AIA-CLF EMBODIED CARBON TOOLKIT FOR ARCHITECTS

PART II:

Measuring embodied carbon

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AIA

CLF Carbon Leadership Forum

Measuring embodied carbon

Measuring embodied carbon is key to evaluating the highest-impact, most cost-effective solutions to reducing embodied carbon on your project. As is often said, “You can’t manage what you can’t measure.” Measuring embodied carbon requires a methodology called life cycle assessment (LCA).

Life cycle assessment

LCA is a methodology that is used to measure the environmental impacts of a building, product, or process over its full life cycle, from raw material extraction through end-of-life and disposal. LCA measures impacts through a variety of metrics, such as global warming potential, acidification potential, eutrophication potential, smog formation potential, and ozone depletion potential. Global warming potential (GWP) is the metric used to measure and track embodied carbon. GWP is quantified in kilograms of CO_2 equivalent (kg CO_2e). The “equivalent” or “e” in “kg CO_2e” means that other greenhouse gases like methane are included alongside carbon dioxide and normalized to the impact of CO_2 based on their radiative forcing potentials relative to CO_2.

Life cycle stages

The life cycle of buildings and building materials (see figure 1) are broken into four main life cycle stages:

» A: Product and construction

» B: Use

» C: End-of-life

» D: Benefits & loads beyond the system boundary

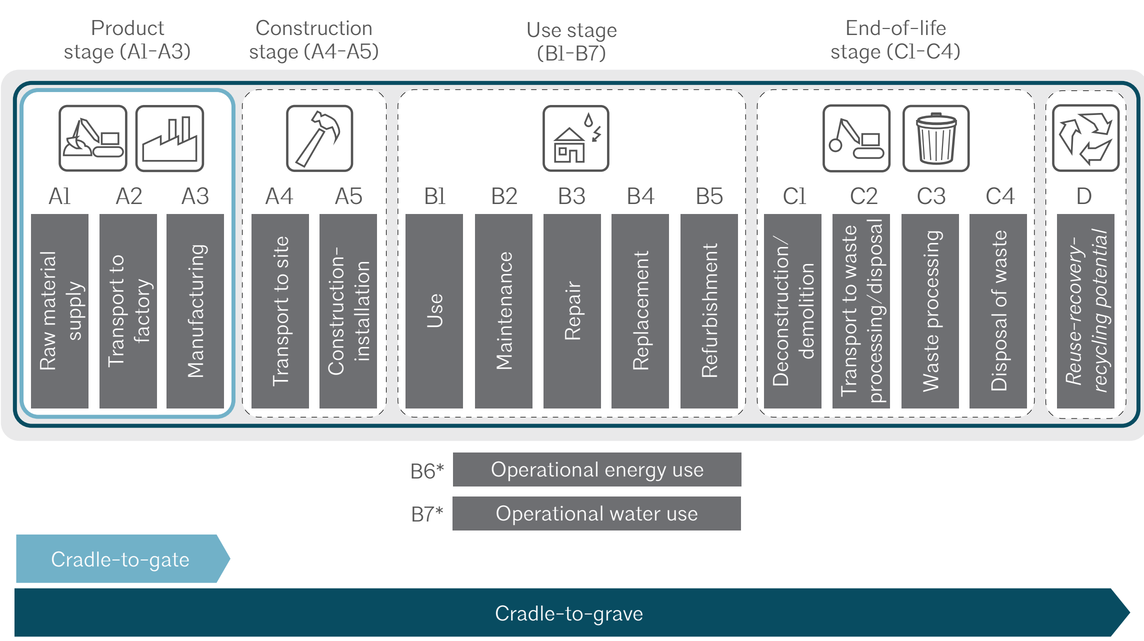


FIGURE 1
Life cycle stages for building products. Based on EN 15978:2011 and ISO 21930:2017.

*Operational carbon stages that are typically excluded from life cycle assessments focused on embodied carbon.

Building vs product LCA

In the building industry, architects will typically encounter LCAs being performed at two different levels:

» Building-level LCAs, which are typically referred to as whole building LCAs (WBLCA).

» Product- or material-level LCAs, which are typically communicated via an environmental product declaration (EPD). EPDs are created by LCA practitioners and product manufacturers.

Whole building LCA

WBLCA provides an assessment of the embodied carbon impact of a whole building. This includes the impact of all materials used in the project, or a subset of the project, like structure and/or envelope, throughout the life cycle of the building. Similar to energy modeling, architects, or their consultants, should perform WBLCAs throughout the design process to actively inform the design of a building.

