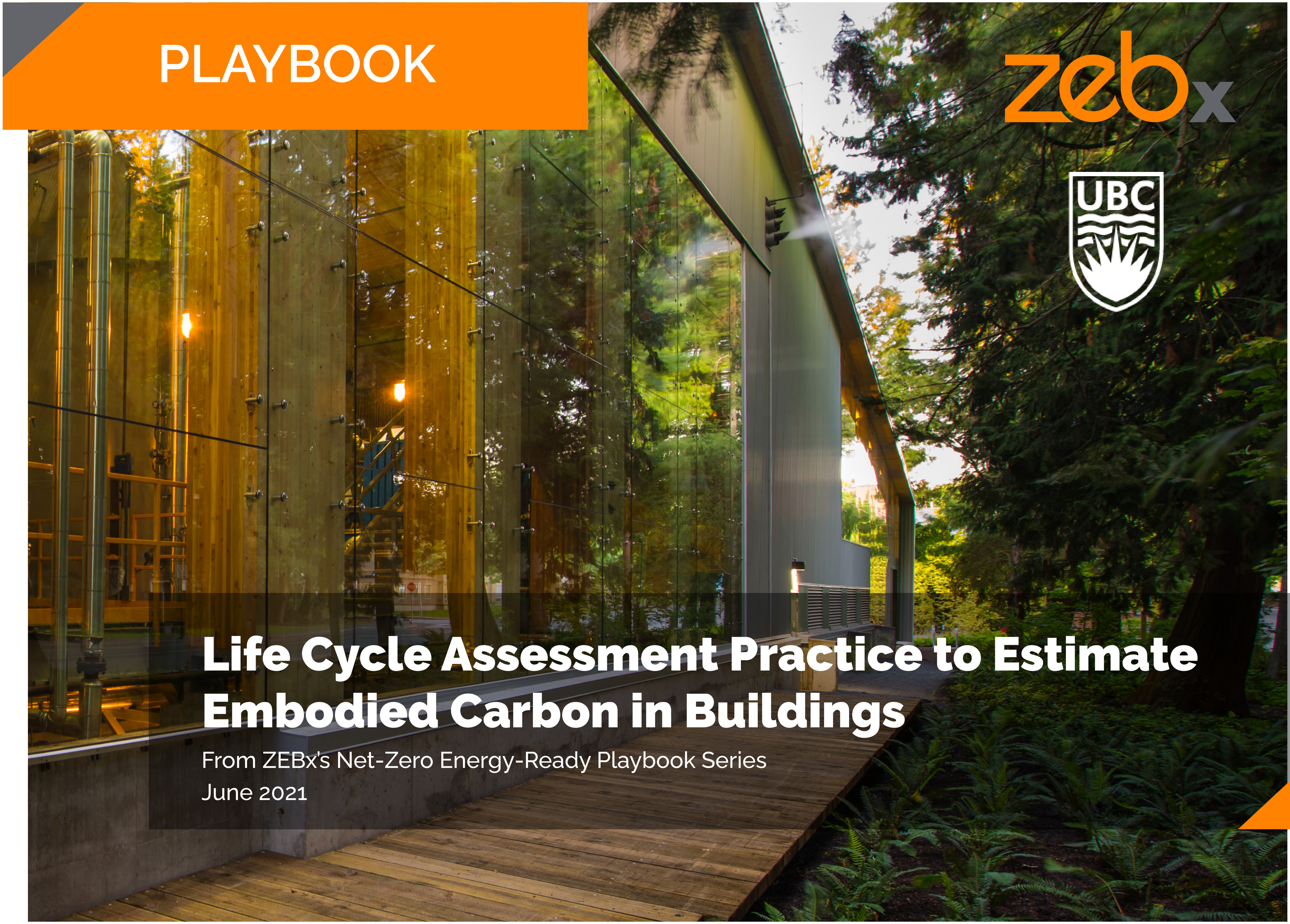
PLAYBOOK



Life Cycle Assessment Practice to Estimate Embodied Carbon in Buildings

From ZEBx's Net-Zero Energy-Ready Playbook Series

June 2021

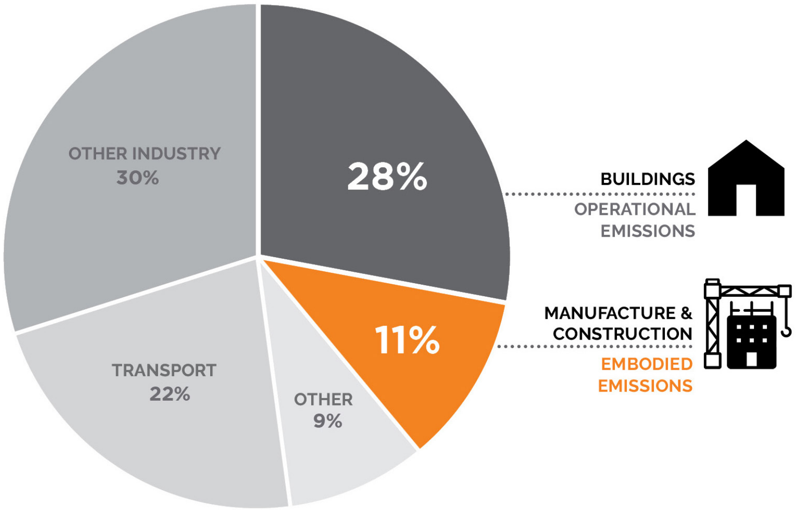
Whole-Building Life Cycle Assessment

The building sector is a significant contributor to the planet's rising levels of greenhouse gases (GHG) and is responsible for 39% of all global GHG emissions. Approximately 11% of these GHG emissions are associated with the manufacturing of construction materials and the construction of buildings.[1] As operational emissions in buildings are reduced, embodied carbon emissions from building material choices are becoming proportionally more significant.

To support the reduction of the embodied carbon footprint of buildings and other environmental impacts, the building industry has been adopting life cycle assessment (LCA) as a framework to quantify these potential impacts across the life cycle of the building. An LCA can help project teams estimate embodied carbon, understand carbon "hot spots" and inform design and construction decisions. It can be applied to individual building components and materials, or to entire buildings (i.e. whole-building LCA).

Carbon emissions are only one type of environmental impact that LCA is capable of measuring, indicated by the global warming potential (GWP) impact category. Other environmental impacts that can be estimated through LCA include creation of smog, depletion of ozone and acidification, among others.

