ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Volume 12 Issue 12 December 2025

Comparative Assessment on Embodied Carbon Emissions & Circular Chain Economy of the RC Building, Composite Steel Building, and Masonry Building using BIM

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Abstract— The construction sector plays a significant role in contributing to global greenhouse gas emissions, particularly through embodied carbon released during the manufacturing of materials, their transportation, and the building process itself.

This project aims to conduct a comparative analysis of embodied carbon emissions for three structural systems: Reinforced Concrete (RC) building, Composite Steel building, and Masonry building to analyze the least carbon emitting structure which helps stakeholders to choose the optimized design with low carbon emission at the concept design phase. G+1 building model is developed in Autodesk Revit using Building Information Modelling (BIM) to accurately quantify material requirements. The embodied carbon for each structural system is calculated by integrating Life Cycle Assessment (LCA) data with BIM outputs. The study considers demolition phase to provide a holistic life cycle perspective and suggests the deconstruction techniques & reuse of the materials to reduce the carbon footprint in the consecutive projects. The results are compared to identify the structural system with the lowest carbon footprint, providing insights into sustainable material selection and design strategies.

This research highlights the potential of BIM as a decision-making tool for reducing embodied carbon in the built environment and supports the transition toward low carbon construction practices which promote circular chain economy.

Index Terms — BIM-LCA, Emboided Carbon Emission, Circular chain, Sustainability, BIM.

I. INTRODUCTION

A. Overview: Global Warming

Global warming is one of the most critical challenges facing humanity today. Even a small rise in Earth's average temperature can have devastating consequences for ecosystems and human life. Scientists warn that an increase of just 10°C could make the planet uninhabitable. This warming is primarily caused by GHGs such as carbon dioxide (CO_2), which stops the heat in the atmosphere. The main sources of these emissions include energy production, transportation, and industrial activities, Upon that, the construction industry is a major contributor for this carbon emission across the globe.

B. Importance of Construction

The construction sector plays a vital role in economic growth, yet it is also a significant source of carbon emissions throughout a building's lifecycle. From raw material extraction and manufacturing to transportation, construction, operation, and eventual demolition, every stage contributes to greenhouse gas emissions. Globally, the buildings and construction sector accounts for about 34% of energy-related CO_2 emissions, which equals nearly 10 gigatons annually, and consumes approximately 32% of global energy.

In India, the construction industry is expanding rapidly. Valued at ₹100.43 lakh crore in 2025 and projected to reach ₹176.79 lakh crore by 2030, it is a major economic driver but also a significant emitter of greenhouse gases. The sector contributes around 32% of India's total GHG emissions, with 60% from operational energy use (such as heating, cooling, and lighting) and 40% from embodied carbon in materials like cement and steel. Over the past 13 years, emissions from construction in India have increased by 1.8 times, highlighting the urgency for change.

Completely stopping construction is not an option, as infrastructure development is essential for economic progress and urbanization. Therefore, the focus must shift towards the structural designs which emits less carbon emission without affecting the space or consumptions requirement.

C. Project's Requirement

In this project we have taken the two strategies to reduce the carbon emission and suggestion to improve circular chain economy by reusing and reducing concept.

Strategy 1: Analyze and compare three structural designs of the same GFA of G+1 building which are as follows,

- Reinforced Concrete Structure,
- Composite steel Structure and

- Masonry Structure

for the analysis to determine the less carbon emission structure with an optimized structural design.

Strategy 2: Implementation of circular economy principles, including recycling and reusing construction waste to reduce embodied carbon.

By adopting these measures, the construction industry can significantly reduce its carbon footprint while continuing to support economic development. Achieving this balance requires collaboration among policymakers, developers, and technology innovators to ensure that sustainability becomes a core principle of future construction practice.

D. Specific Objective of the Study

This comparison study's main goal is to analyze the three different structural models and determine which is emitting the less, medium & high carbon throughout its life cycle from raw material production, construction to end of lifecycle of the building.

This study elaborates the carbon emission of the particular structural framing by analyzing the materials that have been used in that structural optimized design individually and generate the report to understand the variation in the amount of carbon emission and helps the stakeholders to choose the right structural framing based on the purpose, location and future use of the building.

The study considers demolition phase to provide a holistic life cycle perspective and suggests the deconstruction techniques & reuse of the materials to reduce the carbon foot print in the consecutive projects. The results are compared to identify the structural system with the lowest carbon footprint, providing insights into sustainable material selection and design strategies.

It also suggests the best end of life procedure for the building materials such as suitable techniques to deconstruction of the different materials when at the end of life time of the building.

This research highlights the potential of BIM as a decision-making tool for reducing embodied carbon in the built environment and supports the transition toward low carbon construction practices which promotes circular chain economy.

II. PROBLEM SATEMENT

A. The Impact of Carbon Emissions in Construction Sector

The construction industry plays a major role in contributing to global carbon emissions, accounting for a large share of the overall environmental impact. While considerable progress has been made in lowering emissions from building operations such as those linked to energy use during occupancy the carbon embedded in materials remains a crucial yet frequently neglected aspect. This embedded carbon includes emissions generated during the extraction of raw materials, their production, transportation, installation, upkeep, and eventual disposal at the end of the building's life.

B. The Gap in Current Practices

Although awareness of sustainable practices is growing, there remains a noticeable gap in practical, data-oriented approaches that combine digital modeling with life cycle evaluation to assess and compare material-related carbon emissions across various structural designs. This limitation restricts architects, engineers, and decision-makers from making well-informed choices during the early design phase where the opportunity to minimize carbon impact is greatest.

C. Need for Comparative Analysis of Structural Systems

Different structural systems such as Reinforced Concrete (RC), Steel, and Masonry have varying levels of embodied carbon due to differences in material composition, construction techniques, and lifecycle performance. However, there is insufficient comparative data to guide the selection of the most sustainable option. Identifying which structural system emits the least and most carbon throughout its lifecycle can significantly influence sustainable designs.

D. Importance of Early-Stage Decision Making

By integrating BIM with LCA methodologies, designers and engineers can simulate and evaluate the carbon footprint of various structural options during the conceptual design phase. This proactive approach enables the selection of materials and systems that align with low-carbon objectives, ultimately contributing to more sustainable construction practices.

E. Emphasizing Circular Economy in Construction

Another critical aspect often neglected is the end of life-span phase of buildings. A large number of structures are either partially or demolished after their service life, leading to significant material waste and additional emissions. Deconstruction techniques, which involve the careful dismantling of buildings to recover reusable materials, offer a sustainable alternative. However, their application remains limited.

This study not only compares the embodied carbon of three structural systems but also explores deconstruction strategies and circular economy principles. By doing so, it aims to provide actionable insights into how materials can be reused or recycled, thereby extending their lifecycle and reducing the carbon footprint.

III. METHODOLOGY

A. Work Schedule and Planning

The project was initiated with a structured and analytical approach, beginning with a thorough identification of the project's goals and requirements. The team conducted a comprehensive literature review to understand current practices in sustainable structural design and carbon assessment. This was followed by collaborative brainstorming sessions to clearly define the problem statement and determine the most effective solution strategy.

The core objective of the project is to calculate the embodied carbon associated with three distinct structural framing systems ie, Reinforced Concrete (RC), Steel, and Masonry and to perform a comparative analysis to identify the least and most carbon-intensive structure. Based on the findings, the project aims to propose effective strategies for reducing carbon emissions in structural design. Furthermore, it emphasizes the importance of adopting reuse, recycling, and sustainable deconstruction practices widely known as principles of circular economy to minimize the carbon foot-print of structures. was to develop optimized 3D structural design models for three types of structures Reinforced Concrete (RC), Steel, and Masonry using Building Information Modeling (BIM) tools. These models were created with a focus on structural efficiency and environmental sustainability.