This section outlines the four key steps of an LCA with guidance specific to performing a WBLCA.

Step 1: Goal & scope

Goal

Defining the goal of the assessment is important for determining why and how you conduct a WBLCA. Here are a few common goals of WBLCAs:

» Evaluate building design choices by comparing the embodied carbon footprints of multiple designs;

» Meet regulatory or green building certification requirements, such as ILFI's Zero Carbon Certification or LEED BD+C v4 Building Life Cycle Impact Reduction Credit; or

» Benchmark a building's embodied carbon performance using third-party benchmarks or a baseline building.

Scope

During the scoping phase of an LCA, you need to define the functional description, reference unit, reference study period, and system boundary.

Functional description. This typically includes:

» Project use type (e.g., commercial, residential, school, etc.) and form (e.g., low-, mid-, or high-rise)

» Technical requirements: These are likely defined by the building code and other standards and rating systems.

» Functional requirements: These are likely defined by the owner's project requirements, such as the number of residential units or minimum programmatic needs.

» Pattern of use (e.g., expected number of occupants); and

» Reference service life (e.g., expected life span of the building).

To compare WBLCA results from different studies, the buildings must have the same functional description—this is known as functional equivalent.

Reference unit. Whole building LCA results are often reported for the total building, and also per unit of total floor area. This standard reference unit, kg CO_2e/m^2, is requested by AIA COTE,[1] as it allows for comparison of buildings of different shapes and sizes, facilitates tracking emissions across a project or between different projects, and is compatible with other types of building performance accounting.

Reference study period. The reference study period defines the temporal boundary of the LCA, typically measured in years. This has a large impact on the results of the LCA because it affects the magnitude of impacts from maintenance and replacement of materials, particularly for interior components.

System boundary. The system boundary describes the physical scope, life cycle scope, and impacts to be evaluated. Impact categories are described in step 3.

The physical scope of a WBLCA varies widely. Some WBLCAs include structure only, or structure and envelope, whereas others may include a more complete assessment with structure, envelope, interiors, and mechanical, electrical, and plumbing (MEP). Because many LCAs are performed using BIM-integrated WBLCA tools, it is often up to the architect to ensure that the appropriate components are included in the physical scope.

The life cycle scope defines which life cycle assessment stages are included. This is often predetermined by the LCA tool, so architects should make sure their chosen LCA tool has the correct life cycle scope to meet their assessment goals. Minimum scope requirements vary by standard or rating system. See Table 1 for guidance on scope.

TABLE 1:
Guidance on WBLCA scope requirements from different green building programs and policies.

<table>
<tr><th colspan="2" rowspan="2">Goal</th><th colspan="3">Meeting regulatory/Green Building Certification req.</th><th rowspan="2">Comparing to 3rd party benchmark</th></tr>
<tr><th>LEED BD+C v4 Building Life-Cycle Impact Reduction</th><th>ILFI Zero Carbon Certification</th><th>Vancouver ReZoning Policy</th></tr>
<tr><td colspan="2">Reference unit</td><td>kgCO2e/m2</td><td>kgCO2e/m2</td><td>kgCO2e/m2</td><td rowspan="19">Match the reference unit, reference period, and system boundary of the benchmark.</td></tr>
<tr><td colspan="2">Reference period</td><td>60 years</td><td>N/A only includes A1-A5</td><td>60 years</td></tr>
<tr><td rowspan="5">Physical scope</td><td>Foundation</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Structure</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Enclosure</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Interiors</td><td>Optional</td><td>Yes</td><td>Finishes/partitions are optional</td></tr>
<tr><td>MEP</td><td>Optional</td><td>Optional</td><td>Optional</td></tr>
<tr><td rowspan="10">Life cycle scope</td><td>A1-A3</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>A4</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>A5</td><td>Optional</td><td>Yes</td><td>Yes</td></tr>
<tr><td>B1</td><td>Yes</td><td rowspan="3">Not included</td><td>Not included</td></tr>
<tr><td>B2-B4</td><td>Yes</td><td>Yes</td></tr>
<tr><td>B5</td><td>Yes</td><td>Not included</td></tr>
<tr><td>B6-B7</td><td>Not included</td><td>Not included</td><td>Not included</td></tr>
<tr><td>C1-C4</td><td>Yes</td><td>Not included</td><td>Yes</td></tr>
<tr><td>D</td><td>Optional</td><td>Not included</td><td>Optional, report separately</td></tr>
<tr><td rowspan="2">Impacts</td><td>GWP</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Additional impacts</td><td>Additional 2+ impact categories Yes</td><td>Not included</td><td>Optional</td></tr>
</table>

For embodied carbon, best practice is to include (at a minimum) stages A1-A5, B2-B4, and C1-C4. No comparison should be made across material types (e.g., wood vs. concrete structure) without including stages B and C.

