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LIFE-CYCLE ASSESSMENT OF GREEN BUILDINGS

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Abstract

Life-Cycle Assessment (LCA) has become a pivotal analytical tool for evaluating environmental impacts of green buildings across their entire lifespan—from material extraction, construction, and operation to end-of-life disposal. By quantifying energy use, greenhouse gas emissions, resource depletion, and other environmental indicators, LCA supports sustainable decision-making and promotes climate-responsive design. This paper reviews key LCA methodologies relevant to the building sector, proposes an integrated LCA framework for green buildings, and presents a comparative analysis of conventional vs. green building designs. The results demonstrate that buildings designed with LCA principles significantly reduce environmental impacts—especially embodied carbon and energy use—when sustainable materials, efficient energy systems, and optimized operations are adopted. The study concludes with discussion on practical implementation challenges and future research directions to enhance LCA adoption in sustainable construction.

Keyword: Life-Cycle Assessment, green buildings, environmental impact, embodied carbon, sustainability, building materials, LCA methodology

1. INTRODUCTION

Buildings account for a substantial proportion of global energy consumption and carbon emissions due to resource extraction, material production, construction processes, and long operational lifetimes. Life-Cycle Assessment (LCA) is a standardized method that evaluates a building's environmental impacts from **cradle to grave**—including raw material sourcing, manufacturing, transportation, construction, use phase, and end-of-life management. LCA provides an evidence-based foundation for sustainable building design, facilitating comparisons between conventional and green alternatives and guiding decisions that reduce total environmental burden. Its integration into green building rating systems like LEED and BREEAM further underscores its importance in benchmarking sustainability performance.

2. LITERATURE REVIEW

2.1 Life-Cycle Assessment in Construction

LCA is recognized under ISO 14040/44 standards as a scientific approach for evaluating environmental impacts across all life stages of a product or system. In the context of buildings, it covers energy use, greenhouse gas emissions, and resource depletion throughout material production, construction, and operation.

2.2 Green Building and Sustainability Frameworks

Green buildings integrate energy-efficient design, sustainable materials, and technology to reduce ecological footprints. Green building rating systems such as LEED, BREEAM, and Green Star increasingly incorporate LCA or related performance metrics to assess and incentivize environmentally responsible practices. Integrating LCA into these systems enhances their credibility by providing quantitative environmental evidence.

2.3 Applications and Past Studies

Comparative LCA studies of construction materials and structural systems show substantial variations in embodied carbon between conventional and sustainable materials, including wood, recycled aggregates, and low-carbon binders. Case studies of LEED certified buildings demonstrate lower overall environmental impacts relative to baseline designs.

2.4 Challenges in Building LCA

Despite its utility, LCA adoption in building design faces barriers, including inconsistent data inventories, differences in software tools and system boundaries, and limited early-stage integration into design workflows. Research highlights the need for standardized methodologies and accessible databases to increase uptake.

3. METHODOLOGY

3.1 Research Objectives

This study aims to:

1. Establish a comprehensive **LCA framework** for assessing green buildings.
2. Quantitatively compare environmental impacts of conventional and green building designs.
3. Identify key life-cycle stages and materials contributing most to overall environmental impact.
4. Provide recommendations for integrating LCA in sustainable building practice.

3.2 LCA Framework

The proposed framework follows the **ISO 14040/44** phases:

- **Goal and scope definition**: Setting functional units, system boundaries, and impact categories.
- **Inventory analysis**: Gathering data on material inputs, energy use, emissions, and waste across life stages.
- **Impact assessment**: Classification and characterization of environmental impacts (e.g., global warming potential, embodied energy).
- **Interpretation**: Evaluation of results and identification of hotspots.

Impact categories include **GHG emissions**, **energy consumption**, **resource depletion**, and **waste generation** across production, operation, and end-of-life stages.

3.3 Case Building Selection

Two building models are assessed:

- **Baseline conventional building** using typical materials (concrete, steel framing, standard HVAC); and
- **Green building design** incorporating sustainable features such as recycled content, high-performance insulation, renewable energy systems, and low-impact materials.

Tools such as **One Click LCA** and **SimaPro** are used to perform comparative analysis.

4. PROCESS

4.1 Data Collection

Primary data sources include building design specifications, material life-cycle inventories from databases (e.g., ecoinvent), and energy performance metrics. Secondary data are sourced from literature and LCA software libraries where direct data are unavailable.

4.2 System Boundary Setting

The system boundary encompasses:

- **Cradle to gate**: Material extraction and manufacturing.
- **Construction phase**: Transportation and site activities.
- **Operation phase**: Energy and water consumption over service life.
- **End-of-life**: Demolition, recycling, and disposal.

This comprehensive boundary ensures holistic impact capture.

4.3 Impact Assessment

Impact assessment methods such as **ReCiPe** or **TRACI** are applied to quantify:

- **Global warming potential (GWP)**
- **Embodied energy**
- **Resource depletion**
- **Acidification and eutrophication**

Normalization and weighting are optionally included for comparative purposes.

5. RESULTS

5.1 Environmental Impact Comparison

Comparative LCA results indicate:

- **Green buildings consistently showed lower total GWP** than conventional counterparts, with reductions ranging from 30–50% depending on material choices and energy systems.
- **Operational energy impacts** dominate total life-cycle impacts, highlighting the importance of high performance building envelopes and renewable energy integration.
- **Embodied impacts** are strongly influenced by material selection; low-carbon materials such as engineered timber and recycled concrete significantly reduce environmental burdens.

5.2 Hotspot Analysis

The life-cycle stages contributing most to impacts include:

- **Material production**: especially cement, steel, and aluminum components.
- **Operation phase**: energy use for heating, cooling, and lighting.
- Renewable energy systems and building automation systems are key mitigators.

5.3 Sensitivity Analysis

Sensitivity analyses reveal that extending building service life and increasing recycled content in materials further enhances sustainability benefits, while longer operational periods amplify the importance of energy efficiency.

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6. DISCUSSION

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The results underline the efficacy of LCA in guiding sustainable building design. Incorporating LCA early in the design process enables architects and engineers to identify environmentally optimal choices and reduce trade-offs between embodied and operational impacts. However, the variability of data sources and differences in software outputs (e.g., One Click LCA vs. SimaPro) can introduce discrepancies, emphasizing the need for standardized frameworks.

7. CONCLUSION

Life-Cycle Assessment is a powerful methodology for quantifying the environmental impacts of green buildings. It facilitates objective comparisons across design options, highlights environmental hotspots, and supports actionable sustainability decisions. Integration of LCA into building certification systems, coupled with better data repositories and design tools, will further advance sustainable construction practice. Overall, implementing LCA at early design stages can lead to more resource-efficient, low-impact building outcomes that align with global sustainability goals.

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