LCA in construction: status, impact, and limitations

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Introduction

Life cycle thinking in construction is now more important than ever. Practitioners consider costs of buildings over the long term (life cycle costing) and energy performance over the life of buildings. Architects and engineers are becoming increasingly sophisticated in making buildings better by taking a holistic long-range view. Life cycle assessment (LCA) is the latest addition to the life cycle toolbox for buildings. LCA looks at the up- and downstream burden throughout the entire building life cycle with a special focus on embodied environmental impacts. Embodied impacts become progressively more critical as operating consumption, such as energy and water, is reduced through optimization of design and building management.

LCA is the cradle-to-grave quantification of potential environmental impacts of products or services; it is based on natural sciences and considers the entire value chain. With an established history of use in the industrial world, LCA has seen interest grow in its application to the built environment. This is a positive advancement for sustainable construction. With LCA, we can assess products – even complex products like buildings – to understand their environmental “hot spots” and identify greener choices. LCA provides a quantitative basis for environmentally improved designs, removing the guesswork, unintentional greenwashing and burden shifting. LCA is a complex and continuously developing science new to many people in the construction sector. This paper is an introduction to LCA in the context of buildings.

The construction sector and its product suppliers are moving rapidly towards life cycle assessment — the Athena Sustainable Materials Institute was formed in 1997 to help them get there. The Athena Sustainable Materials Institute is the first North American organization dedicated to the use of LCA in construction. The Athena Institute is well-known for its common-good mandate to develop LCA data on construction materials and systems and to make these data accessible to building designers through user-friendly tools such as the Athena Impact Estimator for Buildings. PE INTERNATIONAL is a global leader in LCA and other sustainability services with a proven track record of over 1,500 LCA projects, many of them with raw material producers and associations that supply the construction sector. Along with other partners in the LCA world, the Athena Institute and PE INTERNATIONAL are actively working together to help expand the databases and foster the dissemination of LCA in the built environment.

About LCA

Life cycle thinking in environmental impact assessment has been prevalent in industry for over 40 years, with some early LCA-type practitioners bringing a multi-attribute quantitative approach to decisions related to beverage packaging as far back as the 1960s. This approach evolved into LCA, as it has been called for over 20 years, with well-established international standards for guidance (see appendix).

LCA is science-based, quantitative, and integrative. It measures the material and energy flows to and from nature over the lifetime of a product or service, and assesses the potential impact of those flows on resources, ecosystems and human health. These impacts occur in various segments of the manufacturing value chain and throughout the life of the product. Often the assessment is referred to as a cradle-to-grave evaluation. Commonly reported impact metrics include global warming (“carbon footprint”), acidification (“acid rain”), eutrophication (“algal bloom”), photochemical oxidant creation
in Construction: status, impact and limitations

Athena Sustainable Materials Institute

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LCA is a comprehensive assessment process, but it can’t do everything on the sustainability agenda, and it is not intended to do so. Multiple tools are required to build a house. Similarly, we need several assessment systems while designing that house if we have a complex list of sustainability objectives. For example, LCA does not address or substitute for the proper evaluation of risks, occupational exposure limits, indoor air quality or other legal emission limits, resource management or social equity. It is an environmental evaluation tool, not a triple bottom line sustainability tool.

As with any complex model, assumptions and a degree of uncertainty are inherent to LCA. It is a misconception to expect LCA to deliver precise predictions of environmental impacts; instead, look at LCA as an outstanding tool for estimating potential environmental impacts and comparing relative performance of alternatives. The uncertainty in LCA is not an imperfection; there is no such thing as absolute certainty when evaluating life cycle environmental impacts across a complex and widespread value chain. This uncertainty is due to the scaling of all flows to a functional unit (for example, one square foot of flooring), the difficulty of predicting future states (like end-of-life fate) and the impracticality of having every possible piece of input data in hand at the same level of quality along the entire value chain of a building. This is why LCA is a science of best estimates and not a science of absolute measurement. In spite of its inherent degree of uncertainty and the occasional but inevitable exceptions to the rule, LCA results rarely point in the completely “wrong” direction. A decision informed by LCA results is always preferable to an uninformed decision, or one guided by best intentions but lacking data.