Adapted from the UN Environmental Programme and IEA's Global Status Report, 2017



Some LCA Standards

- ISO 14040 (Environmental Management - Life Cycle Assessment - Principles and Framework)
- ISO 14044 (Environmental Management - Lifecycle Assessment - Requirements and Guidelines)
- BS EN 15978 (Sustainability of Construction Works - Assessment of Environmental Performance in Buildings - Calculation Method)

The Four Assessment Phases

Goal and Scope Definition

Determine the purpose of the assessment, the components of the building that will be assessed and the life cycle stages of interest.

Life Cycle Impact Assessment (LCIA)

Use the LCA tools to evaluate the potential environmental impacts of the elements quantified in the LCI through the chosen impact categories (GWP in the case of embodied carbon). LCA tools calculate these impacts using data from different public or proprietary databases.

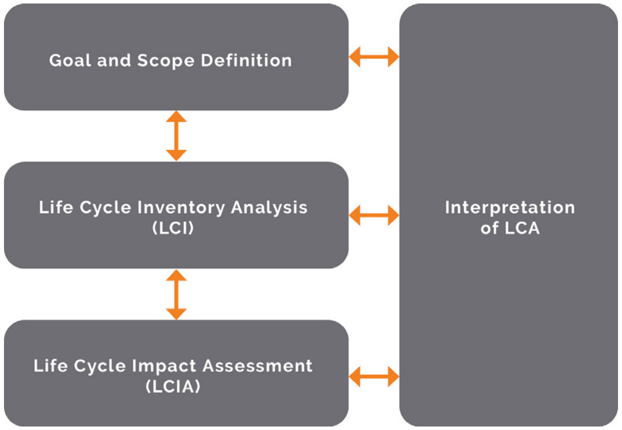
Life Cycle Inventory Analysis (LCI)

Compile and quantify inputs and outputs of the building systems and components throughout its life cycle. Practitioners usually quantify the materials and products within the building and use LCA software tools that estimate the rest of the flows within the system.