Module D should be used to report the following information separately:

» Biogenic carbon storage or benefits

» Recycling benefits, usually of metal

These quantities are relegated to Module D because they occur outside of the building life cycle.

Step 2: Inventory

Creating the inventory for a WBLCA requires the collection of the types and quantities of materials that are a part of the physical scope defined in step 1.

Several design-integrated LCA tools exist primarily to serve this function—increasing the accuracy of quantity takeoffs and translating between descriptions of assemblies (e.g., 100 square feet of wood framing, with studs @ 16 inches o.c.) and discrete quantities of individual materials (e.g., 200 kg softwood kiln-dried lumber).

Alternatively, a contractor may be able to provide a bill of materials depending on the project stage and delivery method.

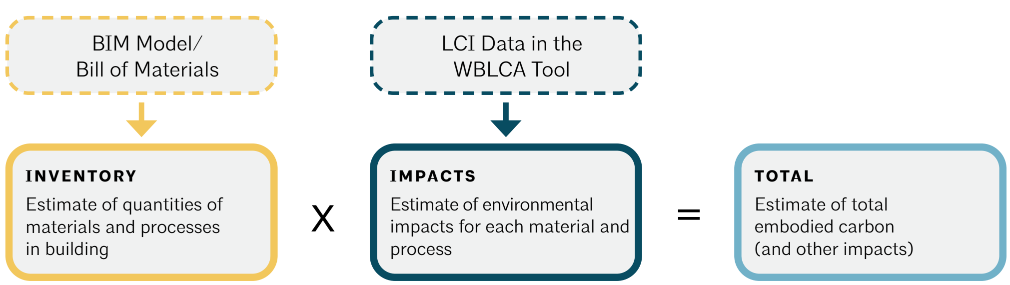
Additional inventory information may be needed to determine scenarios for the WBLCA, such as transportation information and material replacement frequencies (service life). These may be prompted by the LCA tool, depending on the tool selected.

Step 3: Impact assessment

In this step, the material quantities from step 2 are multiplied by environmental impact factors for each respective material, and the results are summed for the whole building. Unless you are an experienced LCA practitioner, step 3 (and step 2) typically requires the use of a WBLCA tool. Learn more in the section Tools for measuring embodied carbon.

Using the same tool consistently throughout the project is important if you want to compare any of the results from different assessments. Be sure to separate the results of the impact assessment by life cycle stage. Separating them will help with the interpretation of the results. See figure 2.

FIGURE 2
Calculation process for impact assessment in LCA



EXAMPLE CALCULATIONS

100 kg steel	x	0.43 kg CO_2e/kg steel	=	43 kg CO_2e
50 kg glass	x	1.064 kg CO_2e/kg glass	=	53.2 kg CO_2e

Step 4: Interpret results

Hot-spot analysis. After an initial overview of the LCA results, a good first step is to break down the environmental impacts by building component, material type, and/or life cycle stage, and visualize the results. This can help you get a sense of which building components, materials, and life cycle stages are significant contributors to the total building impact. This is known as a "hot-spot analysis" or a "contribution analysis."

Check for errors. This can be done by comparing your results to other LCA studies with a similar scope (see step 2) and by "reality checking" your results to see if high-impact and high-quantity items make a significant contribution to the overall impacts.

Comparing your study to benchmarking studies that have the same system boundary (e.g., the same life cycle stages and physical scopes) and use types can also be helpful in confirming whether your results are in the right order of magnitude. See the section Benchmarking buildings. See Table 2 for embodied carbon benchmarking values from various sources.

Understand the results. To deepen your understanding of the results, you can perform (1) a sensitivity analysis to understand which variables have the greatest impact on results; and (2) an uncertainty analysis to understand how variables with a high level of uncertainty affect the overall certainty of the results. To perform these analyses, you simply modify the variable of interest, rerun the LCA, and evaluate the difference in results.