LCA remains in a state of constant improvement through the scientific progress continually put in place by a growing international LCA community working on methods and developing databases. Databases for materials of construction will become more comprehensive as manufacturers add their unique products and as manufacturing associations develop industry-wide LCA-based data for their sectors. LCA methodology improvements are reflected in periodic updates to the international standards followed by LCA practitioners (see the appendix for more information on the two key LCA standards, ISO 14040 and 14044).

**LCA in Codes, Standards and Rating Programs**

Thought-leaders in sustainable construction have long been champions for LCA, encouraging product designers and manufacturers to measure environmental performance so green design can move beyond proxies and guesses. The respected journal *Environmental Building News* has been reporting on LCA developments for a decade, and their editorial promotion of LCA and transparency has intensified over the past few years. Ed Mazria’s Architecture 2030 challenge, launched in 2002, brought its LCA focus front-and-center with the 2030 Challenge for Products announced in 2011. An interest in LCA by the American Institute of Architects (AIA) Committee on the Environment eventually led to the 2010 publication of the “AIA Guide to Building Life Cycle Assessment in Practice.”

LCA is increasingly being integrated in vehicles that influence design decisions. Green Globes®-NC, introduced in the United States in 2005 and promoted by the Green Building Initiative (GBI), was the first commercial building rating system in North America to integrate LCA. Green Globes at that time incorporated LCA as an educational credit. When Green Globes-NC was used as the basis for development of GBI’s ANSI Standard – ANSI/GBI 01-2010: Green Building Assessment Protocol for
Commercial Buildings, finalized in 2010 – the Athena EcoCalculator software tool became the basis for a performance path option as an alternative to the more traditional prescriptive compliance path for material requirements.

LCA will help move green design from a prescriptive basis (where we are guessing about the impact of environmentally-guided decisions) to a performance basis (where we are validating those decisions). Prescriptive standards are intentionally simple for ease-of-use, but they prevent creative solutions and may not actually yield the intended level of performance. Performance-path alternatives allow for designer innovations and trade-offs across building components. Performance options are important for advancing design practices in sustainability because they replace proxies with measurement.

In 2009, ASHRAE published a green building standard known as ANSI/ASHRAE/USGBC/IES Standard 189.1 (now available in a 2011 update). For material selection, this standard has a prescriptive path with a list of single-attribute proxy characteristics like recycled content, and a performance path alternative specifying the use of LCA to show whole-building improvement of the proposed building design over a reference building.

California launched the first statewide green building code in 2009, known as CALGreen, which included LCA as a voluntary measure. In the 2012 amendment of this code, an LCA performance path is available as an alternate to prescriptive compliance on materials selection.

The International Code Council (ICC) 700 National Green Building Standard™ is a residential green standard initiated by the National Association of Home Builders in 2007. The current version recognizes the educational value of using LCA. The 2012 draft has an LCA performance path as an alternative to prescriptive material requirements.

The ICC’s International Green Construction Code (IgCC) is the first North American green building model code. Development started in 2009; after several rounds of drafts and hearings, the 2012 version of the IgCC is now available. LCA has been present in this code from the beginning but has been modified several times through the hearings. Performing LCA on a building design to compare to a reference building is currently available as a performance alternative to the prescriptive elements for building materials.

The US Green Building Council (USGBC) recently proposed to include LCA in LEED in multiple credits, having run a pilot LCA credit since 2007. The current draft of LEED v.4 includes a credit for whole-building LCA and other credits intended to encourage manufacturers towards full disclosure of life cycle environmental impacts through either published LCA reports or environmental product declarations (EPDs) for their products. In addition, this new LEED draft also encourages the selection of products for which there is a full chain of custody back to the extraction phase of production. This credit is designed to encourage sustainable mining and materials processes as they become endorsed by future international standards.

**Recommended Application of LCA**

LCA is about best estimates and gauging relative performance across options. It is not about determining if a product is “green” or not, but about quantifying impacts and seeing if, how, and where we can improve.
LCA is used in the **manufacturing sector** to help reduce the environmental impacts of the production of goods. LCA guides decision-making in industry by identifying environmental “hot spots,” assessing how these hot spots can be mitigated, and ensuring that a reduction in one life cycle activity does not cause an unanticipated increase in environmental impacts associated with another activity stage (this is known as “burden shifting”). In addition to helping manufacturers identify the most effective pathways toward impact reduction, LCA data can also be communicated to the public, most typically through an environmental product declaration (EPD). Governments in several countries are encouraging the development of EPDS, as is a proposed LEED v.4 credit for EPDs. Collectively, this trend is likely to create a demand among building designers for products with this documentation; this in turn will encourage more manufacturers to be transparent about their impacts, ultimately leading to an increased use of LCA and improvement in the next generation of products.