Interpretation of LCA

Interpret the partial and final results within the context of the overall LCA process and assessment system. Some of the considerations for interpreting results include identifying issues from the LCI and LCIA phases (e.g. data limitations, assumptions and exclusions), evaluating the LCA study itself (e.g. consistency and completeness), and other conclusions, limitations and recommendations.

> *EXAMPLE:*
>
> *To assess a 2x4 wood stud wall, the number of studs and their dimensions are calculated by the practitioner and input into the tool. The tool then calculates the energy and resources consumed to cut down the trees to source the wood, transport it to the sawmill, process it into lumber, transport it to the construction site, maintain and replace the stud and dispose or replace it at the end of the building's service life.*



Adapted from ISO 14040:2006

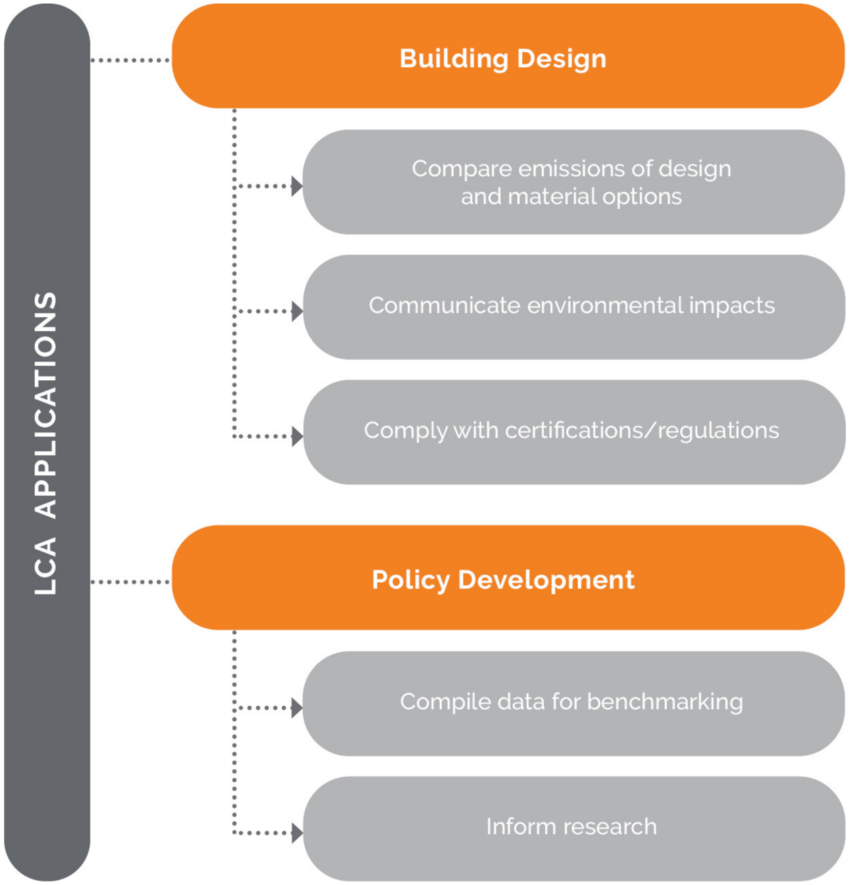
Establishing the LCA Goal

Before conducting the LCA, the practitioner must determine the goal or purpose of the assessment. According to the ISO 14040 standard, the goal of an LCA should state the intended application, the reason for carrying out the study, the intended audience and whether the results will be public.

This goal sets the basis for defining the rest of the LCA parameters, including the scope, timing, data sources, tool and input methods. As results can vary widely based on these parameters, it is important to define them clearly prior to starting the assessment. Some of the most common applications of building LCA are illustrated in the figure on the right.

Depending on the goal, the LCA may be conducted at different points in time during the project design or construction process – referred to as project timing. As the building design is developed, the project data sources become progressively more detailed. It is important to establish the level of detail required of the project data that corresponds with the purpose of the LCA.

