Paving the way to Net Zero Carbon Standards: A guide to designing Net zero carbon building in a region that lacks carbon assessment framework.

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Abstract

This paper presents a provisional pathway for carbon assessment in India, essential for realising net-zero carbon building standards in regions with limited data. It amalgamates various data sources to compute embodied carbon, and utilises dynamic simulation for assessing operational carbon. Importantly, this methodology lays the groundwork for the development of early-stage design tools, empowering architects and engineers to integrate sustainable decisions. The adoption of this framework holds significant potential for transforming the built environment, encouraging greener design practices and enhanced adherence to regulatory standards. This initiative is a crucial step towards environmentally responsible construction practices in India.

Keywords Carbon Assessment Framework, Net-Zero Carbon Buildings, Carbon Emissions, Sustainable building.

1.0 Introduction

The current global climate projections indicate a potential rise in global temperatures by 1.5ºC due to the carbon emissions generated by various industries, especially the construction industry that needs to revaluate its carbon (CO2) emissions as it is one of the highest contributors of said carbon emissions (1). In the U.K for example, the construction sector is responsible for approximately 50% of total carbon emissions, highlighting an urgent need for transformative strategies by 2030(2).

In the context of India, a nation experiencing a unique pattern of urban growth, the discourse takes on a distinct dimension. The construction and infrastructure sectors in India are major contributors to global CO2 emissions, with the industry accounting for 23% of the total carbon emissions (3).The energy consumption profile in the Indian building sector is notably divided, with electricity and biomass constituting 20% and 60% of the energy mix, respectively (4). Despite this, India's investment in energy efficiency is regressive to its Asian counterparts, underscoring the need for increased investment in this critical area. This presents an argument for exploring sustainable building practices, with a focus on reducing the carbon footprint of the construction sector. The Figure 1 below combine the research done by Royal Institute of

British Architects (RIBA) to set embodied carbon and operational energy targets of buildings(5).

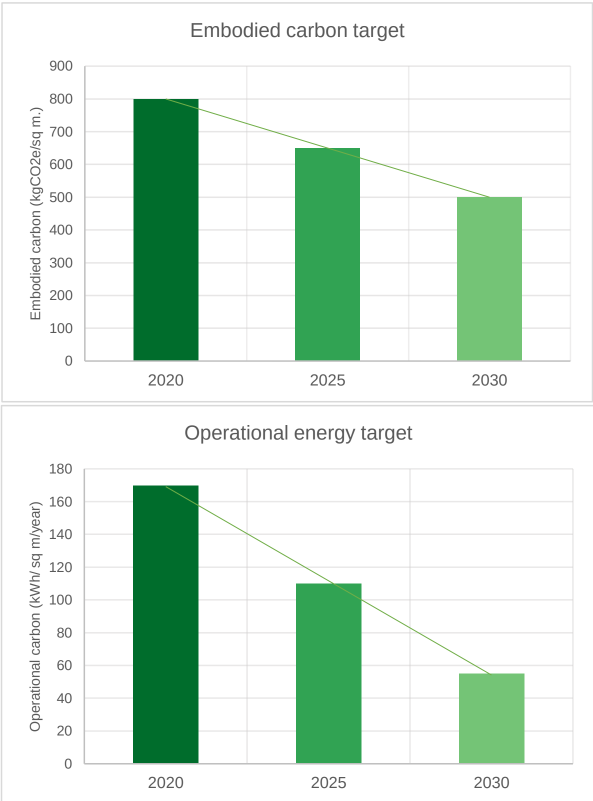

Figure 1: Embodied carbon and operational energy targets by RIBA (5)

The manufacturing of building materials in India is particularly energy-intensive, consuming 25% of the nation's total energy demand, with consequential environmental ramifications such as Greenhouse Gas (GHG) emissions, Global Warming Potential (GWP), and depletion of regional biodiversity(6).

India's housing demand, particularly between 2001 and 2011, coupled with government schemes like "Housing for all" aiming to provide 2 million rural houses by 2023, led to an upswing in ecological resource depleting construction practices (6). One of the key challenges was the potential rise in construction waste due to demolition of older structures, much of which ended up in landfills (7). Reports suggest an alarming 700 million tons of urban construction waste generated annually in India, primarily non-biodegradable (8).

Post-COVID-19, there is a rise in residential real estate across major Indian cities where the third quarter of 2022 alone saw a 24% increase in sales year-over-year, with significant developments in key Tier-1 cities including Bengaluru, Chennai, Hyderabad, Kolkata, Thane, Mumbai, Navi Mumbai, Pune, and Delhi(9) . This massive supply and demand for housing came at the cost of our environment. Figure 2 below highlights growth of Indian construction industry from 2010 to 2026 which would be doubled by the year 2026(10).