LCA in **design practice** will similarly result in a reduction of environmental impacts from buildings. As with manufacturing applications, LCA in design helps us understand embodied impacts of buildings; that is, the environmental burdens due to manufacturing, constructing, maintaining, retrofitting and demolishing buildings. The built environment contains an enormous amount of embodied material resources and energy. While operating energy is normally seen as a dominant concern, embodied energy and carbon are actually equally important: operating energy consumption takes place slowly over time, while architects and engineers make an immediate debit in energy and carbon with their design choices. As an example of the importance of embodied energy, climate change mitigation requires that we drastically reduce emissions today – long term solutions are important too, but reductions have to start right now; in design, that means paying equal attention to embodied environmental impacts. LCA implicitly determines the full impact of energy systems as it follows all forms of energy back to original sources in nature and, therefore, not only considers direct emissions, but also the emissions associated with extracting, refining, transporting and consuming each energy form. Designers ideally use LCA starting in the conceptual stage, since some of the earliest design decisions have the biggest environmental consequences. One way to use LCA early in the design process is to compare LCA results for a proposed building with a relevant benchmark building. LCA is also best used periodically throughout the process of detailed design, to monitor environmental footprint as the design changes and to experiment with options to reduce footprint.

Some tools for integrating LCA in design include the following:

- The Athena Impact Estimator gives architects and engineers access to LCA information (without requiring LCA expertise) at the level of the entire building. Designers specify structure and envelope components in the whole building and receive whole-building impact results. This allows for trade-off opportunities across various building designs and assemblies. When combined with an operating energy simulation, the Impact Estimator can also highlight the trade-offs between embodied and operating effects.

- The Athena EcoCalculator is a simpler and limited version of the Impact Estimator used to access pre-calculated LCA results for walls, roofs and other building assemblies.

- The BEES tool (http://www.nist.gov/el/economics/BEESSoftware.cfm) lets users access and compare LCA data for individual products such as structural components and interior finishes (this is a stand-alone evaluation – BEES does not accommodate the evaluation of products within assemblies or whole buildings).

- More advanced tools, used by LCA professionals typically for assessment of products or processes, can also be applied to building design. For example, a customized LCA can be
developed for building designs using LCA modeling tools such as PE INTERNATIONAL’s GaBi 5 software suite. This may be an appropriate route for some highly complex building projects if they fall outside of the scope of the Athena tools meant for the architecture and engineering community.

The value of LCA is dependent on skilled interpretation of results; this requires knowledge, experience, and caution. LCA is therefore a skilled science conducted by professionals in that field. For building design practitioners, the Athena Impact Estimator minimizes the amount of LCA background required to use this LCA-based tool but does not completely remove the need for careful interpretation of results. Experienced users of the Impact Estimator understand what LCA can and cannot bring to their design process. For LCA professional practitioners, interpretation is fundamental to the value of the published results for a product-specific LCA. LCA professionals recognize that knowledge of the LCA process and the impact assessment methods is necessary but not sufficient to make wise decisions. To truly reap the benefits of a comprehensive LCA requires knowledge of the product, its manufacturing process and its intended use.

Raw numbers alone do not tell the whole story; experienced LCA practitioners go through a process before arriving at conclusions and recommendations. This may include sensitivity and uncertainty analysis, which provide additional insight into the robustness of results and are mandatory for comparative product studies. Critical review by qualified peers ensures proper application of method and accurate interpretation of results; peer review is particularly essential in comparative LCA studies and is required in the ISO standards when LCA is used that way. These rigorous steps provide confidence to the end user of the data – whether the product manufacturer who commissioned the study or a building designer accessing the data through the Impact Estimator and other whole building tools – that the data is accurate.

LCA is an important tool to establish transparency in the value chain. Reliable data on environmental performance is the next wave in public communication for products (and buildings). Not everyone is ready to absorb all of this new data, but for those who are, transparency is long overdue in our greenwashed world. In addition, providing this data triggers a learning process for the involved companies, which establishes a sense of ownership for the upstream and downstream impacts in their value chain. This is good for everyone and will spark a healthy competition for greener solutions.

