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Adopting a Life-Cycle Perspective

Introduction

Together, transportation and building operation accounts for over two-thirds of energy consumption in the United States. The design of the supporting infrastructure — primarily roadway pavements, and residential and commercial buildings — can play a significant role in improving the sustainability of these operations. As we develop strategies to reach sustainability goals, it is vital that we adopt methodologies that use a life-cycle perspective to evaluate impacts and use that knowledge to create a strategic path moving forward. Life-cycle analysis methodologies exist for both environmental and economic impacts, known respectively as life-cycle assessment (LCA) and life-cycle cost analysis (LCCA). These methodologies enable engineers, designers, and decision makers to better understand the impacts of infrastructure and the opportunities that exist to reduce them.

Using LCA to Evaluate Environmental Impact

Life cycle assessment considers all life-cycle phases, from initial construction to demolition. System boundaries are drawn to capture each mechanism by which pavements and buildings impact the environment. These boundaries not only include the materials and activities needed to construct the infrastructure, but also the operation, maintenance, and end of life phases of the life cycle. For pavements, this means accounting for traffic delay, lighting demand, future maintenance, and other phases and components that occur after the pavement is initially put in service. Likewise, the building life cycle includes the fuel and electricity demands needed for heating, cooling, and lighting operations. Figures 1 and 2 show the typical phases and components of the pavement and building life cycles, respectively. While it is important to understand the potential sources of environmental impact over life cycle, it is often not necessary to quantify each of these elements. Designers, engineers, and decision makers should manage the LCA in such a way that the boundaries are consistent with the goals and scope of a particular study.

Drawing upon the best available data, the environmental impacts from each element of the life cycle can be quantified. The infrastructure life cycle is broken down in order to evaluate the relative magnitude of impacts and identify the drivers behind those impacts. For instance, the use phase in buildings often dominates the life cycle, accounting for upwards of 90% of a typical building's life cycle energy use over 60 years. Many buildings in the United States currently use inefficient lighting, and suffer from high rates of air-infiltration, driving up the life cycle energy requirements and resulting in higher environmental impacts. For pavements, the use phase is often important as well, but the distribution of impacts over the life cycle tends to be correlated with traffic volume. High-volume pavements may have large impacts from traffic-related components (e.g., traffic delay, rolling resistance), whereas impacts from low-volume pavements will likely be dominated by materials-related components. The ability to breakdown the life cycle and quantify the impact of each element is a key strength of the LCA approach.

Materials	Construction	Use	Maintenance	End of Life
• Extraction • Production • Transportation	• Equipment • Traffic delay • Transportation	• Rolling resistance • Carbonation • Albedo • Lighting • Leachate	• Materials Phase • Construction Phase	• Equipment • Landfilling • Recycling/reuse • Transportation

Materials	Construction	Use	End of Life
• Extraction • Production • Transportation	• Equipment • Temporary structures • Transportation	• Plug loads • Lighting • HVAC systems • Thermal mass • Routine maintenance	• Demolition • Landfilling • Recycling/reuse • Transportation

Figures 1 and 2: Typical phases and components of the pavement (top) and building (bottom) life cycles

Once quantified, opportunities for reducing impact can be identified and prioritized. The infrastructure life cycle offers a diverse portfolio of impact reductions strategies, and understanding which of these are the low-hanging fruit is a critical step towards reaching sustainability goals. As legislation and market forces increasingly call for reduced environmental impacts, the building and pavement communities must respond with strategic solutions that address the weaknesses in their systems. LCA can identify these weaknesses and offer strategies to strengthen them, such as improving material properties, minimizing maintenance, and supporting efficient operation. However, LCA alone does not provide the economic context that is necessary for decision making. The coupling of LCA with LCCA is the crucial link that transforms environmental reduction strategies into practical applications.

Improving LCA through LCCA

Similar to LCA, the LCCA approach seeks to quantify the economic impacts over the infrastructure life cycle by identifying the costs during each phase. Because LCCA accounts for future maintenance and operational activities, the results are more comprehensive and can provide a more accurate portrayal of the actual economic burden associated with infrastructure than the initial costs alone, which are often a poor predictor of life cycle economic costs. Poorly insulated and leaky residential construction leads to high annual energy costs, which can result in substantially higher life cycle costs. Likewise, roadway closures cause traffic congestion, which leads to higher costs for road users. LCCA attempts to capture these and other economic costs by drawing boundaries that include user and future costs.

LCCA can evaluate the economic impacts of buildings and pavements in various ways. Depending on the objectives of a study, the LCCA can be used to compare alternative designs, evaluate payback periods for proposed improvements, or calculate the cost-effectiveness of environmental improvement strategies. Regardless of the approach, accompanying the environmental impacts from LCA with the economic impacts from LCCA creates a marked advancement in the utility of the assessment as a whole. Whereas LCA quantifies the important environmental issues, LCCA provides the necessary economic context to implement those solutions into the marketplace.

LCA + LCCA: Cost-Effectiveness

Perhaps the most promising interaction of LCA and LCCA is cost-effectiveness. For decision makers, environmental improvement strategies are only practical if the costs are competitive. Embracing this concept, the low-hanging fruit can be redefined as those strategies that offer a large environmental reduction potential at a low economic cost. These low-hanging fruit represent the most feasible approach to reducing the environmental impact of buildings and pavements. After LCA quantifies the relative impacts and proposes environmental reduction strategies, LCCA provides the method for integrating those into existing budgets.

For pavements and buildings, the phases and components illustrated in Figures 1 and 2 represent opportunities to reduce environmental impact. Using greenhouse gas emissions as an example, each opportunity can be evaluated for its potential carbon dioxide equivalents (CO_2e) saved and the accompanying economic cost. Such cost-effectiveness analyses produce results in terms of \$/kg CO_2e saved (or any number of other environmental impact categories), providing decision makers a metric that simultaneously addresses both the environmental and economic impacts of potential improvement strategies. Utilizing this approach, environmental reductions can be balanced with their economic cost, providing a strategic and practical roadmap for achieving sustainability goals.

Summary

The economic and environmental impacts of infrastructure should be evaluated using a life-cycle perspective. The coupling of two methodologies — life-cycle assessment (LCA) for environmental impact and life-cycle cost analysis (LCCA) for economic impacts — provides decision makers with the tools to reach sustainability targets using cost-effective strategies.

More

The research presented here is a part of an ongoing project by the LCA team at the MIT Concrete Sustainability Hub, led by Prof. John Ochsendorf and Dr. Nicholas Santero. More information can be found online at <http://web.mit.edu/cshub/>.

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