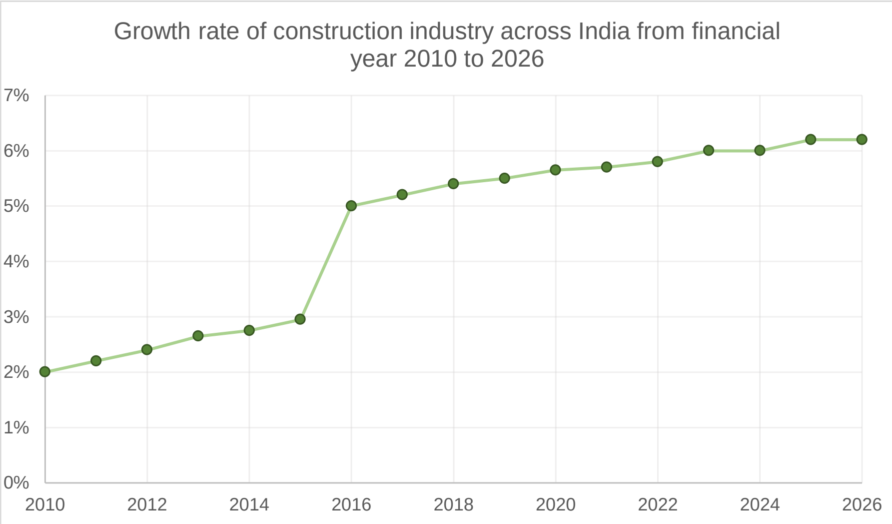

Figure 2: Growth of Indian construction Industry (2022-2026) in GBP

The recent Climate Action Plan (CAP) 2022 underscores India's commitment to global climate goals, with cities like Mumbai aiming to achieve carbon neutrality by 2050, it is evident that India is aiming to be an active participant in the global climate dialogue (7). However, the path forward is not merely about awareness; tangible incentives for stakeholders in the building sector are imperative. Considering India's distinct challenges and aspirations, this study is centred around the development and implementation of an interim carbon assessment framework. The primary focus is to conceptualise and operationalise this framework effectively, with the goal of advocating for and promoting net-zero carbon buildings. This research seeks to align with India's unique environmental, cultural, and economic contexts, providing a tailored approach to sustainable architecture and construction practices.

2.0 Research Objectives and Scope

The aim of this study is to tailor an interim pathway for India, directing the design of buildings towards net-zero carbon emissions. This guidance is meticulously crafted for the Indian context, through an analysis of buildings across various territories and geographical settings within the country. It addresses unique challenges such as the availability of data and local construction practices. Moreover, this research provides a structured roadmap for emerging assessors in India, guiding them through the linear progression method to effectively navigate towards achieving net-zero carbon emissions in buildings. This approach considers regional variations in climate, materials, and building practices, making it highly relevant and practical for the diverse Indian landscape.

Methodologically, the research employs a multifaceted approach, incorporating sensitivity analysis, dynamic simulation, and thermal modelling techniques. The range of topics cover the lifetime carbon emissions of buildings and exploring the benefits of integrating renewable energy systems. This research is contextualised within the global narrative of sustainable development and aligns with India's international commitments, as showcased in forums like the Conference of the Parties (COP)26 summit.

The scope of this research is specifically defined to optimise its structure. This paper concentrates exclusively on the residential housing typology, providing a focused approach. Although the methodology could be applicable to other building types, the pathways validity is justified solely through tests conducted on residential buildings using the proposed route in this specific context. Also establishing limits of the research is helpful as topics like carbon assessment of Heating, ventilation, and air conditioning (HVAC) systems, infrastructure and other building typologies except residential will not be developed in this paper.

2.1 Research objectives

This paper is dedicated to facilitating the advancement of net-zero carbon emissions in the construction sector within India. Its primary objectives are as follows: Firstly, to conduct a thorough analysis of existing carbon assessment methodologies, identifying and addressing the gaps pertinent to the Indian context. Secondly, to review and adapt global best practices and standards in carbon assessment to suit the unique requirements of India through numerical assessments. Thirdly, to provide architects and designers with practical and actionable strategies for integrating carbon-efficient approaches at the early stages of design. In addition, there is a focus on advocating for sustainable building practices and materials, which align with the broader environmental goals of reducing carbon emissions. Lastly, to identify limitations in data and methodologies, ensuring that the approach remains balanced and realistic in its pursuit of carbon reduction in Indian buildings.

