International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 08 | Aug - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Life Cycle Assessment in Structural Design

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Abstract - LCA is an essential instrument in contemporary structural design and constructing it, in which the impact on the environment can be assessed at any stage of the life of a structure, including its extraction and production of raw materials, the process of construction and operation to the demolition and the final stage of disposal. Such assessment method helps in sustainable decision making since it relates the amount of energy a building consumes, amount of gaseous emissions, and amount of resources used based on the design decisions made. The important role of LCA in designing structures is to enable architects and engineers to use environmentally friendly materials and systems in the design and planning to minimise ecological footprint in the completed structure and foster circle economy values. The paper examines nature of LCA principles, LCA methods and its applications in the field of structural engineering and also the importance of sustainable development in the built environment.

❖ **Key Words :** Introduction, Literature Review, Case Studies, Objective, Research Gap, Future Scope, Life Cycle Assessment, Methodology, Benefits Of LCA, LCA in Building Codes and Rating Systems, Limitations,

1. INTRODUCTION

A product Life Cycle Assessment (LCA) is a process of measuring the environmental impact of the objects on the environment through their entire life cycle; starting with the extraction of raw materials, continuing to manufacturing, distribution, use and disposal. In structural engineering, LCA can be used to make judgments about the environmental implications of building materials, designs process of the construction and the functioning and decommissioning of the building and the infrastructure.

In structural engineering, LCA is growingly being accepted as a resource and to facilitate a sustainable practice. The building sector is the major contributor to world emissions and resources usage. Considering LCA as part of the design and decision-making process allows engineers to point out how to impact the environment the least, e.g., by utilizing less energy, emitting less carbon, and using less material.

2. LITERATURE REVIEW

• **Cabeza et al.(2014) -** LCA is a structured approach to diagnosing the environmental consequences of all buildings. It was observed that ESI of LCA has the potential to affect the choice of materials of constructions and energy levels at an early stage of the design process significantly. Likewise, Buyle, Braet, and Audenaert (2013) noted that the differing environmental performance of structural systems (e.g., concrete, steel, and timber) can be fairly compared through LCA because it considers a wide range of impact categories, including global warming potential, energy and water use.

• **Bribian et al. (2011) -** It seems that quickly cooling down can cause a better performance the next time around, but it can worsen as well, and it can also lead to a lower performance.
The researchers have made a comparative analysis of different kinds of materials used in construction and found out that structures made of timber usually have less overall environmental impact than that of strongly crushed and concrete. They however indicated that the advantages of timber will be dependent on sustainable forestry practices and local availability. Sandanayake et al. (2016) confirmed this result, emphasizing that it is significant because of the regional specificity of the data that will be used, seeking to render LCA results more accurate and relevant in construction.

• **Ortiz, O Castells, F and Sonnemann, G. (2009) -** Sustainability in construction industry review of latest advances on basis of LCA. Concentrated on the environmental effects of the materials utilized in structure systems. Identified concrete and steel are some of the significant contributors to embodied substantial impacts. Recommendations of material substitutions and optimization during designing.

• **Gervasio, H. & da Silva, L.S. (2012) -**LCA of steel-concrete composite buildings: It conducted LCA of and compared conventional buildings made of steel and concrete to those made of steel-concrete composite. Demonstrated that structural choices have a great influence on the composite environmental impact.

• **Sinha, A., Lennartsson, M., and Frostell, B. (2013) -** Use of input-output LCA in evaluating buildings with comparison of building using wood sturctures, steel structures and concrete structures. The most eco-friendly according to the global warming potential was timber. Arguments of trade-offs between material selection, performance and environmental impact have been discussed.

• **Wolf, C., Pomponi, F. and Moncaster, A., 2017** - The quantification of embodied carbon dioxide equivalent of buildings: a critique of current industry practice. Raised criticism of industry-practices towards embodied carbon assessment. The improved situation is suggested to be the integration of LCA in BIM (building information modeling) and design processes. Facilitated open-access databases to materials.