To assess the carbon impact, the team incorporated carbon factors from the HTECE Version 3 manual, published by the Institution of Civil Engineers (ICE, UK). These factors were used to evaluate the embodied carbon associated with each material and construction process.

Material quantities were accurately extracted from the BIM models, ensuring consistency and precision. These quantities were then used in Excel to calculate the embodied carbon for each structural system. This integrated approach enabled a detailed comparison of the environmental footprint of different structural types, supporting informed decision-making for low-carbon design solutions.

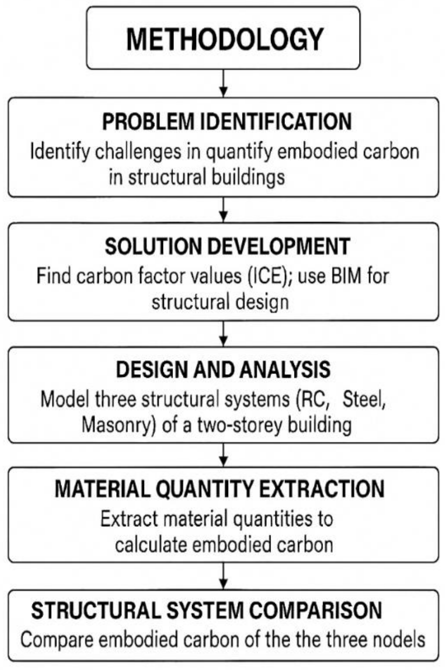


Figure 1. Methodology

The work schedule was meticulously planned to incorporate the following key steps:

1. Problem Identification: The project commenced with a collaborative effort to accurately identify the challenges associated with quantifying carbon emissions in structural buildings. The primary focus was on determining the embodied carbon across various structural systems, which required a clear understanding of the contributing factors and data sources.

2. Solution Development: Through continuous brainstorming sessions, the team discovered standardized carbon factor values outlined in the manual “How to Calculate Embodied Carbon, version 3” published by the Institution of Civil Engineers (ICE, UK). Building Information Modeling (BIM) was integrated into the workflow to produce precise structural designs and facilitate accurate material quantification.

3. Design and analysis: To ensure a fair and consistent comparison, a hypothetical building with identical parameters have the same footprint and two-storey configuration (G+1) was assumed for all three structural systems: Reinforced Concrete (RC), Steel, and Masonry. Optimized 3D models were developed for each system using BIM tools.

4. ECE Study: A detailed study of embodied carbon was conducted for all materials used in the project. The assessment followed the guidelines and lifecycle stages defined in the ICE manual, including raw material extraction, manufacturing, transportation, construction, usage, and end-of-life processes. All relevant carbon factors were documented and applied accordingly.

5. Material Quantity extraction: Quantities such as volume, area, and length of structural elements were extracted directly from the BIM models. These values were then multiplied by the corresponding carbon factors to calculate the embodied carbon for each element, ensuring precision in the results.

6. Structural System Comparison: The embodied carbon results derived from the three structural models were systematically evaluated. A comparative table was prepared, highlighting the carbon impact across lifecycle stages. This analysis provided insights into the most sustainable structural system and offered recommendations for enhancing circular economy practices through reuse, recycling, and deconstruction technologies.

B. Model Preparation

The development of optimized structural design models for three different framing systems Reinforced Concrete (RC), Steel, and Masonry was carried out using Autodesk Revit 2023. The process was structured into three distinct phases: Design, Modeling, and Analysis, each contributing to the accuracy and reliability of the final outputs.

i. Design Phase:

Initial 2D architectural and structural drawings were created using AutoCAD 2021.

Room dimensions, layout configurations, and spatial planning were carefully considered to ensure functional efficiency.

Strategic positioning of structural elements such as columns, beams, and walls was done to optimize load distribution and structural performance.

Design standards and building codes were referenced to maintain compliance and safety.

ii. Model Phase:

Detailed 3D models for each structural framing system were developed in Autodesk Revit.

Structural components were assigned appropriate material properties (e.g., concrete grade, steel type, masonry units) to reflect realistic construction scenarios.

BIM tools were utilized to extract initial quantities of structural elements including volume, area, and length.

iii. Analysis Phase:

The structural models were imported into Autodesk Robot Structural Analysis for validation.

Load combinations and boundary conditions were applied to simulate real-world structural behavior.

C. ECE Study

To assess the carbon emissions associated with structural materials, the project utilized the manual "How to Calculate Embodied Carbon – Version 3" published by the Institution of Civil Engineers (ICE, UK). This manual provides standardized carbon factors for various materials across different lifecycle stages. The evaluation process was carried out in a structured manner as follows,

Figure 2. Lifecycle stages

i. Reference and Data Collection:

Carbon factors for each material were extracted from the ICE manual, covering all relevant lifecycle stages:

a. Raw material extraction
b. Manufacturing and processing
c. Transportation
d. Construction and installation
e. Operational use
f. End-of-life (demolition, recycling, disposal)

These values were documented and organized for integration into the carbon calculation workflow.

ii. Excel-Based Calculation:

All carbon factor values and material quantities were systematically entered into Excel.

A structured spreadsheet was prepared to tabulate the data clearly, allowing for easy reference and validation.

Assumptions and limitations were applied where necessary to ensure comparability across different structural systems.

D. Structural system comparison

Following the completion of the ECE study and BIM model development, the next phase involved applying the collected data to calculate and compare the embodied carbon across the three structural systems. This process was executed using Excel for clarity, traceability, and analytical Equipment

1. Data Integration

Material quantities extracted from Revit models were matched with corresponding carbon factors from the ICE manual for all the Lifecycle stages.

2. Assumptions and Limitations

Certain assumptions were made to standardize comparisons across structural systems, such as:

Uniform building dimensions and layout (G+1 configuration)

Consistent usage scenarios and lifecycle boundaries Limitations were acknowledged, including:

Variability in regional material sourcing and transportation.

Exclusion of non-structural components

3. Comparative Analysis

Embodied carbon values were summarized and compared across the three models.

A stage-wise comparison table was prepared to highlight carbon contributions at each lifecycle phase.

Insights were drawn to identify the most and least carbon-intensive system.

4. Recommendations

Based on the comparison, strategies were proposed to reduce carbon emissions, including:

Material substitution with low-carbon alternatives

Adoption of reuse and recycling practices

Integration of circular economy principles in design and construction.

IV. DESIGN AND CALCULATIONS

A. Design Process

The structural design for three different framing systems Reinforced Concrete (RC), Steel, and Masonry was carried out for a residential building with a consistent built-up area and layout (G+1 configuration). The design process was executed in three main stages: Layout Preparation, Model Development, and Structural Analysis.

Layout preparation:

A new project was initiated using Autodesk AutoCAD 2021.

The plot boundary was defined based on assumed site dimensions.

Room spaces were allocated by considering functional and circulation requirements.

Grid lines were established to guide the accurate placement of structural elements.

Building including slab edges and room boundaries were drawn to scale.

Structural elements such as columns and walls were positioned strategically to ensure optimal load transfer and spatial efficiency.