An LCA based on early design documents could be useful for project teams to select between different design options, but would not be able to assess the actual building's environmental impacts. In contrast, an LCA based on as-built documents that include detailed information on all building elements and components provide a more accurate estimate of the building material quantities and respective environmental impacts, and are better suited for benchmarking or reporting on performance.



Defining the LCA Scope

The LCA scope should be well-defined to ensure that the breadth, depth and detail of the study are compatible with the goal. A typical LCA scope includes:

Object of Assessment:

the building components to be assessed

Reference Study Period:

the period over which the building is being assessed

System Boundary:

the life cycle stages included in the assessment

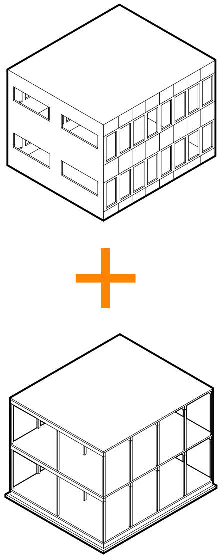
If the LCA is a comparative assessment for design decision-making or for certain certifications, a functional equivalent should also be defined. The functional equivalent is a baseline building that represents the required characteristics and functionalities of the building to be assessed. This can be either an actual or theoretical model building.

As outlined in the ISO 14044 standard, other relevant elements that should be considered when defining the scope include the subjective values and assumptions that will guide decisions while conducting the LCA, as well as methodological procedures. These include data requirements and limitations, approaches to peer review, and others.

LCA Scope Requirements

When conducting an LCA to comply with regulations or building certification standards, some aspects of the LCA scope might already be predefined.

For example, to obtain LEED points under credit MRc1 – Option 4, LEED v4.1 requires a whole-building LCA of the project's structure and enclosure, predetermining the object of assessment. LEED also requires compliance with the ISO 14040/44 standards.[2]

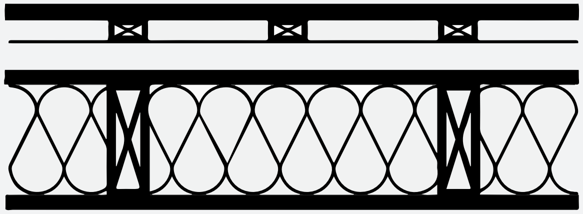


1 Object of Assessment

Selecting the object of assessment should be done in a way that aligns with the LCA goal, and may depend on the data sources and project timing. LCAs can include only parts of the building, such as a certain assembly or individual products, or consider the entire building holistically in a whole-building LCA. Whole-building LCAs typically include the building's structure, envelope and interior elements (i.e. groups A-C of UNIFORMAT II), and exclude mechanical, electrical and plumbing (MEP) systems and other services, equipment, and furnishings, as well as other site activities (i.e. groups D-G of UNIFORMAT II). However, there is no universal definition of whole-building LCA in terms of the object of assessment. Different regulations or rating systems have different requirements.

Once the overall object of assessment is defined, the next decision is to determine the assembly detail. The assembly detail refers to the level of detail of the construction elements included within the object of assessment.

> *EXAMPLE:*
>
> *In an exterior wall assembly, the assembly detail refers to which layers within those walls should be included.*



This consideration is one of the more difficult to prescribe and relies heavily on the purpose of the assessment, the information available and the practitioner's interpretation of the scope. Maintaining consistent levels of assembly detail should rely on standardized requirements and guidelines, as well as a rigorous approach to decision-making.

> *EXAMPLE:*
>
> *The level of detail used for curtain wall mullions should correspond to the level of detail used for other window and door frames.*

Certain classification systems, such as UNIFORMAT II, provide frameworks for determining the assembly detail, but this often occurs on a case-by-case basis due to each building's unique assemblies and data limitations.

2 Reference Study Period

The reference study period is the time period over which the building is being assessed. This time period often corresponds to the required service life of the building. Sometimes the reference study period differs from the required service life depending on the LCA goal or the regulatory or certification requirements. In cases where the required service life and the reference study periods are different, the EN 15978 standard recommends applying a factor to account for the difference between the two. Whole-building LCA tools allow the practitioner to specify the reference study period, which will only impact the 'use' life cycle stage. Most buildings in North America have a required service life ranging from 50 to 100 years, or sometimes less.