Develop conclusions. This should address whether or not you met the goal of the LCA, and include any interesting or significant observations.

Perform verification (optional). Verification means that an outside individual or organization conducts a peer review of your LCA to verify the results. While this is rarely done for WBLCAs and is not necessary for internal design studies, critical reviews provide a useful level of oversight for the occasions when LCAs are used for public claims of environmental performance.

TABLE 2:
Embodied carbon benchmarking values from difference sources

			System boundary		Embodied carbon benchmarking values (kg CO_2e/m^2)				
					Building type				
Source	Geographic region	Reference study period	Life cycle scope*	Physical scope	Residential	Office	School	Industrial	Mixed
CLF	North America	Assumptions unknown	A only	Foundation Structure Enclosure Interiors	200–660	270–540	230–460	-	200–640
LETI	UK	Assumptions unknown	A1–A5	Substructure Superstructure Facade Internal finishes MEP	800	1000	1000	-	-
RIBA	UK	Assumptions unknown	A1–A5, B1–B5, C1–C4	Substructure Superstructure Finishes/fixed FF&E Building services (and associated refrigerant leakage)	1200	1400	1400	-	-
One Click LCA	Europe	Assumptions unknown	A1–A3, A4, B4–B5, C1–C4	Varies	-	520–680	380–490	500–560	-
Zimmerman et al.	Denmark	60 years	C1–A3, B4, B6, C3–C4	Substructure Superstructure Facade Building services Vertical circulation	315–425		-	-	-

Benchmarking buildings

A benchmark establishes a reference point to evaluate the relative performance of a building. For example, energy use intensity (EUI) benchmarks are used for operational energy. Efforts to develop building-level LCA benchmarks are not yet widely available in North America.

Architecture firms that perform WBLCA regularly can create their own firm benchmarks for different project types. Adopting firm-wide modeling standards for WBLCA will increase the utility of these benchmarks for checking errors and tracking progress towards reducing embodied carbon. For example, firms may encourage projects to use the same physical scope, life cycle stages, and LCA tools.

> Contribute to establishing North American building benchmarks by submitting your data to the Carbon Leadership Forum using the template in the Architect Toolkit Home Page.

Environmental Product Declarations

EPDs are standardized documents that report the results of an LCA for a particular material or product. EPDs are based on product LCAs that cover, at a minimum, the impacts of product extraction, transportation, and manufacturing (stages A1–A3). EPDs are therefore well-suited to capture manufacturing and supply chain strategies that prioritize material and energy efficiency, and low-carbon energy sources.

EPDs are third-party–verified and governed by product category rules (PCRs). A PCR is a set of rules and guidelines for a particular product or group of products. A PCR dictates how the practitioner should perform the LCA for an EPD of that product category.

There are several “flavors” of EPDs:

» Industry-wide EPDs represent typical manufacturing impacts for a range of products for a group of manufacturers. Industry-wide EPDs provide the least-specific data on a product’s embodied carbon footprint and cannot be used to compare products. However, they are helpful in understanding the typical impact of a product.

» Product-specific EPDs represent the impacts for a specific product and manufacturer across multiple facilities.

» Facility-specific EPDs are product-specific EPDs in which the environmental impacts can be attributed to a single manufacturer and manufacturing facility. This type of EPD was introduced by the Buy Clean California Act in 2017.

These types of EPDs vary primarily across two criteria:

» Which facilities and companies contributed data?

» How specific is the data to the supply chain of the product? In other words, how well does the data represent the actual supply chain?

Checklist: Can I use an EPD to compare these products?

(You must check all of the following boxes for the EPDs of both products in order to fairly compare them.)

- ☐ Functionally equivalent (e.g., strength, stiffness, insulative properties, etc.)
- ☐ Created using the same PCR
- ☐ Include the same life cycle stages
- ☐ Use of one product versus another does not change other aspects of the design or assembly

If you can't check all of these boxes but would like to compare two products, then it is important to use WBLCA or other tools rather than use EPDs.

See Table 3 to determine whether you should use a WBLCA or EPD based on your goal.