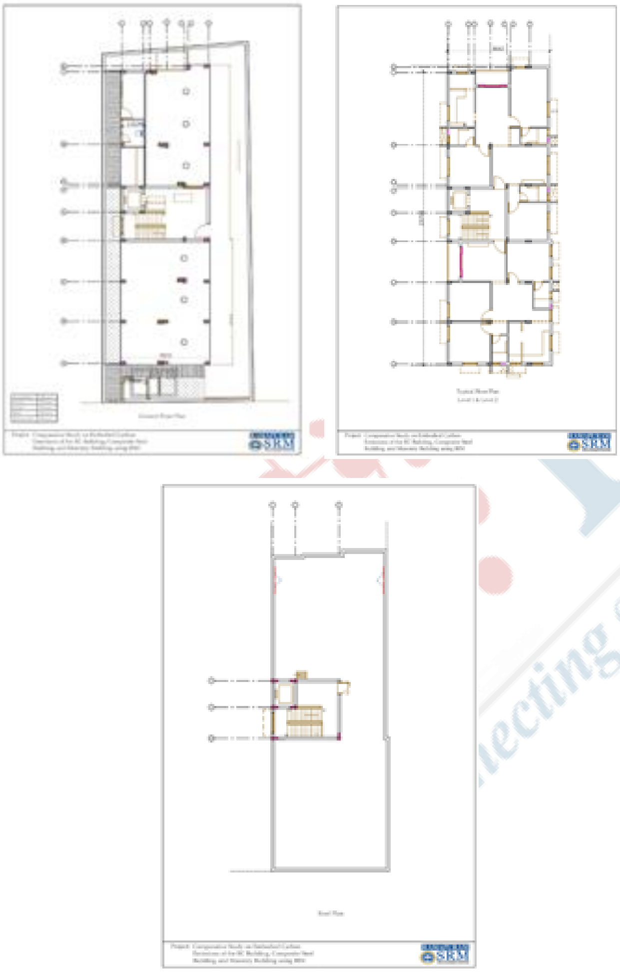


Figure 3. Structural CAD Layout

B. Model preparation:

A new project was initiated in Autodesk Revit 2023 for each structural system.

The previously prepared CAD layouts were linked into the working views (W/C views) for reference.

Grids and levels were created in Revit, aligned with the CAD drawings to maintain dimensional accuracy.

Structural elements such as columns and walls were modeled at designated locations. (RC columns have been used for RC structures whereas steel columns RC Pedestal to support base plate have been used for composite structure.)

Footings were designed and placed beneath all columns and load-bearing walls.

Foundation elements, including raft slabs, were modeled to reflect realistic ground support conditions.

Floor slabs for each level and roof slabs were accurately modeled.

Structural beams have been added. (RC beams have been used for RC structures whereas steel beams used for composite structure.)

Lift core walls and staircases were incorporated into the model for vertical circulation.

AAC (Autoclaved Aerated Concrete) blocks were used for modeling both internal and external walls in the masonry structure.

Brick wall types have been changed for Masonry building.

Floor and roof finishes were added to reflect actual construction layers and material usage.

Material properties (e.g., density, strength, thermal performance) were assigned to each element based on the structural system.

Sheets, sections, and elevations were generated to support documentation and further analysis.

This entire modeling process was repeated for other two structural systems to ensure uniformity in comparison.

Once the models are prepared, 3D views of each structural models have been exported to visualize the outcome.

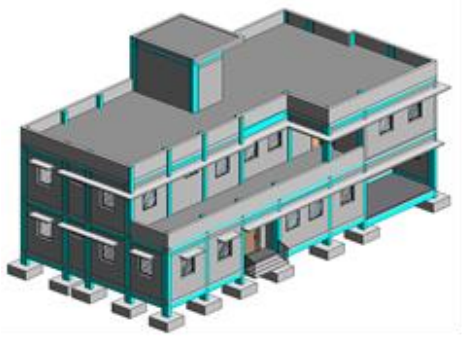


Figure 4. 3D View – RC Structure

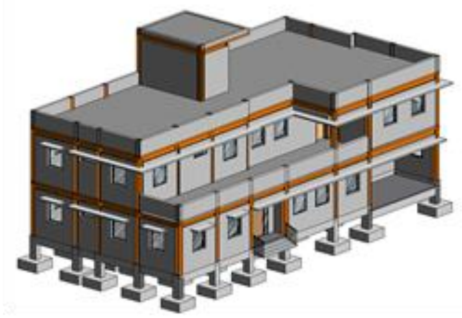


Figure 5. 3D View – Steel composite Structure

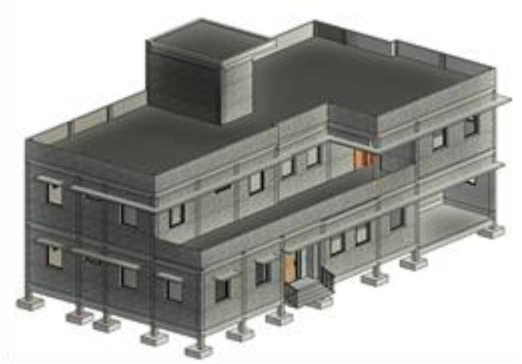


Figure 6. 3D View – Masonry Structure

C. Material Quantity Extraction

Quantities of structural materials were extracted directly from the Revit BIM models. The following parameters were considered:

Volume of concrete, steel, and masonry components,

Length of beams and columns,

Area of slabs, walls, and finishes.

These quantities were cross verified for accuracy and consistency across all three structural systems.

The quantity of the elements are directly extracted from Revit and populated in Excel to calculate the Volume of the elements in Tons.

The Overall Gross Floor area is 591.86 m2

The standard units for Weight (kg & Ton), Length (mm & m) are used.

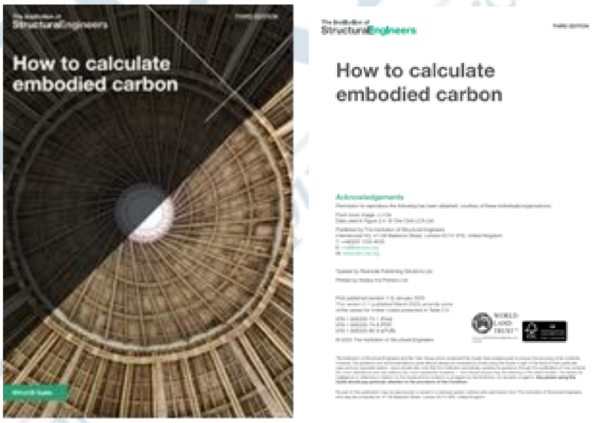
a) Material Quantity calculations:
b) Mass of concrete = 2400 kg/m³
c) Mass of RC Steel = 90kg/m³
d) Mass of steel = 40 kg/m²
e) Mass of Deck slab = 2590 kg/m³
f) Mass of Brick = 1800 kg/m³
g) Mass of ACC Block = 600 kg/m³
h) Mass of screed = 2000 kg/m³

Refer ‘Table 1 – Material Quantity’ for detailed Quantity of Material which are extracted from Revit Models for three structural systems.

D. ECE Study

To measure the environmental impact of structural materials used in the project, a systematic Embodied Carbon Evaluation (ECE) was conducted. The methodology followed the guidelines provided in the “How to Calculate Embodied Carbon Version 3” manual, published by (ICE, UK).

Refer ‘Table 2 – Carbon Factors’ referred from the manual.