3.0 Literature review

In a study conducted in Ahmedabad, Jain and Rawal quantified the gap between net-zero energy and carbon building standards, revealing that buildings could still have significant carbon impacts despite achieving net-zero operation annually, thus highlighting how crucial thermal modelling can be in calculating the carbon impacts(8). Ming Hu evaluated the energy, environmental, and economic performance of a retrofit zero energy building and concluded that Current Zero Energy Building (ZEB) certifications or designations may not be adequate to measure the actual building performance in achieving carbon neutrality (11). Usman and Abdullah developed parameters for assessing energy use and carbon footprint in green building design because they observed a need for universally acceptable parameters to assess design and construction strategies for reducing operational energy usage and its associated GHG emission (12).

Sangamesh et al. (2021) emphasized energy and water conservation in Indian construction by implementing green and zero energy concepts leading to water conservation(13). Sharma et al. (2018) focused on energy efficiency in educational buildings, particularly libraries and their results indicate renewable energy solutions, like solar photovoltaic panels can make buildings self-sufficient (14). Kumar (2016) discussed that transitioning from conventional energy buildings to net zero energy buildings is pertinent for reducing carbon emissions (15).

Rethnam and Thomas (2023) proposed a community-based hybrid bottom-up modelling approach using UBEM for energy conservation (16). Agnihotri et al. (2023) analysed the impact of façade shading in reducing energy demand in commercial buildings (17). Ohene et al. (2022) identified substantial obstacles to adopting Net Zero Carbon Buildings (NZCBs) such as financial barriers, coupled with skill and knowledge constraints, which were more difficult than legislative challenges, highlighting the importance of increased public awareness, appropriate regulations, and capacity building (18).

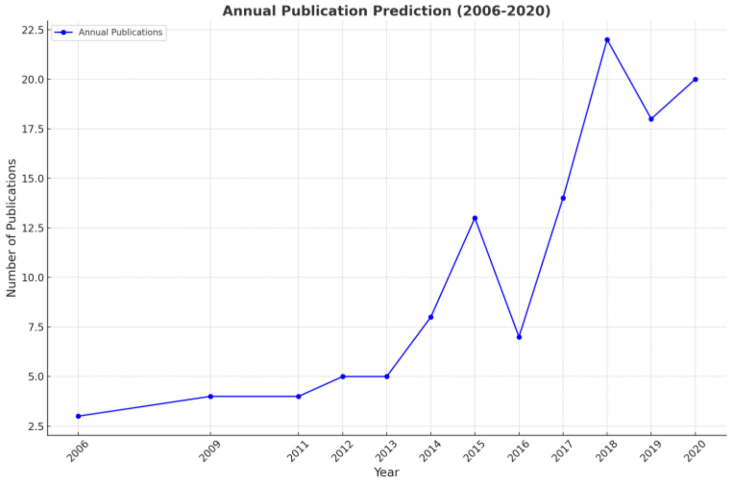

Figure 3: Annual publications on Whole Life Cycle (WLC) assessment(19)

In 2020, India contributed 20 publications (Figure 3) on Whole Life Cycle (WLC) Assessment against a worldwide total of 191, a relatively small output considering the country's increasing contribution to global greenhouse gas emissions and the urgent necessity for India to adopt a proactive and responsible stance in the evolving climate regime(20).

3.1 Existing Indian frameworks and drawbacks:

India's current benchmarks for net-zero buildings encompass several frameworks and schemes. Key benchmarks include the Model Building Byelaws and the Energy Conservation Building Code (ECBC) from the federal government, aiming at clean energy integration in building design (21). The Indian Green Building Council (IGBC) initiated voluntary ratings in 2018, focusing on renewable energy and energy-efficient designs (21). The Ministry of Power launched the Shunya scheme in 2021, certifying buildings offsetting their energy with renewable sources (22).

There are numerous drawbacks that can be observed in these frameworks. The lack of clear government guidelines on net-zero buildings creates ambiguity, making consistent design, assessment, and certification challenging. The voluntary nature of IGBC ratings may lead to less adherence to net-zero principles. Shunya scheme's narrow focus on energy offset overlooks energy-saving opportunities through design and operation, specifically the fabric first approach (22). The lack of a nationalized LCA inventory may hinder accurate emissions assessment. Existing building codes have a limited scope regarding net-zero buildings, potentially inhibiting a holistic approach towards achieving net-zero status. Additionally, a possible lack of awareness, expertise, and adequate infrastructure can further impede the adoption and effective implementation of net-zero principles in India.

There may still be a debate about the necessity of India developing its own benchmarking system for carbon emissions, given the existence of international standards. This need can be explained by two key reasons. First, India's building sector is vast and continuously expanding, driven by initiatives like the "housing for all" scheme. Second, the geographical context of a benchmarking authority significantly influences the standards it sets. Many existing carbon assessment frameworks originate from countries where there is already a high awareness of carbon emissions in the building sector, and the climate is generally colder, necessitating heat gains, higher U-values, and efficient heating systems. In contrast, India, while seeing emerging initiatives in benchmarking, lacks mandatory certifications for buildings to demonstrate their carbon emission reductions. In countries like the UK, mandatory certifications such as Energy Performance Certificates (EPCs) and Environmental Product Declaration (EPDs) facilitate the early-stage assessment of buildings. This approach not only sheds light on the current state of the building stock but also identifies potential improvements.

