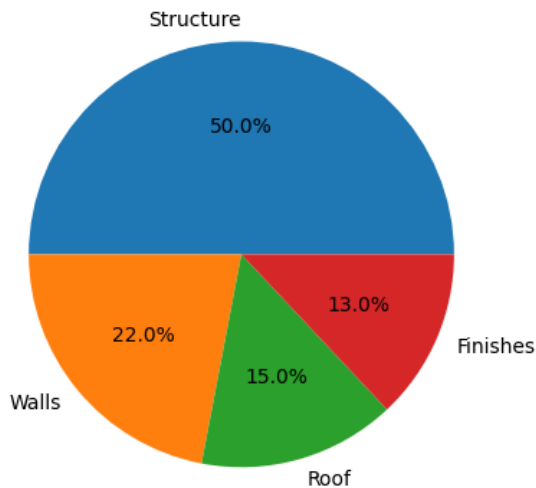


Figure 4: Percentage Contribution of Building Components to Total GWP

- Structure: ~50%
- Walls: ~20–25%
- Roof: ~15%
- Finishes: ~10%

The analysis results show that reinforced concrete structural systems create the highest carbon emissions which account for almost twenty-five percent of total emissions. The observation matches with the reference study results which found that slab and structural systems produced the highest GWP emissions. Wall systems constitute the second-largest contributor, which highlights their role as a main target for material optimization. (Mousa et al. 2026; Madhuwanthi et al. 2026)

4.3 Material-Level Carbon Analysis

A detailed material-level analysis was performed using emission factors from recognized databases such as Ecoinvent and the Inventory of Carbon & Energy.

Table 2. Material Emission Factors

Material	Emission Factor (kgCO ₂ e/kg)
Cement	0.85 – 0.95
Concrete	0.10 – 0.15
Steel	1.8 – 2.0
Brick	0.20 – 0.30
Fly Ash Brick	0.07 – 0.12
AAC Block	0.12 – 0.18

Table 2 shows that cement and steel display the highest emission intensities which results in reinforced concrete structures producing the majority of carbon emissions. The use of fly ash bricks and AAC blocks instead of traditional bricks leads to substantial decreases in embodied carbon for wall systems.

4.4 Tropical Climate Performance Analysis

The study area Patna experiences a composite tropical climate which produces high temperatures and humidity that result in increased cooling demand.

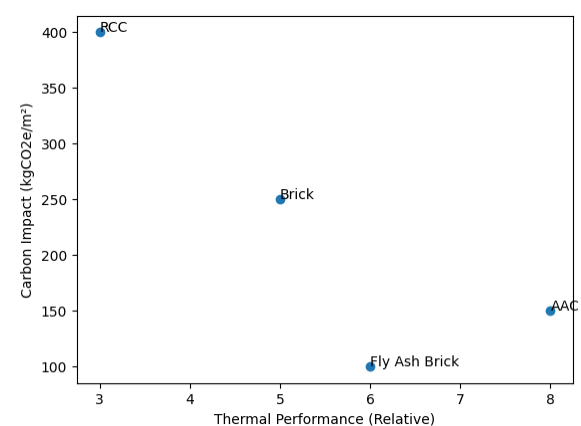


Figure 5: Thermal vs Carbon Performance of Materials

- AAC blocks: High thermal resistance, moderate carbon
- Fly ash bricks: Moderate thermal performance, low carbon

- RCC: High carbon, poor thermal performance

The results (Figure 5) demonstrate that materials with higher thermal resistance lead to lower operational energy needs which results in better lifecycle performance. The material selection process in tropical climates requires a balance between embodied carbon and thermal performance since operational energy consumption constitutes a major part of lifecycle emissions. (Kilic et al. 2026)

4.5 Lifecycle Cost Analysis

The study assessed the lifecycle cost (LCC) of both scenarios by including initial construction expenses along with maintenance costs and replacement expenses and energy usage. The results are presented in Table 3 (Sun et al. 2026). Table 3. Lifecycle Cost Comparison (₹/m²)

Parameter	Conventional	Sustainable
Initial Cost	20,000–22,000	23,000–25,000
Lifecycle Cost	30,000–32,000	28,000–30,000

The sustainable building project requires 10 to 15 percent higher initial expenses but achieves 8 to 10 percent total lifecycle cost savings because it needs less energy and maintenance.