The Institution of StructuralEngineers

How to calculate embodied carbon

The Institution of StructuralEngineers

How to calculate embodied carbon

Acknowledgements

Figure 7. HTCEC-V3 Manual

Table 1: Material Quantity

Structure	Element	Total Area	Total Volume	Total Length	Tonne		Total Tonne
					Concrete	**Steel**	
RC Frame	RC Footing	72	43.2		103.68	3.89	107.57
RC Frame	RC Raft	25.531875	3.607225		8.66	0.32	8.98
RC Frame	RC Slab	885.2541095	167.4321652		401.84	15.07	416.91
RC Frame	RC Beam		22.65502935	336081.6273	54.37	2.04	56.41
RC Frame	RC Column		29.94320131	275001.6	71.86	2.69	74.56
RC Frame	RC Wall	155.6125	31.1225		74.69	2.80	77.50
RC Frame	RC Stair	6.93	2.772		6.65	0.25	6.90
RC Frame	75 mm Blinding	289	21.675		52.02	1.95	53.97
RC Frame	ACC Block wall	801.4056842	142.7248918		85.63		85.63
RC Frame	Civil Floor finishes	751.2177283	103.5793694		207.16		207.16
STEEL Frame	RC Footing	80	47.3125		113.55	4.26	117.81
STEEL Frame	RC Raft	25.531875	5.315375		12.76	0.48	13.24
STEEL Frame	RC Slab	84.5235561	8.45235561		20.29	0.76	21.05
STEEL Frame	RC Beam		6.11825378	104041.0605	14.68	0.55	15.23
STEEL Frame	RC Column Pedestal		8.1534675	48006.4	19.57	0.73	20.30

Structure	Element	Total Area	Total Volume	Total Length	Tonne		Total Tonne
					Concrete	Steel	
STEEL Frame	RC Wall	67.08	13.416		32.20	1.21	33.41
STEEL Frame	Steel composite Slab	536.0413034	80.40619552		208.25		208.25
STEEL Frame	Steel Beam		0.71675505	225745.2276		9.03	9.03
STEEL Frame	Steel Column		5.138784	243001.6		9.72	9.72
STEEL Frame	Steel Stair	13.86				0.55	0.55
STEEL Frame	75 mm Blinding	289	21.675		52.02	1.95	53.97
STEEL Frame	ACC Block wall	854.7567317	152.9851671		91.79		91.79
STEEL Frame	Civil Floor finishes	750.4610408	103.4280319		206.86		206.86
MASONRY	RC Footing	32	11.2		26.88	1.01	27.89
MASONRY	RC Raft	25.531875	3.607225		8.66	0.32	8.98
MASONRY	RC Slab	884.2831253	167.3350668		401.60	15.06	416.66
MASONRY	RC Beam		12.66378234	336556.6273	30.39	1.14	31.53
MASONRY	RC Column		15.02722606	275001.6	36.07	1.35	37.42
MASONRY	RC Wall	64.4	12.88		30.91	1.16	32.07
MASONRY	RC Stair	6.93	2.772		6.65	0.25	6.90
MASONRY	External Brick Wall	509.9935371	116.0499468		208.89		208.89
MASONRY	Internal Brick wall	396.0971471	41.28525756		24.77		24.77
MASONRY	75 mm Blinding	289	21.675		52.02	1.95	53.97
MASONRY	Civil Floor finishes	756.7508533	104.6859944		209.37		209.37

Table 2: Carbon Factors

Element	Production	Transport	Construction				End life			Beyond EOL
			A5.3				C1-C4	C2		D1
	A1-A3	A4	A5.3.1 Factor	A5.3.2 Waste Factor	A5.3.3 Transport Factor	A5.3.4 Landfill	EOL Scenario	No DC	With DC	
Blinding concrete, 1:4 Screed	0.146	0.003	0.0084376	0.053	0.009	0.0012	90% Recycling - landfill	0.009	0.0045	-0.008
Concrete C32/40 - All elements	0.113	0.003	0.0066939	0.053	0.009	0.0013	90% Recycling - landfill	0.009	0.0045	-0.007
Rebars - All elements	0.72	0.021	0.0404549	0.053	0.021	0.0013	92% Recycling - landfill	0.009	0.0045	-0.68
Steel - I section	1.64	0.021	0.016833	0.01	0.021	0.0013	95% Recycling - landfill	0.009	0.0045	-0.91
Composite deck profile	2.83	0.021	0.028733	0.01	0.021	0.0013	85% Recycling - landfill	0.009	0.0045	-1.3
ACC Block - External	0.28	0.014	0.0167586	0.053	0.021	0.0012	95% Recycling - 5%landfill onsite	0.009	0.0045	-0.007
ACC Block - Internal	0.085	0.014	0.0064236	0.053	0.021	0.0012	95% Recycling - 5%landfill onsite	0.009	0.0045	-0.007
Single Brick	0.213	0.014	0.0151808	0.064	0.009	0.0012	90% Recycling - landfill	0.009	0.0045	-0.016
Brick-Single side mortar	36.9	0.014	2.3631488	0.064	0.009	0.0012	90% Recycling - landfill	0.009	0.0045	-0.016
Brick-Double side mortar	79	0.014	5.0575488	0.064	0.009	0.0012	90% Recycling - landfill	0.009	0.0045	-0.016

Abbreviations:

EOL – End of Life
No DC – No Decarbonization
With DC – With Decarbonization

E. ECE Calculation

General Assumptions:
Assuming the structure is in Early-stage design
Uncertainly Factor 15%
Building GFA = 591.86 m2
Refer Table-1 for material quantity calculation.
Refer Table-2 for Carbon Factors.

Excel-Based Carbon Calculation

A dedicated Excel workbook was developed to perform the embodied carbon calculations. The process included:

Inputting material quantities and corresponding carbon factors into structured tables.

Applying formulas to compute embodied carbon per element and total embodied carbon per structure.

Organizing data into separate sheets for each structural system (RC, Steel, Masonry) for clarity.

Assumptions and limitations were applied including:
Standardized lifecycle boundaries.
Exclusion of non-structural elements and services.

a) Up front Carbon (Modules A1-A5)

i. A0 - can be negligible as it is early stage of design
ii. A5.1 - is negligible as there is no preconstruction demolition.
iii. A5.2 = 20kgC02e/m^2 x 591.86m^2 = 11.8372 tC02e
iv. A1-A4 & A5.3
Blinding = [Area x thickness of blinding x Mass of Conc. / 1000] x [A1+A2+A3+A4+A5.3] = ** tC02e
RC Elements (Conc.) = [Volume x Mass of Conc. / 1000] x [A1+A2+A3+A4+A5.3] = ** tC02e
RC Elements (Reinf.) = [Volume of conc. x 90 / 1000] x [A1+A2+A3+A4+A5.3] = ** tC02e
(Assuming 90kg/m^3 of Concrete)
Steel Elements (I-sections) = [(Total length/1000) x (Mass of Steel/1000) x[A1+A2+A3+A4+A5.3] = ** tC02e
Steel Elements (Composite deck) = [Volume x Mass of Metal Deck / 1000] x [A1+A2+A3+A4+A5.3] = ** tC02e
Steel Elements (Steel Staircase) = [Area x Mass of Steel / 1000] x [A1+A2+A3+A4+A5.3] = ** tC02e
ACC Block wall = [Volume x Mass of ACC / 1000] x [A1+A2+A3+A4+A5.3] = ** tC02e
Floor finishes screed = [Volume x Mass of Screed / 1000] x [A1+A2+A3+A4+A5.3] = ** tC02e

b) Up front Carbon (Modules B1-B5)

i. B1-B5 can be negligible as the emission of Carbon is less for Structures in the usage stage other than the maintenance, Extension or Refurbishments.