4.0 Methodology

4.1 Background research for Embodied carbon assessment:

The Indian government's response to the urban housing deficit, as identified by KPMG (2014), involves the ambitious "Pradhan Mantri Awas Yojna" (PMAY) (*Prime Minister Housing scheme*), which aims to construct millions of houses under its Urban and Rural schemes(21). This large-scale development, while addressing the housing shortage, also creates a need for sustainability, particularly concerning waste generation and the use of non-renewable materials. As shown in the Figure 4 below, more than 11 million houses were under construction under this scheme.

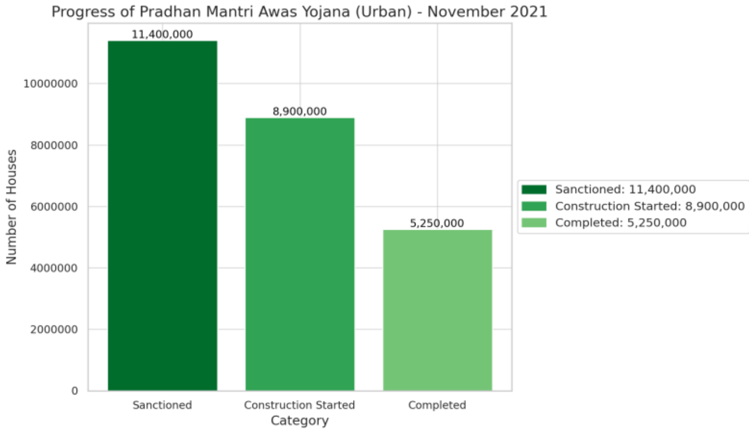

Figure 4: Progress of Pradhan Mantri Awas Yojana (PMAY) (*Prime Minister Housing scheme*) – November 2021(21)

The Light House Projects (LHP) and Demonstration Housing Projects (DHP), initiatives of PMAY in collaboration with Affordable Sustainable Housing Accelerators (ASHA) and the Global Housing Technology Challenge (GHTC), were designed to demonstrate sustainable construction practices (23).However, to utilise the full potential of these projects, it should be imperative that they align with international benchmarks for sustainability, particularly in terms of carbon emissions and the built environment.

The considerations while adopting embodied carbon calculations from various datasets to the Indian context are understanding locally sourced materials, local construction practices, regional climatic conditions, relevance of international emission factors depending on local energy source, availability of data specific to carbon calculation and the impact of diverse socio-economic state on design choices.

Framework for Embodied Carbon Assessment in Building Projects

1. **Initial data assessment :**The first step involves studying various construction techniques and their carbon emissions in stages such as material production, transport and disposal. The carbon emission data related to specific materials should be researched before determining any construction details such as build-up of the fabric etc. For example: replacing a wooden frame window with a steel frame window due to factors such as cost can be highly carbon intensive.

2. **Defining System Boundaries for Material Assessment:** This step involves establishing a cradle-to-cradle (recycling potential) system boundary for evaluating building materials. This can be attained by utilising tools like One Click Life Cycle Assessment (LCA)(24) focusing on the building construction, modifying the data according to the building assessed, and expanding the assessment to include waste management and recycling capabilities. This step is crucial for a comprehensive understanding of the materials' total lifecycle impacts.

3. **Life Cycle Assessment (LCA) of Building Materials:** Conduct a context-based LCA on a diverse range of building materials, assessing them across multiple impact categories such as Global Warming Potential, Acidification, and Biogenic Carbon Storage. This procedure assists in pinpointing materials that emit a high level of carbon, such as steel and aluminium, and omits them from further assessment unless their use is imperative for technical justifications. In this step the worst performing material in the baseline model is replaced by an alternative materials to test its feasibility. The Figure 5 below highlights how 20 materials selected by the author to test, perform under comparative analysis done by using Global warming potential as the metrics(25).