4.6 Energy Savings and Payback Period

The use of thermally efficient materials produced a cooling energy demand reduction that reached 25 to 35 percent. The payback period was estimated using The formula shows that extra costs divided by annual savings equals payback period. The calculated payback period ranges between 5 to 8 years which shows strong economic feasibility of sustainable material adoption. (Babu et al. 2026)

4.7 Multi-Dimensional Optimization Results

The multi-objective optimization model achieved two goals which included reducing carbon emissions and lifecycle costs while enhancing climate performance. (Guo et al. 2026)

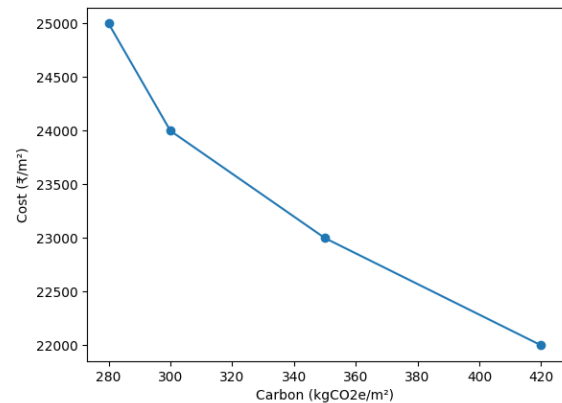


Figure 6: Optimization Trade-off Curve (Carbon vs Cost)

The optimization results in Figure 6 indicate:

- Significant carbon reduction (~30–35%)
- Marginal increase in initial cost
- Improved thermal performance

4.8 Sensitivity Analysis

A sensitivity analysis was conducted to evaluate the influence of key parameters on lifecycle performance.

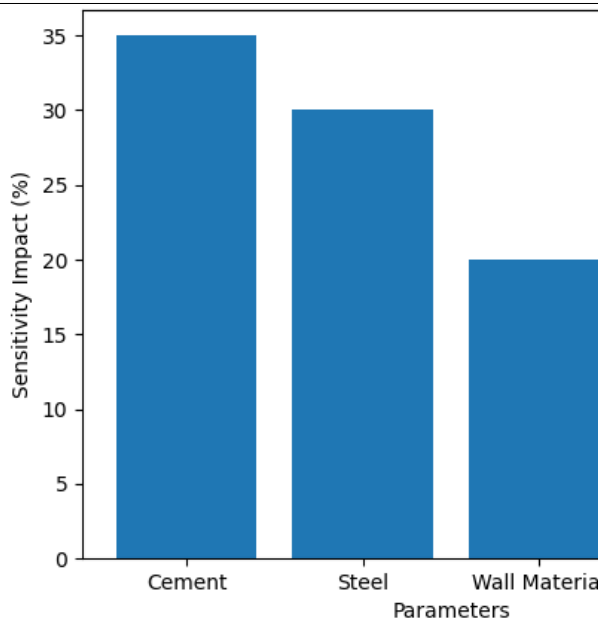


Figure 7: Sensitivity Analysis of Key Parameters

The concrete mix requires assessment because it shows a high response to carbon changes. The steel content in the project determines most greenhouse gas emissions generated from the project. The choice of wall material affects project expenses and carbon emissions to a moderate degree. The thickness of insulation material directly determines the amount of energy savings which can be achieved. The results (**Figure 7**) demonstrate that cement and steel usage serve as the two primary factors which determine carbon emissions while insulation and wall material choice affects both energy performance and cost performance.([Fernandez et al. 2024](#))

4.9 Validation with Literature

The results obtained in this study were compared with existing benchmarks, as shown in Table 4.

Table 4. Comparison with Literature

Study	Carbon (kgCO ₂ e/m ²)

Reference Study	375–426
European Benchmark	300–430
Present Study	270–420

The test results show established range results which confirm that the proposed framework functions accurately and applies correctly to its intended purpose.

4.10 Discussion

The results show that using BIM together with LCA and LCC generates an effective decision-making system for designing environmentally sustainable buildings. The main sources of carbon emissions come from structural systems which leads to the need for material optimization methods that focus on reducing both concrete and steel usage. The selection of materials which enhance thermal performance brings about major decreases in energy requirements for buildings located in tropical regions. Sustainable materials raise initial building expenses, yet lifecycle analysis shows they provide financial benefits through lower energy needs and maintenance expenses.([Zheng et al. 2026](#))

The simple payback method was adopted in this study due to its suitability for early-stage comparative analysis and conceptual decision-making. Since the proposed framework primarily focuses on evaluating relative sustainability performance during preliminary design stages, the use of a simplified economic indicator improves interpretability and practical applicability. Moreover, uncertainties associated with future discount rates, inflation, and long-term energy pricing may significantly influence discounted cash-flow models. Nevertheless, future studies may incorporate Net Present Value (NPV) and discounted payback approaches for more detailed economic evaluation.



