About Whole-building LCA and Embodied Carbon

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LCA brings cradle-to-grave performance metrics to sustainable design. Here’s a brief plain language primer on this complex topic and its unfamiliar lingo.

Life cycle assessment (LCA) estimates environmental burden due to a product over its entire life span, from resource extraction to landfilling and beyond. It’s a rigorous methodological technique for measuring and rationalizing “green” choices, applying a holistic cradle-to-grave perspective. Long used in the manufacturing sector for product development, LCA (and its subset, embodied carbon) is increasingly being considered for the complex “products” known as buildings.

LCA for construction is complicated
LCA originated in the industrial sector, where it has been used for decades in business decisions for the manufacturing of clothing, detergent and many other products. LCA is a useful tool in guiding sustainability decisions for just about anything.

But LCA applied to the building sector is quite a bit more complicated than for something like a consumer product. Buildings are complex one-off assemblies of thousands of products and materials, involving countless participants, a long lifetime (with many changes along the way), and a great deal of uncertainty about what will happen in the future.

The process of whole-building LCA
As with any cradle-to-grave LCA study, LCA for a building (whole-building LCA) measures all the flows between a building and nature over its lifetime and then estimates the resulting impacts on air, land and water.

The cradle-to-grave lifetime of a building includes manufacturing and transporting of construction materials, the process of construction, a long phase of building occupancy and maintenance, demolition, and removal of waste materials. Resources are consumed and emissions created during every life phase (see Figure 1).

In LCA, we inventory all resources (energy, water, materials) consumed at each life phase as well as all emissions (wastes, and emissions to air, land and water) at each phase. Cumulatively, these elementary flows result in a life cycle inventory (LCI). Next, we run the LCI through a life cycle impact assessment (LCIA) model to compute the potential environmental impacts (like global warming, the creation of smog, the eutrophication of water bodies, etc.) due to the LCI.
Figure 1: Life cycle phases of a building

Clearly, LCA is a complex process requiring access to extensive data and sophisticated software tools, even when applying LCA to simple products. This is why LCA is a specialty discipline practiced by experts. To solve that problem, there are simplified whole-building LCA software tools available\(^1\), which were created with the data and methods in the background so that LCA is accessible to non-experts in the building sector.

Step one for any LCA is setting its “goal and scope” – identifying the purpose of, and audience for, the study and what will be included. This will influence how the study is conducted: for example, whether it is done in-house or via a consultant, which software tool to use, how much information needs to be gathered, and how long the study will take.

At the core of a whole-building LCA study is a bill of materials. This includes types and quantities of the major materials that comprise the building, any material waste during product manufacturing and construction, and material replacements over the life of the building. Cradle-to-grave consumption of energy and water resources are also included: for example, product transportation to site, the operation of construction equipment, and, optionally, building operation. With the simplified tools, preparing this information is the key task for users (each tool offers different functionality in assisting with this task). The task includes applying diligence in verifying accuracy and completeness of the bill of materials in accordance with the goal and scope of the study. Users may need to make some decisions regarding elements being omitted, product substitutions when something is missing in the software’s data, and so forth.

Typically, a simplified tool would tap into LCI datasets to create a cradle-to-gate LCI for the bill of materials. These are the data for the life phases from resource extraction to the factory shipping gate, for all materials. Next, the tool needs to address the remaining life phases: the gate-to-grave portion.

\(^1\) The Athena Impact Estimator for Buildings is the original simplified whole-building LCA software tool in North America, first released in 2002 and available to the public for free. More recently, other (commercial) tools have entered the market.
For this, “scenario” data is tapped – these data are the assumptions about product transportation distances and modes, on-site construction equipment usage, product waste during construction, product replacement schedules, end-of-life fate for materials. Operating energy and water consumption can also be an input. The tool would then run a cradle-to-grave LCI through an LCIA model. The LCA results are then provided to the user. See Figure 2 for a diagram of the inputs and the flow. (Note that not all the available tools work this way.)

Next step is to review the results. Do they make sense, where are the hot spots, and what’s next: maybe some what-if experiments, refining the design, re-running the model, and documenting the final results.

Figure 2: Whole-building LCA general flow
Why do LCA for a building
The purpose of LCA is to bring comprehensive data to sustainability decisions. It quantifies and validates design decisions that are assumed to be “green.”