c) Up front Carbon (Modules C1-C5)

i. C1 - Demolition and Deconstruction
No decarbonization = GFAx(A5.2x0.5) = ** tC02e
With decarbonization = GFAx(A5.2x0.25) = ** tC02e
Where,
Demolition= 25% of EC A5.2 (With decarbonization)
Deconstruction= 50% of EC A5.2 (No decarbonization)
ii. C2-C4 – Transportation, Waste processing & Disposal
Where,
C2.a = 25% of EC A5.2 (With decarbonization)
C2.b = 50% of EC A5.2 (No decarbonization)
A5.3.4 = Disposal type (Landfill)
Blinding = [Area x thickness of blinding x Mass of Conc. / 1000] x [C2+A5.3.4] = ** tC02e
RC Elements (Conc.) = [Volume x Mass of Conc. / 1000] x [C2+A5.3.4] = ** tC02e
RC Elements (Reinf.) = [Volume of conc. x 90 / 1000] x [C2+A5.3.4] = ** tC02e
(Assuming 90kg/m3 of Concrete)
Steel Elements (I-sections) = [(Total length/1000) x (Mass of Steel/1000) x[C2+A5.3.4] = ** tC02e
Steel Elements (Composite deck) = [Volume x Mass of Metal Deck / 1000] x [C2+A5.3.4] = ** tC02e
Steel Elements (Steel Staircase) = [Area x Mass of Steel / 1000] x [C2+A5.3.4] = ** tC02e
ACC Block wall = [Volume x Mass of ACC / 1000] x [C2+A5.3.4] = ** tC02e
Floor finishes screed = [Volume x Mass of Screed / 1000] x [C2+A5.3.4] = ** tC02e

V. DATA ANALYSIS AND REPORTS

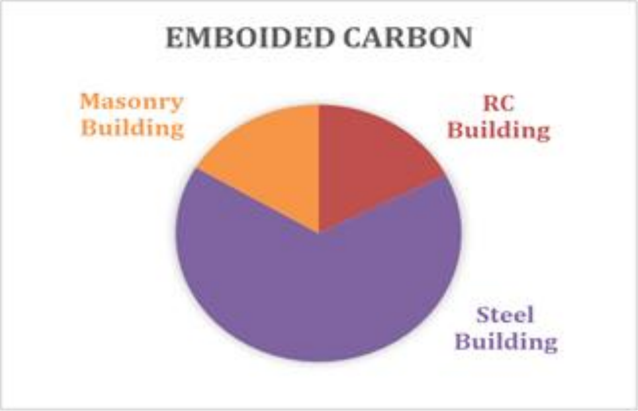
A. Observations

Values calculated based on the derivations from the manual "How to Calculate Embodied Carbon Version 3" manual, published by (ICE, UK).

By analyzing the Emboided Carbon Emission (ECE) factors and the total material quantities for all elements across each building type with respect to lifecycle stage, we can calculate the quantum of Emboided carbon emissions generated by each structure. This approach provides a clear and data-driven comparison between the three building systems Reinforced Concrete (RC), Steel, and Masonry highlighting their relative environmental impacts throughout their entire lifecycle.

By comparing the data is clearly showing that steel structural system has more carbon emission compared to other two system at the first fresh construction.

RC Building and Masonry sharing approximately same amount of Carbon emission as the taken building's GFA is smaller. But when it comes to big towers and Infrastructure the RC building and steel system will be the efficient.



a) Steel Building:

Production Stage (A1–A4): Steel manufacturing is the most carbon emission processes in the construction industry. It involves smelting iron ore in blast furnaces, rolling, and finishing all of which require enormous amounts of energy, primarily from fossil fuels. This stage alone accounts for the majority of emissions in steel.

Transportation Impact: Steel components are often fabricated off-site and transported over long distances, adding significant emissions from logistics. In general, the steel components manufactured nationally and distributed across the cities and having minimum 50 kms from the project site.

Overall Effect: Steel buildings have the highest carbon footprint across all lifecycle stages, making them the least sustainable option.

b) RC Building:

Concrete Production: Cement, the key ingredient in concrete, is responsible for substantial CO_2 emissions due to the calcination process and high-temperature kilns.

Reinforcement Steel: Adds additional embodied carbon, but far less than a full steel structure.

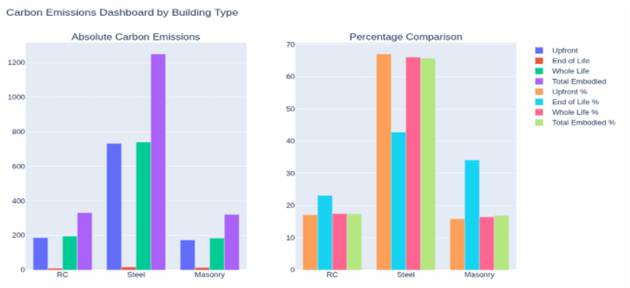
Overall Effect: RC buildings have moderate emissions higher than masonry but significantly lower than steel.

c) Masonry Building:

Material Characteristics: Masonry uses bricks or blocks, which generally have lower embodied carbon compared to steel or concrete.

Local Sourcing Advantage: Masonry materials are often locally sourced, reducing transportation related emissions.

Overall Effect: Masonry emerges as the most sustainable option among the three, with the lowest whole life carbon footprint but limited only to the small buildings. When it comes to tall buildings and infrastructure, RC or Steel structure are more efficient.



B. Circular Chain Economy

The detailed review on Deconstruction Technologies of each system gives the clear idea to offset the Carbon by using the reused and recycled materials to build the new structure irrespective of Structural system.

Below is the report showing the detailed review on Deconstruction Technologies and Strategies for each system.

a) Deconstruction Technologies and Strategies for Steel Buildings:

The Steel buildings are well-suited for deconstruction due to their modular design, high strength-to-weight ratio, and excellent recyclability. These features align with sustainable construction and circular economic principles. Deconstruction involves carefully dismantling structural components for reuse or recycling, rather than demolishing and discarding them.

A major advantage of steel structures is the use of bolted connections. Unlike welded joints, which are permanent and require cutting, bolted connections can be easily unfastened. This allows beams, columns, and trusses to be removed without damage. During my academic training, When DfD principles are applied during the design phase, buildings become easier to deconstruct at the end of their life cycle.

In a 591.86 sq.m steel building, the deconstruction process begins with a detailed assessment. This includes identifying bolted joints, cataloging steel member types and sizes, and evaluating their condition. Building Information Modeling (BIM) plays a key role by creating a digital twin of the structure. BIM stores metadata such as material grade, dimensions, and connection types, which helps plan the deconstruction sequence and estimate reuse potential.

After assessment, non-structural elements like cladding, insulation, and partitions are removed. These materials are sorted for recycling. The structural frame is then dismantled in reverse construction order using cranes and lifting equipment. Each component is inspected and either stored for reuse or sent to a recycling facility.

Steel's ability to be reused endlessly without losing its strength is a major environmental advantage. Recycling steel drastically lowers carbon emissions by as much as 75% compared to producing new steel from raw materials. Even damaged parts can be melted down and reshaped into new components, making it a highly sustainable option in construction.

Deconstruction also offers economic advantages. Reusable steel components have high salvage value, which can offset costs. During my internship, I observed salvaged steel beams being sold to a local fabricator, generating revenue that was reinvested into the project. This demonstrated the practical value of sustainable practices.

Modular construction is another effective strategy. Prefabricated steel modules can be quickly assembled and disassembled. They simplify both construction and deconstruction, and can be reused in other projects, reducing waste and conserving resources. As a student, I find this approach promising for future adaptive building systems.

Ensuring safety during dismantling activities is crucial, especially when handling heavy steel elements. These components require precise management to avoid accidents. Proper instruction, use of protective gear, and adherence to strict safety measures are vital. Examples from training sessions have shown that overlooking safety can result in injuries and project delays, reinforcing the importance of careful planning and close supervision.

To measure carbon savings, life cycle assessment (LCA) tools are used. These tools evaluate environmental impact across a building's life cycle. Comparing a deconstructed steel building to a demolished one shows substantial carbon savings, especially when a large percentage of steel is reused or recycled.