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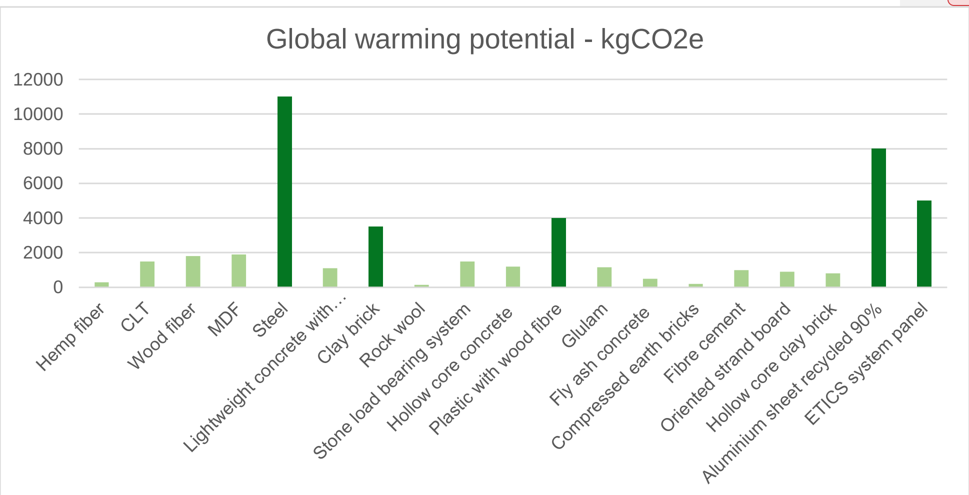

Figure 5: Global warming potential of 20 materials in comparison(25)

4. **Comparative Analysis and Material Shortlisting:** Highlighting the materials with lower carbon emissions, leading to the shortlisting of sustainable options. Further scrutinise these materials across identified impact categories. Factor in the recyclability

of materials at their end-of-life stage. After thorough analysis and comparison, select the material with the most favourable carbon emission profile.

5. **Final Analysis and Conclusion:** Conclude the assessment by highlighting the chosen material's superior performance in carbon emission metrics compared to other alternatives, such as steel. This rigorous methodological approach ensures the selection of an environmentally optimal material, considering both its impact and recyclability.

4.2 Background research for Operational carbon assessment:

In the operational carbon assessment in conjunction with the Passivhaus Trust's 'fabric first' approach(26) , key simulation parameters such as Window to Wall Ratio (WWR), External Shading type, Insulation/U-value, g-value of glazing, cooling-set-point temperature, and Natural ventilation were meticulously analysed. This process involved distinguishing between optimisation and sensitivity analysis, with the latter employing the Latin Hypercube Sampling method to identify variables like WWR, external shading, wall construction type, cooling set point temperature, and glazing type, most sensitive to operational carbon.

Pathway for Assessing Operational Carbon in Buildings:

1. **Initial Dynamic Thermal Modelling:** Start with dynamic thermal modelling to assess the interplay between passive and active strategies on operational carbon. This involves evaluating different building design scenarios for their impact on energy efficiency and carbon emissions.

2. **Comprehensive Sensitivity Analysis:** Conduct a detailed sensitivity analysis to pinpoint critical variables that significantly affect carbon reduction. Focus on elements such as building orientation, construction of external walls, position of windows, window-to-wall ratio, shading devices and explore their influence on operational carbon by assessing their effectiveness in lessening solar gain. Evaluate these variables for their impact on the building's thermal performance.

3. **Detailed Uncertainty Analysis:** Use multiple simulations for uncertainty analysis of design variables such as fabric, form and orientation to refine the model. This step is essential to improve the confidence in achieving carbon reduction targets and affirming the model's forecasts.

4. **Development of Objective Functions for Key Performance Indicators (KPIs):** Establish objective functions for KPIs, relevant to the research such as "Minimising Discomfort" and "Minimising Total Site Energy". Set explicit performance targets to direct the optimisation process.

5. **Iterative Analysis for Optimisation:** Perform extensive iterative analysis, using insights from sensitivity analysis, to identify the best solutions like the variable window-to-wall ratios. Undertake numerous iterations to enhance the building design for optimal performance. The Figure 6 below illustrates that while the Pareto graph provides results for each simulation, further evaluation is necessary to arrive at a comprehensive outcome. Merely selecting the top result may not always lead to the best solution, as it is essential to consider a holistic approach for the final decision.

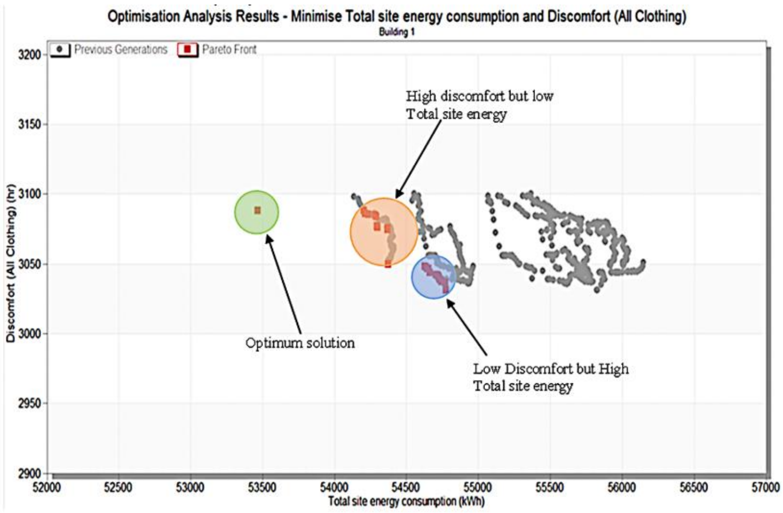

Figure 6: Optimization results with Pareto graph(25)