3. CASE STUDIES

• **Comparative Life Cycle Analysis of carbon reinforced concrete -** It is found that this paper compares the environmental consequences of various terminals to end a carbon reinforced concrete structure. It discusses the effectiveness of recycling and reusing where they can reduce the carbon footprint of the material by a lot.
• **LCA of a Low-Cost Building at Rishra, West Bengal, India -** This case study will evaluate a PMAY or Pradhan Mantri Awas Yojana, low-cost housing project. The LCA lists the significant environmental impacts and offers some improvements to impactful building processes within affordable housing.
• **LCA of building construction materials in Brazil -**This paper employs LCA in order to assess the environmental impact of construction materials. It shows the high impact of steel, cement, and ceramic materials on the consumption of non-renewable energy and the global warming potential.
• **Luxembourg, Comparative LCA of structural systems** - on office buildings -This study contrasts the three building structures, steel concrete composite, prefabricated reinforced concrete and timber frame of a nine-story office building in Luxembourg. The timber frame had the lowest embodied carbon on a 50-year lifespan highlighting the environmental benefits of wood-based construct.
• **Daniel Gorin, Ph.D. HDR Revue dEtudes Ferroviaires 142 (2013) -** The paper presents a detailed LCA of the Tours-Bordeaux high-speed rail project and evaluates the impacts during the construction and operating stages through the end of life. The paper has found primary steel production as one of the major contributors of environmental impacts.

4. OBJECTIVE

The main aim of the study is to discuss how Life Cycle Assessment (LCA) can be used in structural design and how useful LCA can be as a means of making construction process more environmentally sustainable. In particular, the objects of the study are as follows :-

• Examine the LCA principles and methodologies as related to the structural systems.
• Evaluate the environmental consequences of the main structural materials (e.g. concrete, steel, timber) at the level of life cycles.
• Compare the approach of alternative design strategies in terms of LCA-based indicators like carbon footprint, energy use and resources consumption.
• Determine the problems and constraints in the application of LCA in reality where it comes to structural design.

5. RESEARCH GAP

• Ways and means of effectively integrating LCA at the design stage have not yet been worked out, with little to offer in the way of practical methods and tools to enable LCA to be incorporated easily into day-to-day design practice.
• The need for region-specific information due to most available LCA databases being already generalized and therefore having no suitable interpretation to a specific region in terms of where materials are sourced, energy providers, etc.
• They pay less attention to narrow materials categories (e.g., engineered timber, geopolymer concrete, nanoengineered composites) that may not fit existing broad categories (e.g., timber, concrete, and steel).
• The majority of LCAs are steady-state and do not consider long-term technological changes, evolving energy grids or material recycling in the future, thus providing oversimplified long-term impact analyses.
• Many caution that despite the promise of LCA to inform sustainable material selection, LCA is not being utilized in the practice of design, procurement, and policymaking.

6. FUTURE SCOPE

• Creation of Regional and Material-Specific LCA Databases: The use of area-specific data sets of materials and energy systems will both increase the accuracy of LCA findings and facilitate design in a sensitive context.
• Full integration with building and design AI (LCA) artificial intelligence can be used in interaction with the building information management (BIM) models to perform real-time design optimization on a environmental basis.
• Adoption of Circular Economy and Modularity Principles: LCA will facilitate a transition to recyclable, reusable and modular construction systems by assessing the long-term environmental advantages and fostering designability to disassemble.
• Cloud-based and Real-time LCA Tools: The future anticipates cloud-based systems to enable multi-stakeholder collaboration and real-time updates of LCA results as construction progresses to encourage informed, low-carbon decisions throughout the project life.

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7. LIFE CYCLE ASSESMENT

LCA is a process that undertakes to explore the cycle of life in a structure in relation to environmental consequences of each process. It assists engineers evaluate sustainability of building materials, designs and construction practice based on analysis of their environmental impacts throughout cradle to grave, important phases of LCA are :

• **Material Extraction -** The impact on the environment of extracting raw materials (including steel, concrete, timber etc.).

• **Manufacturing and Transportation -** The energy and resources it takes to process, manufacture and transport materials to the site of construction.

• **Construction -** The effects of the construction of the building energy, waste generated, and emissions equipment and process.

• **Use and Operation -** How the building is used and operated (e.g. energy usage such as heating, cooling, lighting, water usage, as well as maintenance).

• **End-of-Life (Demolition or Recycling) -** Disposal, demolition or recycling of materials at end of life of the building, energy used and waste generated at this stage.

8. METHODOLOGY

The procedure of using the methodology incorporates the following steps with a combination of other tools:

Selection of LCA tools

Selection of LCA software is a matter of project scope, complexity and data availability, taking into account region specifications. The most often used tools in structural LCA are :

• SimaPro - One of the most popular applications to perform a full LCA analysis, includes strong database (e.g., Ecoinvent) and a broad range of impact assessment methods (e.g., ReCiPe, Eco-indicator 99).

• GaBi - Mostly used in industry, data libraries are heavy in the field of construction materials and process.