In conclusion, steel building deconstruction is a practical way to reduce carbon emissions and promote sustainability in construction. By using BIM, applying DfD principles, and encouraging reuse and recycling, we can build a more responsible and resource-efficient future.

b) Deconstruction Technologies and Strategies for RC Buildings:

Reinforced concrete is widely used for its strength, durability, and versatility. However, it carries a high embodied carbon footprint, mainly due to cement production, which significantly contributes to global CO_2 emissions. Reducing this footprint through effective deconstruction and material recovery is essential for sustainable construction.

Unlike demolition, deconstruction involves the careful disassembly of building components to enable reuse or recycling. This approach conserves resources, reduces waste, and lowers emissions from new material production. RC buildings pose unique challenges due to their monolithic structure and embedded steel reinforcement, but with the right strategies, meaningful environmental benefits can be achieved.

The process begins with a detailed structural assessment. This includes identifying material types, quantities, and conditions to evaluate reuse or recycling potential. Building Information Modeling (BIM) supports this phase by providing accurate data on material locations, types, and connection details, enabling efficient planning.

Selective demolition is a key strategy for RC buildings. Instead of tearing down the entire structure, specific components are removed in a controlled manner. This allows recovery of valuable materials like steel rebar, concrete aggregates, and embedded fixtures. Tools such as concrete saws, hydraulic breakers, and wire saws help separate elements without damaging reusable parts.

Recovered materials are then processed. Rebar can be extracted using magnetic separators, cleaned, and straightened for reuse. Although not yet common due to certification concerns, reused rebar has strong potential to reduce embodied carbon. Alternatively, it can be recycled into new steel products, which still offers lower emissions than producing steel from raw materials.

Concrete can be crushed and reused as recycled aggregate in new mixes or as base material for roads. The quality of recycled concrete aggregate (RCA) depends on original strength, contamination levels, and crushing methods. Advances in crushing technology have improved RCA consistency, making it a viable alternative to natural aggregates.

Hazardous materials in older buildings, such as asbestos or lead-based paint, must be identified and safely removed. This requires coordination with environmental experts and strict adherence to regulations to protect workers and the environment.

Structural components like precast beams, slabs, and columns can also be reused if carefully removed and assessed for integrity and compliance with current codes. This reduces demand for new materials and shortens construction timelines.

Designing RC buildings with deconstruction in mind known as Design for Deconstruction (DfD) is crucial. DfD involves using bolted connections, avoiding composite materials, and labeling components with material data to support future recovery. This makes buildings more adaptable and sustainable.

Economically, deconstruction may have higher upfront costs than demolition, but these can be offset by the value of recovered materials and reduced disposal fees. It also creates jobs in recovery, processing, and resale, supporting the local economy. Incentives and green certifications further improve financial viability.

c) Deconstruction Technologies and Strategies for Masonry Buildings:

Masonry buildings, typically built with load-bearing walls using bricks or concrete blocks bonded with mortar, are more labor-intensive to deconstruct than steel or concrete structures. Their monolithic nature presents challenges, but with the right strategies and technologies, a significant portion of materials can be salvaged and reused, supporting a circular economy.

Manual dismantling is one of the most effective methods for masonry deconstruction. It involves carefully removing bricks or blocks one by one from the top down using tools like chisels, hammers, and crowbars. This technique allows for a high recovery rate of reusable bricks, which can be cleaned and reused in new projects. A major challenge is removing hardened mortar. Lime-based mortars are easier to clean than cement-based ones. Techniques such as soaking bricks in water, using wire brushes, or applying chemical agents help soften mortar, though chemicals must be used cautiously to avoid environmental harm.

For larger structures, mechanical equipment like mini excavators with specialized attachments can speed up the process. These machines can dismantle walls with minimal damage to bricks, but care must be taken to avoid excessive material loss. Once bricks are removed, they are sorted by condition and type. Reusable bricks are cleaned and stored in dry, covered areas to prevent degradation. Proper labeling and inventory management ensure efficient reuse in future projects.

Reusing bricks significantly reduces the embodied carbon associated with new brick production, which involves energy-intensive kilns and high CO_2 emissions. Local reuse also cuts transportation emissions. Despite these benefits, masonry deconstruction faces challenges. Manual dismantling is time-consuming and costly, and variability in brick quality and mortar composition affects reusability. The lack of standardized guidelines and incentives further limits adoption.

Technological innovations are helping address these issues. Robotic arms with vision systems are being developed to automate brick removal with precision. Digital tools like Building Information Modeling (BIM) assist in planning and tracking material flows. Case studies show the potential of masonry deconstruction. In one project, over 80% of bricks from a historic building were reused in a new community center, preserving architectural character and reducing waste. Best practices include early planning, stakeholder engagement, and integrating deconstruction goals into the design phase.

Policy support is essential to promote masonry deconstruction. Governments can offer incentives like tax credits or grants, update building codes to allow reclaimed materials, and run awareness campaigns to highlight environmental and economic benefits. Education also plays a key role. Universities and technical institutes should include deconstruction and material recovery in their curricula. Hands-on training can equip future professionals with the skills needed to implement these strategies effectively.

In conclusion, masonry deconstruction offers a practical path to reducing the carbon footprint of the built environment. Through manual and mechanical techniques, improved mortar removal, and technological innovation, we can enhance material recovery and reuse.

C. Comparison W.R.T SDGs Aspects:

The comparison table evaluates RC, Steel, and Masonry buildings across 15 sustainability-oriented aspects aligned with UN SDGs, focusing on Circular Economy Potential. Each aspect such as carbon emissions, energy efficiency, resource use, water consumption, waste management, recyclability, affordability, health, durability, adaptability, construction speed, fire safety, comfort, and cultural integration includes comprehensive strategies for improving circularity.

Table 3: Comparison with respect to Sustainable Development Goals of UN Aspects

Aspects (SDG Link)	**RC Building**	**Steel Building**	**Masonry Building**
Carbon Emissions (SDG 13)	Medium carbon footprint due to cement production.	Very high carbon footprint from steel manufacturing.	Low carbon footprint with locally sourced materials.
Energy Efficiency (SDG 7)	Good thermal mass helps regulate temperature.	Poor insulation properties.	Excellent thermal mass and insulation.
Resource Efficiency (SDG 12)	Moderate use of resources, potential for recycled aggregates.	High resource demand, low efficiency.	Efficient use of local materials.
Water Usage (SDG 6)	High water usage in concrete curing.	Low water usage in steel fabrication.	Moderate water usage in masonry construction.
Waste Management (SDG 12)	Moderate waste, potential for reuse.	Low waste if recycled properly.	High waste but reusable bricks.
Recyclability (SDG 12)	Low recyclability of concrete.	High recyclability of steel components.	Low recyclability but potential for reuse.
Economic Affordability (SDG 8)	Moderate initial and lifecycle cost.	High initial cost, moderate lifecycle cost.	Low initial cost, moderate lifecycle cost.
Local Employment (SDG 8 & 11)	Moderate local labor involvement.	Requires skilled labor.	High local labor involvement.

Aspects (SDG Link)	RC Building	Steel Building	Masonry Building
Health & IAQ (SDG 3)	Good indoor air quality with proper finishes.	Moderate IAQ depending on coatings.	Excellent IAQ with natural materials.
Durability (SDG 9)	High durability and long lifespan.	Very high durability and resistance.	Moderate durability, depends on maintenance.
Adaptability (SDG 11)	Moderate adaptability in design.	High adaptability with modular systems.	Low adaptability due to rigid structure.
Construction Speed (SDG 11)	Moderate speed with cast-in-place methods.	Fast construction with prefabricated steel.	Slow construction due to manual labour.
Fire Safety (SDG 11 & 13)	High fire resistance.	Moderate fire resistance.	High fire resistance with masonry walls.
Comfort (SDG 3 & 11)	Good thermal and acoustic comfort.	Poor comfort without insulation.	Excellent comfort with thermal mass.