6. **Secondary Simulation for Active Cooling System Selection:** After passive optimisation, execute a secondary simulation to select the most efficient active cooling system. Assess various systems, including Heat Pumps for their reverse cooling and potential to improve energy efficiency and reduce carbon emissions.

7. **Comparative Analysis of Base vs Optimised Models:** Carry out a comparative analysis between the original and optimised models, focusing on the changes in variables and strategies. Highlight the significant role of passive strategies in reducing overall energy consumption and operational carbon.

8. **Exploration and Integration of Renewable Energy Systems:** Investigate and incorporate renewable energy systems, especially Photovoltaic (PV) systems, to lessen dependence on grid-supplied electricity. This is a critical step in the research to advance the building's sustainability profile.

9. **Implementation and Optimisation of PV Systems:** Conduct a comparison of the annual operational carbon figures between the optimised model and those with integrated renewable energy systems. Aim to show the success of these strategies in realising negative carbon emissions through in-situ energy generation. Install photovoltaic systems, using tools like Photovoltaic Geographical Information System (PVGIS) for the best sizing and orientation. Integrate these findings into the thermal model to promote the building's energy self-sufficiency.

10. **Operational Carbon Data Comparative Analysis:** As showcased in the Figure 7 below when this pathway was followed a significant reduction in carbon emissions was observed by meticulous planning at early design stage and implementation of various active and passive strategies.

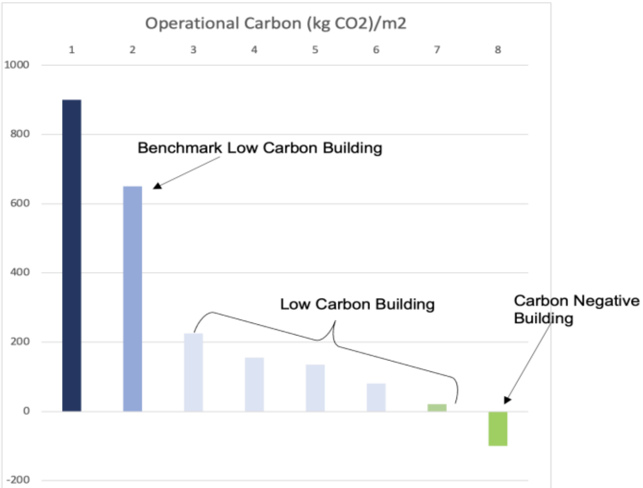

Figure 7: Operational carbon comparison from baseline to final iteration(25)

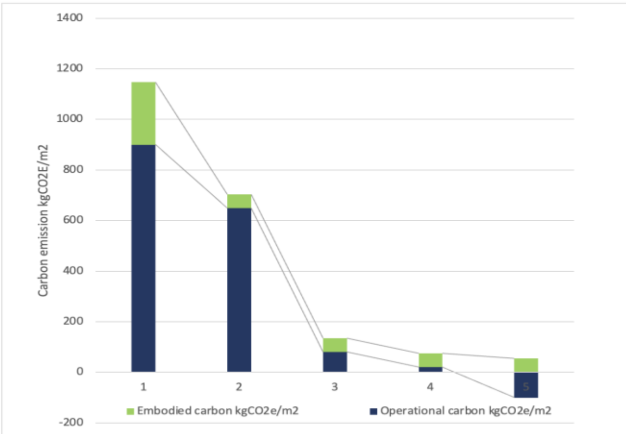

Figure 8: WLC emission comparison (Author)

The pathway's success in lowering embodied and operational carbon in buildings, which reduces their total carbon footprint, is shown in Figure 8.

5.0 Pathway to Net zero

In the 2022 analysis conducted by the author, the focus was on the impact of using an embodied carbon framework (Figure 9) for construction methods, showcasing significant strides towards carbon assessment for residential buildings in India (25). This research included the calculations of embodied and operational carbon emissions, leading to optimisations that aligned with global environmental standards and reinforced India's commitment to sustainable practices (25). Particularly notable was the Life Cycle Assessment (LCA) of six Light House Projects across India. This assessment revealed substantial environmental impacts due to carbon emissions, with the Chennai project being the most carbon-intensive, primarily due to its use of prefabricated sandwich panels and steel frames.