• OpenLCA - The tool, which has flexible modeling capabilities and access to multiple databases and includes ELCD and Agribalyse.

• Athena Impact Estimator - specifically customized to North American building projects, it is appropriate at the early design stage of building LCA.

9. BENEFITS OF LCA

LCA has a number of important advantages related to structural engineering and sustainability objectives more generally. The most important benefits of using the LCA in designing and developing buildings and infrastructure include the following:

(a) Reduction in environmental impact :

• Reducing Carbon Footprint - LCA allows engineers to learn which material, construction or operational stage may have the least environmental impact and offers a greenhouse emitters reduction alternative.

• Resource Conservation - LCA enables it to determine the entire life cycle of a structure, which helps it use materials with minimal impacts that are also renewable and avoids using finite resources to the extent possible.

• Waste Reduction - LCA documents the opportunities to reduce material waste, maximize recycling and reuse of materials at the end of the life of the building.

(b) Conformance with regulations and standards :

• **Complying with Sustainability Requirements -** LCA is particularly asked to do so in order to achieve green building certifications, like LEED, BREEAM, or WELL, which are based on demonstrating environmental performance.

• **Servicing Regulatory Adherence -** LCA can assist structures to achieve the regulatory requirements in terms of carbon footprint, energy consumption, and waste disposal in most jurisdictions.

(c) Increased Sustainability Performance :

• **Holistic Approach -** LCA considers the full life of a building including everything, material extraction to deconstruction ensuring sustainability is a consideration with every step.

• **Practices promoting Circular Economy -** LCA promotes behaviour that favours the circular economy by designing buildings where materials may be reused and recycled and hence minimizing consumption of new raw materials and creation of waste material.

10. LCA IN BUILDING CODES & CODING SYSTEMS

• LCA is becoming an increasingly popular method of sustainable design as building codes and green building rating systems change and adapt. A couple of examples can speak about this tendency (Anderson et. al., 2012).
• Future LEED v4 (formerly known as LEED 2012), a whole building LCA tool, is a Materials and Resources credit alternative, due to be released in the fall of this year and is currently available to LEEDv3 projects as Pilot Credit 63.
• IgCC 2012 provides several elective project points when whole building LCA is published
• American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) 189.1 provides an option to use LCA as a performance alternative in choosing building materials instead of prescriptive requirements of recycled, regional and biobased materials
• LBC 2.0 has an embodied carbon calculation of the project under Materials Petal
• International rating systems like the UK, Germany and Hong Kong have tools that allow them to gauge building material impacts through the use of LCA.

11. LIMITATIONS

On the same breath, those who utilize LCA should also remember its weaknesses. LCA does very well what it can do, which is take account of the flows of the inputs and outputs of a given process or a given system, and correlate those to measurable identifications of environmental and health sides, when there are well-known and well-understood correlations. As a result, in the case of uncertain risks or risk that is not present in the inventory, the consequences can be equally uncertain or cannot be given by LCA at all. As an example the effects of building products in use will often be poorly quantified under LCA due to lack of data collection or research on emissions in use under wide range of conditions. Buildings are not similar to consumer goods (such as bottles of water and cellular phones) where their future content, usage, and length of life are relatively predictable. Virtually each building is individual and how it will be used and evolve throughout its life is largely unpredictable.

12. CONCLUSIONS

In a wrap, Life Cycle Assessment (LCA) is a useful instrument in structural engineering in offering sustainability through assessing the environmental effects of a material, design and mode of construction during the life of such a building. LCA allows structural engineers to make more wise decisions that will minimize resource use, carbon footprint, and waste, and ensure more eco-friendly buildings and infrastructure. Nevertheless, its applicability is conditioned by the quality of data, correct modelling and the possibility to take into account regional and temporal differences.
Even though LCA has its limitations, the tool still presents an important way to know about the environmental performance of projects, lending itself to regulatory operations and offering support to the sustainability of the built environment over the long term. Adopting LCA in their work, engineers will make contributions to the creation of more sustainable structures that will meet the standards of global sustainability, having a lower environmental impact.

13. ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude to our respected Professor Dr. Anup Kumar Mandal , Associate Professor of Civil Engineering Department Techno India University for providing valuable advice, resourceful guidance and close supervision in all respect all throughout. I do acknowledge my gratefulness to all professors and staff of Civil Engineering Department Techno India University, Salt Lake for extending all facilities to carry out the present study. Finally, I am grateful to all my friends, seniors and my parents for their co-operation during the preparation of this research proposal. It is due to their regular encouragements and enlightening discussions for which this Term paper could be brought to the current shape.

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