VI. RECOMMENDATIONS AND RESULTS

A. Recommendations for Emboided Carbon Reduction:

The embodied carbon emission can be optimized and reduced by following generic recommendations.

a) ECE reduction for Steel building:

Steel structures have the highest embodied carbon and typically highest cost per tonne of material due to energy-intensive production.

i. Material Optimization

Action: Use high-recycled-content steel and lightweight structural systems.

Carbon Impact: Reduces upfront emissions by 20–30%.

Cost Impact: Recycled steel may cost slightly more initially (+5–10%), but savings occur through reduced material quantity and lower disposal costs.

ii. Decarbonization Strategies

Action: Source steel from plants using renewable energy and electric arc furnaces.

Carbon Impact: Can cut emissions by up to 40% in production.

Cost Impact: Premium for green steel (~10–15%), but offsets through compliance with green building certifications and potential tax incentives.

iii. Transportation Efficiency

Action: Prefer local suppliers and optimize logistics.

Carbon Impact: Reduces transport emissions by 10–15%.

Cost Impact: Lower freight costs and reduced lead times.

iv. End-of-Life Planning

Action: Design for disassembly and reuse.

Carbon Impact: Enables 90–95% steel recycling.

Cost Impact: Salvage value of steel reduces demolition costs significantly.

b) ECE reduction for RC building:

RC buildings have moderate emissions and generally lower material cost per cubic meter compared to steel.

i. Low-Carbon Concrete

Action: Use blended cements (fly ash, slag) and recycled aggregates.

Carbon Impact: Cuts cement-related emissions by 30–40%.

Cost Impact: Blended cement often costs less than OPC, reducing material cost by 5–10%.

ii. Structural Efficiency

Action: Optimize design and consider post-tensioning.

Carbon Impact: Reduces concrete volume by 10–15%.

Cost Impact: Slight increase in design fees but significant savings in material cost.

iii. Decarbonization Measures

Action: Source cement from plants using alternative fuels and carbon capture.

Carbon Impact: Reduces emissions by 20–25%.

Cost Impact: Minimal cost increase, often offset by sustainability incentives.

iv. End-of-Life Strategy

Action: Crush and reuse concrete as aggregate.

Carbon Impact: Avoids landfill emissions and reduces need for virgin aggregates.

Cost Impact: Lowers disposal costs and provides material for future projects.

c) ECE reduction for Masonry building:

Masonry has the lowest embodied carbon and competitive cost, especially when locally sourced.

i. Material Selection

Action: Use locally sourced bricks or blocks and consider

CSEB (Compressed Stabilized Earth Blocks).

Carbon Impact: Cuts transport emissions by 15–20%.

Cost Impact: Local sourcing reduces material and freight costs.

ii. Energy Efficiency

Action: Design masonry walls for thermal performance.

Carbon Impact: Reduces operational energy demand by 10–15%.

Cost Impact: Slight increase in insulation cost but major savings in energy bills.

iii. Decarbonization Opportunities

Action: Encourage renewable energy use in brick kilns.

Carbon Impact: Cuts emissions by 20–30%.

Cost Impact: May increase brick cost slightly, but long-term benefits outweigh initial premium.

iv. End-of-Life Planning

Action: Reuse bricks or recycle into aggregates.

Carbon Impact: Reduces disposal emissions and landfill burden.

Cost Impact: Salvaged bricks can be resold, reducing demolition costs.

B. Recommendations for Sustainable Deconstruction:

The recommendations for Sustainable way of deconstruction as follows,

i. Design for Deconstruction (DfD)

One of the most effective ways to ensure sustainable deconstruction is to incorporate Design for Deconstruction (DfD) principles during the initial design phase.

This involves:

- Using modular construction techniques.
- Avoiding composite materials that are difficult to separate.
- Designing connections that are easy to disassemble (e.g., bolts instead of welds or cast-in-place joints).
- Labelling materials and components for future identification and reuse.

ii. Material Selection and Documentation

Choosing materials with high recyclability and reusability is crucial. For example:

- Use of high-grade steel that can be reused without significant reprocessing.
- Use of concrete with recycled aggregates.
- Use of lime-based mortar in masonry for easier brick Recovery.
- Additionally, maintaining a detailed material inventory using BIM can help track the origin, composition, and potential reuse of each component.

iii. BIM Integration for Lifecycle Management

BIM should be used not only for design and construction but also for lifecycle management. By tagging elements with metadata such as material type, expected lifespan, and recyclability, BIM can serve as a powerful tool for planning deconstruction. This enables:

- Accurate quantity takeoffs for salvage estimation
- Simulation of deconstruction sequences
- Identification of high-value components for reuse

iv. Training and Workforce Development

Deconstruction requires a different skill set compared to demolition. Therefore:

- Training programs should be developed for workers to safely and efficiently dismantle structures.
- Awareness campaigns should be conducted to promote the benefits of deconstruction.
- Universities should include deconstruction and circular economy principles in civil engineering curricula.

v. Policy and Incentives

Government policies and incentives can play a significant role in promoting sustainable deconstruction:

- Mandating material recovery targets for large-scale Projects.
- Offering tax incentives or subsidies for using reclaimed Materials.
- Establishing certification systems for deconstruction-friendly buildings.

vi. Material Recovery and Sorting Facilities

To maximize the reuse and recycling of materials:

- On-site sorting stations should be established to separate materials during deconstruction.
- Partnerships with local recycling and salvage companies should be encouraged.
- Investment in mobile crushing and processing units for concrete and masonry waste can reduce transportation emissions.

vii. Carbon Footprint Monitoring

Carbon accounting tools should be integrated into the deconstruction planning process:

- Use of LCA software to estimate emissions from deconstruction activities.
- Tracking carbon savings from reused and recycled Materials.
- Reporting carbon offset data to stakeholders and regulatory bodies.

viii. Community Engagement and Awareness

- Engaging the local community can enhance the success of deconstruction projects.
- Donating reusable materials to local NGOs or community projects.
- Hosting workshops and open houses to demonstrate sustainable practices.

- Encouraging public participation in material salvage and reuse.

ix. Research and Innovation

Continuous research is essential to improve deconstruction practices:

- Development of new tools and equipment for efficient Dismantling.
- Studies on the long-term performance of reused Materials.
- Pilot projects to test innovative deconstruction methods.

x. Comparative Evaluation and Feedback Loops

Finally, it is important to evaluate the outcomes of deconstruction projects:

- Comparing actual material recovery rates with projected Estimates.
- Documenting lessons learned and best practices
- Creating feedback loops to improve future designs and deconstruction plan.