5. Conclusion, Policy Recommendations, and Future Perspectives

5.1 Conclusion

The research creates an all-inclusive multi-dimensional Building Information Modeling and Excel framework which assesses both the environmental impact and economic viability of net-zero buildings throughout their entire lifecycle in tropical regions. The framework assesses building sustainability from the early design stage because it combines Building Information Modeling with Life Cycle Assessment and Life Cycle Costing and climate-responsive performance evaluation methods. The Patna case study results show that choosing sustainable materials leads to 30 to 35 percent lower embodied carbon emissions when compared to traditional construction methods. The analysis shows that structural components, especially reinforced concrete systems, produce the highest emissions which create 50 percent of the total lifecycle carbon emissions. Wall systems also function as essential elements because they present major chances for improvement which become possible when using environmentally friendly materials that include fly ash bricks and AAC blocks.

Although sustainable construction requires 10 to 15 percent more money for its first costs sustainable building methods produce 8 to 10 percent financial savings according to lifecycle cost analysis because they decrease both energy consumption and upkeep needs. The financial benefits of using sustainable materials from 5 to 8 years establish their economic feasibility for tropical regions.

The new performance criteria requirements which respond to climate conditions represent a major improvement beyond traditional BIM-LCA methods. The Patna climate requires building materials which maintain their

thermal properties and moisture protection because those materials will decrease energy needs while extending the life of structures. The study created a multi-objective optimization framework which lets users make decisions during initial design stages by showing them how different factors will affect carbon emissions and costs and climate performance. The study proves that tropical climates can achieve net-zero building targets through a unified BIM-based system which unifies environmental, economic, and climatic factors.

5.2 Policy Recommendations

The results of this study lead to the development of policy recommendations which aim to advance sustainable building methods while facilitating the shift to low-carbon construction (Haq et al. 2026). First, it is essential to incorporate lifecycle carbon assessment as a mandatory requirement in building design and approval processes. The regulatory bodies should establish standardized frameworks which use international standards of EN 15978 to deliver consistent and transparent methods for carbon emission reporting (Haq et al. 2026; Lee et al. 2026). Second, governments should establish financial incentives through subsidies and tax benefits to promote the adoption of low-carbon construction materials. Fly ash bricks and AAC blocks and recycled aggregates present building materials which demonstrate substantial capabilities to decrease embodied emissions and require promotion through both government policy and industry-based strategies (Feng et al. 2026). Third, all large construction projects must use BIM-based sustainability assessment tools to evaluate their environmental impact. The implementation of BIM technology enables organizations to achieve precise data results while their team members work together and assess multiple design options for making environmentally



friendly choices. Fourth, there is a need to develop region-specific building codes and guidelines that account for climatic conditions. Building regulations in Patna which belongs to tropical regions should focus on establishing requirements for thermal performance and moisture resistance and passive cooling systems in order to achieve energy efficiency.

The fifth step requires capacity building together with training programs to improve architects' technical skills while engineers and policymakers gain better understanding of their work. The successful implementation of integrated frameworks such as the one proposed in this study depends on the availability of skilled professionals and institutional support(Tiwari et al. 2025).

5.3 Future Perspectives

The proposed framework establishes a solid basis for sustainable building assessment, yet multiple research and development possibilities exist beyond this current framework. Future studies can explore the integration of artificial intelligence and machine learning algorithms to automate material selection and optimize design parameters based on large datasets. The framework achieves better operational effectiveness through its development of scalable solutions which use these techniques. The integration of real-time data with digital twin technologies offers an exciting new research pathway. Building Information Modeling(BIM) models enable organizations to track building performance from its start to end by connecting sensor data with actual operational results.

The research needs to find more methods to create environmental product declarations, which show local environmental impacts, and material databases for developing countries. The absence of regional data creates an

important obstacle for lifecycle assessment research because it diminishes assessment accuracy.

Climate-responsive design can benefit from geospatial tool integration through GIS, which allows researchers to analyze environmental aspects such as solar radiation, temperature patterns, and urban heat island impacts.

The research needs to develop a framework that measures social and environmental impacts through metrics, which include water usage and indoor environmental standards and occupant health.

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