LCA supports evidence-based decisions because it puts numbers on them, which tells us if an assumed benefit is real and if it’s significant. It also tells us the whole life story – it doesn’t allow us to hide environmental burdens in a life phase that we might be ignoring if not for LCA. For example, an improvement in product manufacturing may increase environmental impacts at end of life (this is called “burden-shifting”). Full cradle-to-grave LCA provides the complete lifetime accounting.

LCA is very helpful in directing the decision-maker’s attention to the hot spots; that is, where should the building designer look for changes, in order to get the biggest environmental bang for the buck.

There are secondary benefits or purposes for whole-building LCA beyond the pure intention of achieving a quantifiably better building. Most common would be compliance with provisions in a green building program or policy\textsuperscript{2}. Another purpose is for communication, where there may be marketing or advocacy value in transparently declaring LCA results for a project.

Limitations for whole-building LCA
Although LCA has a long track record in the industrial sector, it is still a developing practice in the buildings sector, and there are kinks to be worked out. Significant issues are currently limiting how it can be used.

Some factors that affect the reliability of results and applicability of LCA for buildings:

- **Data gaps**: Some important products and processes are missing or incomplete in LCI databases. As seen in Figure 2, LCI data on materials and energy is fundamental to a whole-building LCA. A potential work-around is to use the LCA data reported in environmental product declarations (EPDs), although EPDs are not intended for and arguably not suitable for this purpose. Instead, the LCI data that lies underneath every EPD would ideally be accessible via an LCI database.

- **Data inconsistency**: There can be variation in method and quality for the data that underlies whole-building LCA, a circumstance exacerbated by the fact that data resides in multiple (often proprietary) places. Data on materials may be too old and may not adequately reflect the regional circumstances for the building location. A whole-building LCA will additionally suffer if it is done using inconsistent and incompatible data, for example, using LCI data from different sources or combining LCI data with LCA results from an EPD.

- **Method inconsistency**: There can be variation in approach to whole-building LCA, which means results are not comparable across studies. For example, users may choose different system boundaries and scope, and they may use different levels of assessment accuracy (breadth of the study, accuracy and completeness of the bill of materials, and so forth).

- **Scenario uncertainty**: The assumptions made about the future (“scenarios”) are an inherent uncertainty in LCA, and variations in user assumptions affect comparability of results. This would

\textsuperscript{2} For example, to earn the LCA credit in LEED® or Green Globes, or to report embodied carbon for the Canada Green Building Council’s Zero Carbon Building program, the ILFI Zero Carbon program or a City of Vancouver rezoning application.
be mitigated if there were generic, default data available for assumed maintenance and refurbishment schedules, end-of-life disposition of materials, and so forth.

- **Incomplete or inconsistent standards:** Standards for LCA and whole-building LCA should theoretically constrain the factors that affect reliability and comparability of results, given that the purpose of a standard is to enable consistency in practice. Current standards for LCA and whole-building LCA have not yet achieved this goal. While certainly improving as they evolve, current standards still allow a large amount of user interpretation, which leads to wide variations in methods.

- **Lack of detailed, comprehensive guidelines:** Given all the opportunity for variability in method and accuracy, effective whole-building LCA guidelines would provide a critical benefit for consistency of practice and comparability and reliability of results. Comprehensive, rigorous guidelines would address decisions such as boundary, scope, LCA method, data sources, scenario assumptions and bill of material accuracy. In addition, guidelines would mitigate a common problem of users misinterpreting results and potentially making bad decisions.

In all applications, LCA is used as an estimating science, not an exact one. This is particularly true when applying LCA to buildings, given our currently incomplete level of supportive technical infrastructure for whole-building LCA. What this means is that whole-building LCA results likely have a high level of uncertainty at the moment.

Whole-building LCA is nonetheless useful for providing information to guide decisions, so long as design teams recognize that their results represent a range and not an absolute. The range will narrow as the factors discussed above are resolved. In the meantime, the sustainable design community is in an important educational period that includes developing awareness about embodied environmental impacts, learning the language of LCA, and picking up skills in using whole-building LCA software tools.

**Embodied carbon explained**

“Embodied carbon” is an imperfect term. The word “embodied” may suggest to some the idea of carbon encapsulated in a material. Instead, it’s a shorthand way to refer to all the lifetime greenhouse gas (GHG) emissions due to a building other than for building operation. For example, the GHGs emitted from fossil fuel combustion in transporting a product to the building site are part of the embodied carbon in the product.