A crucial element of the study was the design optimisation with alternative materials. Glulam emerged as the least carbon-emitting material among the 20 evaluated, prompting a shift in the construction approach for the Chennai LHP project. By substituting precast concrete with Glulam, a notable reduction in carbon emissions was observed (25).The implementation of passive strategies and efficient active systems, including photovoltaic (PV) panels, led to significant reductions in both energy demand and operational carbon emissions, surpassing the 2025 ZERO EMISSION TARGET (27) and indicating a move towards a carbon-negative status. Moreover, the selection of Glulam, sourced from a facility less than 300 km away, significantly reduced carbon emissions related to transportation(25).

The operational carbon framework further complemented these results. Initial dynamic thermal modelling set the stage for comprehensive sensitivity and uncertainty analyses, leading to the development of objective functions for Key Performance Indicators (KPIs) (25) .The selection of effective design variables and iterative analysis optimized the building's operational carbon performance. The integration of renewable energy systems, particularly PV systems, dramatically reduced operational carbon emissions, achieving a carbon-negative status.

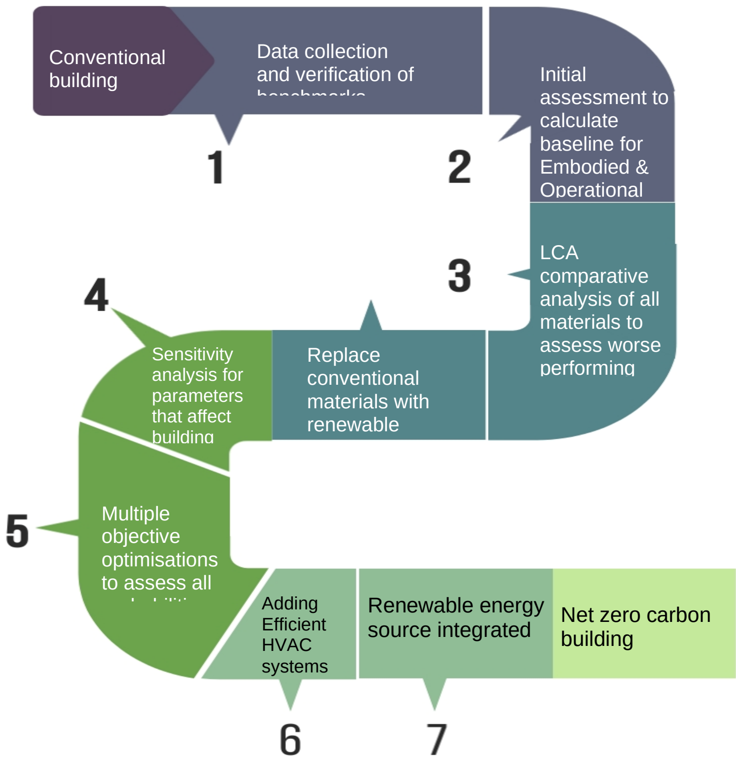

Figure 9: Graphical representation of Pathway to Net zero carbon (Author)

6.0 Conclusions

In conclusion, the proposed pathway established by the author proved instrumental in guiding design decisions at an early stage, ensuring that both embodied and operational carbon assessments were thoroughly considered. The resultant reductions in carbon emissions across multiple projects underscore the framework's utility in steering construction projects toward sustainability and achieving ambitious environmental targets. This structured approach to carbon assessment is particularly beneficial for assessors in contexts with limited data sets and Environmental Product Declarations (EPDs), offering a comprehensive pathway to sustainable and low-carbon construction.