C. Potential of Circular Economy:

The recommendations for Sustainable way of deconstruction as follows,

i. For RC Buildings:

- Use Recycled Aggregates from demolished concrete to reduce raw material demand.
- Design for Disassembly by avoiding monolithic pours and using separable components.
- Adopt Modular Prefabrication for faster assembly and easier reuse of elements.
- Incorporate Recycled Content like fly ash, slag, and recycled steel in mixes.
- Promote Material Reuse through salvaging formwork, scaffolding, and concrete debris.
- Conduct Life Cycle Assessment (LCA) during design to minimize environmental impact.
- Enable Community Reuse by donating surplus materials and creating recycling hubs.
- Improve Construction Speed using precast components and optimized workflows.
- Implement Digital Material Passports for traceability and future recovery.
- Align with Circular Economy Certifications such as LEED and Cradle-to-Cradle.

ii. For Steel Buildings:

- **Bolted Connections for Easy Dismantling –** Use bolted joints instead of welding to enable quick disassembly and reuse of steel components.
- **Design for Disassembly –** Plan structural layouts and connections for future dismantling without damaging elements.
- **Closed-Loop Recycling –** Establish partnerships with steel manufacturers for reclaiming and recycling steel into new products.
- **Building Reuse –** Encourage adaptive reuse of steel frames and components in new projects to extend lifecycle.
- **High Recycled Content –** Source steel with high recycled content to reduce embodied carbon and resource extraction.
- **Leasing of Components –** Implement leasing models for steel elements, allowing return and reuse after project completion.
- **Digital Material Passports –** Maintain records of steel components for traceability and future recovery.
- **Compliance with Circular Standards –** Align with certifications like LEED and ISO 14040 for circular economy practices.

iii. For Masonry Buildings:

- Salvaged Brick Reuse – Recover bricks from demolition sites for reuse in new construction projects.
- **Design for Disassembly –** Use reversible joints and lime-based mortars to allow easy dismantling of masonry walls.
- **Selective Demolition –** Implement controlled demolition techniques to preserve reusable masonry units.
- **Recycled Aggregates –** Crush broken bricks and blocks for use as aggregates in concrete or landscaping applications.
- **Lime-Based Mortars –** Employ lime mortars instead of cement for easier separation and reuse of bricks.
- **Repair & Retrofit –** Extend building life through repair and retrofitting rather than complete demolition.
- **Community Recycling –** Establish local recycling hubs for masonry waste and promote community participation.
- **Material Tracking –** Maintain records of masonry materials for future recovery and circular supply chains.

VII. CONCLUSION

A. Summary of Findings and Implications:

The project presented an effective approach to explore the embodied carbon emissions and circular economy potential of three building types Reinforced Concrete (RC), Composite Steel, and Masonry using Building Information Modeling (BIM) as a central tool for analysis and planning.

Composite steel buildings demonstrated the highest potential for circularity and carbon reduction. Their modular design and bolted connections allow for efficient deconstruction and high recovery rates of structural components. Steel's ability to be recycled indefinitely without loss of quality, combined with BIM's capability to track material metadata, enables significant carbon savings up to 75% when recycled steel is used instead of virgin material.

RC buildings, while structurally strong and widely used, present challenges in deconstruction due to their monolithic nature and embedded reinforcement. However, selective demolition techniques and the use of BIM for material quantification enable partial recovery of rebar and concrete aggregates. Although reuse of structural components is limited, recycling still contributes to reduced embodied carbon. Design for Deconstruction (DfD) principles can improve sustainability if integrated during the design phase.

Masonry buildings, traditionally seen as less adaptable, showed promising results when manual and mechanical dismantling techniques were applied. Reusable bricks, especially those bonded with lime-based mortar, can be recovered at high rates. The reuse of bricks significantly reduces carbon emissions associated with new brick production. Innovations such as robotic dismantling and BIM-based tracking enhance recovery efficiency. Case studies confirmed that with proper planning, over 80% of masonry materials can be reused.

Across all building types, BIM proved essential for enabling circular construction. It facilitated accurate material quantification, supported life cycle assessments, and improved planning for deconstruction and reuse. The integration of BIM with DfD strategies and selective demolition techniques enhances both environmental and economic outcomes.

Overall, composite steel buildings emerged as the most favorable in terms of embodied carbon reduction and circular economy potential, followed by RC and masonry buildings. Each typology presents unique opportunities and challenges, but all benefit from the strategic use of BIM and sustainable design principles.

B. Conclusion

This study has provided a comprehensive comparative analysis of three major building typologies Reinforced Concrete (RC), Composite Steel, and Masonry focusing on their embodied carbon emissions and potential contributions to a circular economy through deconstruction strategies, all supported by Building Information Modeling (BIM).

Composite steel buildings offer the greatest potential for circularity. Their modular design, bolted connections, and high recyclability of steel components make them highly suitable for deconstruction and reuse. BIM plays a critical role in mapping structural elements, enabling efficient planning and tracking of reusable materials. The embodied carbon of steel structures can be significantly reduced up to 75% when recycled steel is used, making them the most environmentally favorable option among the three.

Reinforced concrete buildings, while structurally robust and widely used, pose challenges in deconstruction due to their monolithic nature and embedded steel reinforcement. However, selective demolition techniques and advances in crushing technology allow for partial recovery of materials such as rebar and recycled concrete aggregates (RCA). BIM aids in quantifying material recovery and planning selective demolition. Although the reuse of structural components is limited, the recycling of concrete and steel still contributes to carbon savings. Design for Deconstruction (DfD) principles can further enhance the sustainability of RC buildings if integrated early in the design phase.

Masonry buildings, traditionally seen as less adaptable, show promising results when manual and mechanical dismantling techniques are applied. Reusable bricks, especially those bonded with lime-based mortar, can be recovered at high rates. The reuse of bricks significantly reduces embodied carbon, especially when sourced locally. Challenges such as labor intensity and mortar removal are being addressed through innovations like robotic dismantling and BIM-based material tracking. Case studies demonstrate that with proper planning and stakeholder engagement, over 80% of masonry materials can be reused, preserving architectural heritage and reducing waste.

Across all three building types, BIM has proven to be a transformative tool. It enables accurate material quantification, supports life cycle assessment (LCA), and facilitates the integration of circular economy principles into design and deconstruction workflows. The use of BIM enhances transparency, efficiency, and decision-making throughout the building lifecycle.

In terms of carbon footprint, composite steel buildings emerge as the most sustainable option when designed for disassembly and supported by BIM. RC buildings follow, with moderate potential for recycling and reuse. Masonry buildings, while traditionally less favored for deconstruction, show strong potential when manual recovery is prioritized and supported by policy and education.

To advance circular construction practices, policy support, education, and industry collaboration are essential. Incentives for material reuse, updated building codes, and training programs can accelerate adoption. As a B.Tech Civil Engineering student, this project has reinforced the importance of integrating sustainability into every phase of construction—from design to end-of-life. Through continued innovation and responsible engineering, we can transform the built environment into a regenerative system that respects both resources and future generations.

VIII. FUTURE SCOPE

A. Carbon Reduction Strategy

Future research can focus on integrating operational carbon analysis alongside embodied carbon to provide a full lifecycle carbon footprint for each building type. Exploring hybrid structural systems that combine low-carbon materials with high-performance design can further reduce emissions. Additionally, developing carbon benchmarking tools specific to regional construction practices will help tailor reduction strategies more effectively.

B. BIM Integration and Automation

The role of BIM can be expanded beyond design and deconstruction planning. Future studies can explore BIM integration with real-time sensors, AI-based material condition assessment, and automated inventory tracking. Linking BIM with Life Cycle Assessment (LCA) databases and carbon calculators will enable dynamic carbon monitoring throughout the building lifecycle. Research into open-source BIM platforms can also improve accessibility and adoption in small-scale projects.

C. Economic Optimization

Further investigation into the cost-benefit analysis of deconstruction versus demolition across different building types and scales is needed. Future work can model long-term savings from material reuse, reduced landfill fees, and carbon credits. Exploring business models for reclaimed material marketplaces and reverse logistics systems will support the economic viability of circular construction.

D. Sustainability Enhancement

Research can expand to include social sustainability indicators such as job creation, community engagement, and heritage preservation. Studies on adaptive reuse of components and buildings can promote longevity and reduce the need for new construction. Future work should also assess the environmental impact of deconstruction equipment and processes to ensure holistic sustainability.

E. Alternative Materials and Innovation

Exploring low-carbon and bio-based alternatives such as geopolymer concrete, bamboo, recycled plastic blocks, and engineered timber can diversify sustainable building options. Future research should evaluate the deconstruction potential, recyclability, and embodied carbon of these materials. Integrating alternative materials into BIM libraries and DfD frameworks will support their practical implementation.

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