Embodied carbon is also known as value chain emissions, upstream/downstream emissions, or Scope 3 emissions. The complete “carbon footprint” of a product includes these GHG emissions. For example, a true “zero carbon” building would account for and offset its embodied carbon.

To visualize embodied carbon, look again at Figure 1 and imagine the “emissions out” is referring only to greenhouse gases. The embodied carbon is all the emissions over all life phases, except for those due to building operation.

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3 Carbon accounting practice widely follows the GHG Protocol and its language (https://ghgprotocol.org). Scope 1 is direct emissions from sources controlled by an entity (site emissions, in the context of a building). Scope 2 is indirect emissions from the generation of purchased energy (source emissions, in the context of a building). Scope 3 is other indirect emissions in the value chain (in the context of a building, this would include embodied carbon, occupant commute travel, and so forth).
Embodied carbon is simply the global warming potential (GWP) result from a whole-building LCA study. In other words, to calculate embodied carbon requires a full LCA study, although only one result from the study will be used.

Most embodied emissions are upstream of building occupancy – they are primarily related to the manufacturing of materials. This includes extraction of raw resources, manufacturing and transportation.

GHG emissions due to material manufacturing, use and disposal are more significant than many people realize. First, these emissions are a big upfront GHG pulse (versus the slow accumulation of GHG savings over time from low-carbon building operation), which makes them a good near-term target for climate change mitigation. Second, as buildings approach net-zero operation, embodied impacts will make up most of the carbon footprint in the built environment. See Figure 3. Embodied emissions can be tackled at the material level (all products have environmental impact and therefore room for improvement) – in other words, at the supply end. Or they can be tackled at the demand end, i.e., at the building level: building smaller, reusing existing buildings and materials, using less materials in general, and replacing materials less often.

Figure 3: Carbon footprint of a typical building after 10 years of occupancy

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4 This graphic is illustrating the proportional contribution of embodied and operating greenhouse gas emissions to the cumulative carbon footprint at approximately year ten in the life of a typical mid-rise building in Toronto. Data source: a comprehensive Athena Institute whole-building LCA study (see “Life cycle assessment for sustainable design of precast concrete commercial buildings in Canada,” M. Marceau et al, 2012).
Glossary

**Life cycle assessment** (LCA) is a multi-step procedure for calculating the lifetime environmental impact of a product or service. The complete process of LCA includes goal and scope definition, inventory analysis, impact assessment, and interpretation. The process is naturally iterative as the quality and completeness of information and its plausibility is constantly being tested.

LCI is the **life cycle inventory**, which is the data collection portion of LCA. LCI is the straight-forward accounting of everything involved in the “system” of interest. It consists of detailed tracking of all the flows in and out of the product system, including raw resources or materials, energy by type, water, and emissions to air, water and land by specific substance. This kind of analysis can be extremely complex and may involve dozens of individual unit processes in a supply chain (e.g., the extraction of raw resources, various primary and secondary production processes, transportation, etc.) as well as hundreds of tracked substances.

LCIA is **life cycle impact assessment**, the “what does it mean” step. In LCIA, the inventory is analyzed for environmental impact. For example, manufacturing a product may consume a known quantity of natural gas (this data is part of the inventory); in the LCIA phase, the global warming impact from combustion of that fuel is calculated. There are various methods in use around the world for categorizing and characterizing the life cycle impact of the flows to and from the environment, which can somewhat complicate the comparability of different LCA studies. Other variables in LCIA include the system boundary (how far upstream, downstream and sidestream does the analysis go), the functional unit (what is the volume/mass/purpose of the object being assessed), and specific LCIA methods such as allocation (how are impacts assigned to the product and by-products, on what basis). When comparing two LCA studies, these factors are critical to understanding if the comparison is apples-to-apples.

LCI and LCA should not be confused with **life cycle costing** or life cycle cost analysis (LCC or LCCA). This is another life cycle approach (i.e., cradle to grave), but it looks at the direct monetary costs involved with a product or service and not environmental impact.

About the Athena Institute

The Athena Sustainable Materials Institute is a non-profit research group that advocates for environmental performance measurement and accountability in the built environment. The Athena Institute is the North American leader in LCA for construction and its materials and has been providing ground-breaking research and free resources since 1997. Visit our website to learn more about us and how you can help.

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