7.0 References

1. Ondon L, Nergy E, Ransformation T. LETI Climate Emergency Design Guide How new buildings can meet UK climate change targets.
2. LETI Embodied Carbon Primer [Internet]. Available from: www.LETI.london
3. Ohene E, Chan APC, Darko A, Nani G. Navigating toward net zero by 2050: Drivers, barriers, and strategies for net zero carbon buildings in an emerging market. Build Environ. 2023 Aug 15;242:110472.
4. 2021 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION Towards a zero-emissions, efficient and resilient buildings and construction sector [Internet]. Available from: www.globalabc.org.
5. 2030 Climate Challenge [Internet]. [cited 2023 Dec 10]. Available from: https://www.architecture.com/about/policy/climate-action/2030-climate-challenge
6. Kumar A, Singh P, Kapoor NR, Meena CS, Jain K, Kulkarni KS, et al. Ecological footprint of residential buildings in composite climate of India—A case study. Sustainability (Switzerland). 2021 Nov 1;13(21).
7. Characterization of wastes from construction and demolition sector _ SpringerLink.
8. Jain M, Rawal R. Emissions from a net-zero building in India: life cycle assessment. Buildings and Cities. 2022;3(1):398–416.
9. Decoding India’s real estate boom_ What’s driving the demand_ - India Today.
10. India - growth rate of construction industry 2010-2020 | Statista [Internet]. [cited 2023 Dec 10]. Available from: https://www.statista.com/statistics/878482/india-growth-rate-of-construction-industry/
11. Hu M. Building impact assessment—A combined life cycle assessment and multi-criteria decision analysis framework. Resour Conserv Recycl. 2019 Nov 1;150.
12. Usman AM, Abdullah K. Development of comprehensive energy usage impact and carbon footprint parameters for green building life cycle assessment. Journal of Engineering, Design and Technology. 2022;ahead-of-print(ahead-of-print).
13. Sangamesh, Faraz M, Gagan, Mallinath, Aqib M, Patil N. Net Zero Energy Apartment. IOP Conf Ser Mater Sci Eng [Internet]. 2021 Feb 1 [cited 2023 Dec 3];1070(1):012093. Available from: https://iopscience.iop.org/article/10.1088/1757-899X/1070/1/012093
14. Sharma S, Kumar A, Kumar N, Gupta S. Developing a Net Zero Energy Building: A Case Study of an Institutional Library. SSRN Electronic Journal [Internet]. 2018 Jun 19 [cited 2023 Dec 3]; Available from: https://papers.ssrn.com/abstract=3198651

15. Kumar S. Towards net zero energy solar building, system, and concepts. 2016 1st International Conference on Sustainable Green Buildings and Communities, SGBC 2016. 2017 May 30;
16. Ramalingam Rethnam O, Thomas A. Urban building energy modelling-based framework to analyze the effectiveness of the community-wide implementation of national energy conservation codes. Smart and Sustainable Built Environment. 2023;ahead-of-print(ahead-of-print).
17. Agnihotri S, Kumar S, Meenatchisundaram A. Role of façade shades in energy efficiency in commercial buildings. IOP Conf Ser Earth Environ Sci [Internet]. 2023 Jul 1 [cited 2023 Dec 3];1210(1):012005. Available from: https://iopscience.iop.org/article/10.1088/1755-1315/1210/1/012005
18. Ohene E, Chan APC, Darko A. Prioritizing barriers and developing mitigation strategies toward net-zero carbon building sector. Build Environ. 2022 Sep 1;223:109437.
19. Keyhani M, Abbaspour A, Bahadori-Jahromi A, Mylona A, Janbey A, Godfrey P, et al. Whole Life Carbon Assessment of a Typical UK Residential Building Using Different Embodied Carbon Data Sources. Sustainability 2023, Vol 15, Page 5115 [Internet]. 2023 Mar 14 [cited 2023 Dec 10];15(6):5115. Available from: https://www.mdpi.com/2071-1050/15/6/5115/htm
20. Hussien A, Abdeen Saleem A, Mushtaha E, Jannat N, Al-Shammaa A, Bin Ali S, et al. A statistical analysis of life cycle assessment for buildings and buildings' refurbishment research. Ain Shams Engineering Journal. 2023 Oct 1;14(10):102143.
21. Indian Green building council [Internet]. [cited 2023 Dec 3]. Available from: https://igbc.in/igbc-green-new-buildings.php
22. Shunya Labeling | BUREAU OF ENERGY EFFICIENCY, Government of India, Ministry of Power [Internet]. [cited 2023 Dec 3]. Available from: https://beeindia.gov.in/en/programmesenergy-efficiency-in-buildings/shunya-labeling
23. Bureau of Energy Efficiency 1 Schedule for Shunya (Zero) Labelling Programme for Net Zero and Net Positive Energy Buildings Schedule for Shunya (Zero) Labelling Programme for Net Zero and Net Positive Energy Buildings 1. SCOPE: The programme targets the Net Zero Energy Buildings (NZEB) and Net Positive Energy Buildings (NPEB).
24. Automate Building Life Cycle Assessment with One Click LCA [Internet]. [cited 2024 Jan 27]. Available from: https://www.oneclicklca.com/construction/life-cycle-assessment-software/
25. Shweta Salvankar. Affordable Sustainable housing in India Life cycle assessment (LCA) of conventional building materials and renewable alternatives. [Cardiff]: Welsh school of architecture; 2022.
26. How to build a Passivhaus • Building fabric.
27. Whole life carbon assessment (WLCA) for the built environment [Internet]. [cited 2023 Dec 10]. Available from: https://www.rics.org/profession-standards/rics-standards-and-guidance/sector-standards/construction-standards/whole-life-carbon-assessment