TABLE 3:
Guidance on whether to use WBLCA or EPD

Goal	Use a WBLCA	Use an EPD
Measure the embodied carbon savings from building reuse	●	
Identify hot spots at the beginning of a project	●	
Estimate the carbon footprint (GWP impact) of a whole building	●	
Compare the carbon footprints of two building designs	●	
Compare the carbon footprint impact of two systems/assemblies (e.g., steel vs. mass timber; facade options, etc.)	●	
Compare the carbon footprint per unit of two functionally equivalent products from the same (or different) manufacturers (see the checklist above)		●
Compare the carbon footprint of a specific product to third-party targets (see section "Benchmarking Materials") during product selection and procurement		●

Benchmarking materials

The Carbon Leadership Forum publishes a Material Baselines report[2] that provides three values to provide a snapshot of variability within a product category, according to the best publicly available data: high, median (typical), and low (achievable). Collectively, these values represent the expected range of embodied carbon impacts for most products in their category, taking variability and uncertainty into account.

Tools for measuring embodied carbon

This section provides a quick overview of the spectrum of tools that are available for architects to evaluate buildings and building materials.

Visit the Architect Toolkit Home Page to see a list of specific tools.

Tool selection

Tools vary widely in their goal, target audience, cost, and type of software. Here are a few key differences to focus on when selecting a tool.

BIM integration. BIM-integrated LCA tools are plug-in tools embedded into BIM software such as Revit. BIM-integrated tools automate parts of the LCA process by extracting inventory data from the BIM model, increasing integration with the design process and reducing the chance of human error from manual takeoffs.

Background data. Life cycle inventories (LCIs) are datasets that report emissions for different processes that contribute to the creation of a material or product.

Different tools may use different LCIs, so it is important to know which datasets each tool uses, since the results can differ.

LCI databases are created and managed by governmental, non-governmental, and private organizations. Examples of public datasets in the U.S. are the Federal LCA Commons and USLCI. An example of a private database is GaBi.

Geographic location. LCIs can have different geographic scopes (e.g., North America versus Europe). Ideally, the dataset in the tool should match the geographic location of the project.

Life cycle scope. If being used to report the results of a WBLCA, the tool must include life cycle stages A, B, and C, and optionally D.

Categories of tools

Calculators

Calculators are typically simple online or spreadsheet-based tools designed to allow for targeted and quick decision-making.

Building calculators help designers get a quick sense of the order of magnitude of embodied carbon. These are typically most helpful in early design stages before modeling has begun.

While building calculators are useful tools, they are not typically appropriate for reporting embodied carbon to meet the requirements of standards or rating systems. Programs like LEED v4 require the use of whole building LCA tools, rather than calculators, unless a specific tool has been developed for compliance with the policy or program.

Examples: Build Carbon Neutral, Athena EcoCalculator

Material-specific or assembly-specific calculators help designers quickly evaluate design or sourcing decisions related to a single material or assembly, such as wood or façades.

Examples: Kaleidoscope, Upstream Forestry & Carbon LCA Tool

Design-integrated LCA tools

Design-integrated LCA tools may be integrated into software that architects already use, or they may be freestanding tools.

Whole building LCA tools. A WBLCA tool has features that allow the user to easily model the whole building at a fair level of detail (in terms of material types and material quantities) and performs the calculations to produce the LCA results.

Examples (North America): Tally (a plug-in for Revit), One Click LCA, Athena Impact Estimator

Assembly-specific design tools. Some tools have been developed to track and manage embodied carbon for a specific physical scope, such as structure or façade.

Examples: Beacon, Building and Habitats object Model (BHoM)

Product selection/procurement tools

This type of tool collects product data, such as EPDs, and facilitates comparison to help users select a product or supplier.

Example: Embodied Carbon in Construction Calculator (EC3)

Professional LCA software

Professional LCA software tools are primarily used by LCA experts and consultants for all types of products, not just those related to the building industry. These software tools are also commonly used to perform the LCA that an EPD is based upon and are used to create the background datasets used in most WBLCA tools.

Examples: SimaPro, OpenLCA, GaBi

Endnotes

1 American Institute of Architects (AIA) Committee on the Environment (COTE). (2021). A*IA COTE Top Ten, 2021 Call for Entries*. https://content.aia.org/sites/default/files/2020-11/STN20_COTE-call-for-entries_v03.pdf

2 Carlisle, S., Waldman, B., Lewis, M., and Simonen, K. (2021). *2021 Carbon Leadership Forum Material Baseline Report.* (version 2). Carbon Leadership Forum, University of Washington. Seattle, WA. July 2021. http://hdl.handle.net/1773/47141