**Summary**

LCA is a tool that will help lower the environmental footprint of the construction industry, green our products, and ultimately guide us to a more sustainable way of doing business.

LCA is an important tool in the sustainability toolkit and helps close the gap between science and empty marketing claims. In Europe, LCA has a strong presence in the construction sector, with hundreds of EPDs available for construction products. Our North American learning curve may be steep at the beginning, but early adopters will teach by example.

In North America, LCA in construction is already here and in use by leading-edge designers. It is simultaneously robust and in a constant process of improvement. The LCA world is working diligently to make LCA as accessible, applicable, and reliable as possible for the construction sector. The major producers of building materials are using LCA to improve their processes and EPDs to communicate this
improvement. Building design practitioners will increasingly use LCA in their businesses to complement other tools such as building information modeling (BIM), energy simulation and life cycle costing. A constant feedback loop from these linked activities refines the entire application of LCA towards better buildings.

We urge design professionals to demand more environmental life cycle disclosure from the materials sector. LCA is a long-established, credible, multi-criteria based method for the transparent evaluation of a wide range of goods and services. LCA has a lot to offer the architectural and engineering community; we recommend that designers incorporate LCA in their decision framework. Ask your material suppliers what they know about their carbon footprint, embodied energy and other effects on the environment; then ask the same of yourself for your building designs – where’s the LCA?

About the Athena Sustainable Materials Institute
The Athena Sustainable Materials Institute is a non-profit research group bringing tools and data to the construction sector for the next generation of “green.” Since 1997, the Athena Institute has focused on quantification of sustainability in design. We work with leading edge architects, engineers, building owners and material manufacturers to measure the real environmental impact of buildings, infrastructure and construction materials using life cycle assessment (LCA). The only North American organization dedicated to construction-sector LCA, Athena develops and maintains a large LCA database for construction materials and provides the LCA-based Impact Estimator and EcoCalculator software tools to building designers. Contact us to learn more about LCA in design practice, get our tools, or support us in our work to advance the tools and the construction databases.

www.athenasmi.org

About PE INTERNATIONAL
PE INTERNATIONAL is the global leader in integrated product and enterprise sustainability performance providing market leading software solutions, sustainability databases and consulting expertise. With over 20 years of experience and 20 offices around the globe, PE INTERNATIONAL enables clients to understand sustainability, improve their performance and succeed in the marketplace. PE INTERNATIONAL is working with 1,500 clients including some of the world’s most respected brands to develop the strategies, management systems, tools and processes necessary to achieve leadership in sustainability.

For more information: http://www.pe-international.com
Appendix: Excerpts from the ISO LCA standards

ISO, the International Organization for Standardization, has several standards for LCA that are followed by practitioners and are the appropriate resource for internationally-accepted definitions and clarity about life cycle assessment. When considering the application of LCA, it is instructive to review these ISO standards. We offer some key excerpts here:

• There is no single method for conducting LCA. Organizations have the flexibility to implement LCA as established in this International Standard, in accordance with the intended application and the requirements of the organization.

• LCA is different from many other techniques (such as environmental performance evaluation, environmental impact assessment and risk assessment) as it is a relative approach based on a functional unit; LCA may, however, use information gathered by these other techniques.

• LCA addresses potential environmental impacts; LCA does not predict absolute or precise environmental impacts due to –
  
  o the relative expression of potential environmental impacts to a reference unit,
  
  o the integration of environmental data over space and time,
  
  o the inherent uncertainty in modeling of environmental impacts, and
  
  o the fact that some possible environmental impacts are clearly future impacts.

• The interpretation should reflect the fact that the impact results are based on a relative approach, that they indicate potential environmental effects, and that they do not predict actual impacts on category endpoints, the exceeding of thresholds or safety margins or risks.

• Impact results shall not provide the sole basis of comparative assertion intended to be disclosed to the public of overall environmental superiority or equivalence, as additional information will be necessary to overcome some of the inherent limitations in the impact assessment. Value-choices, exclusion of spatial and temporal, threshold and dose-response information, relative approach, and the variation in precision among impact categories are examples of such limitations.