3 System Boundary

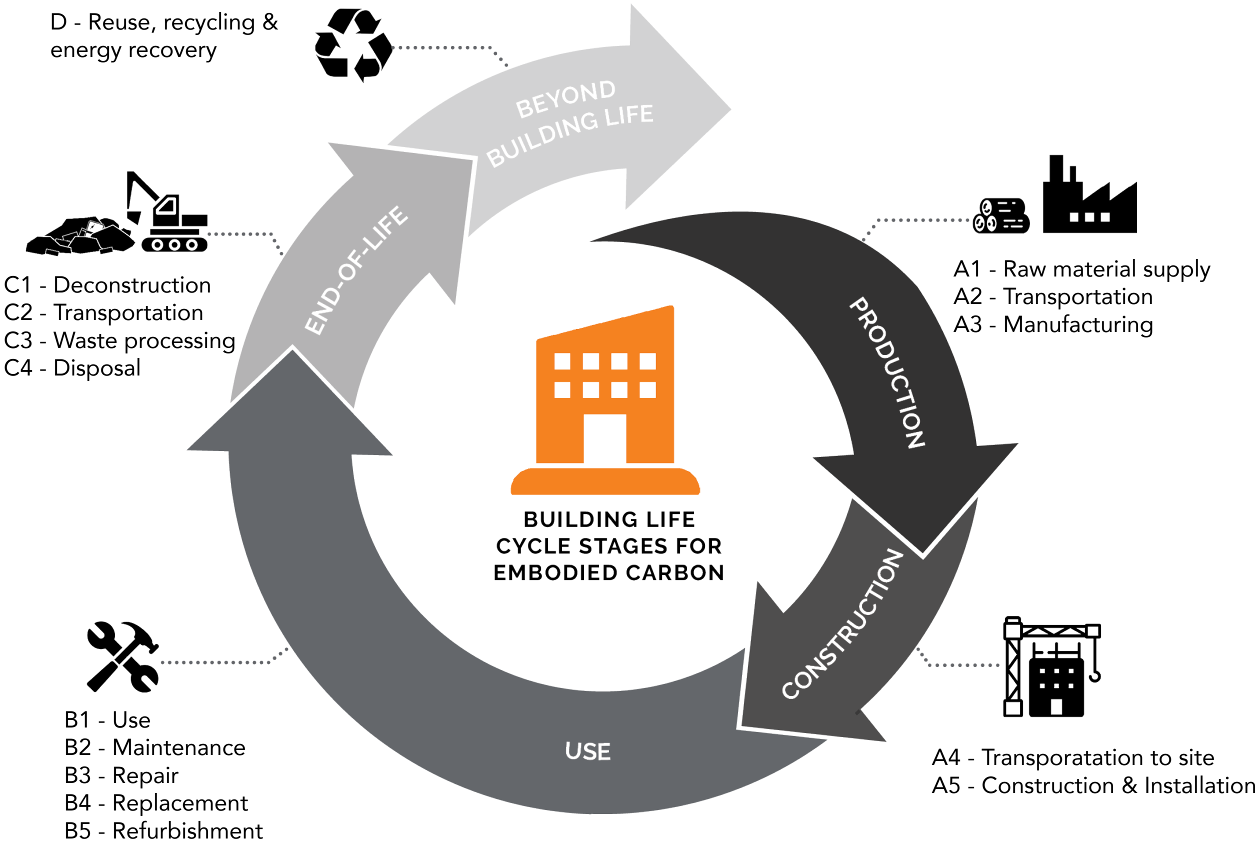
The system boundary refers to the life cycle stages that are included in the LCA. According to the EN 15978 standard, life cycle stages are grouped in the following modules[3]:

- Product (A1-A3)
- Construction process (A4-A5)
- Use (B1-B5)
- End-of-life (C1-C4)
- Benefits and loads beyond the building life (D)

Whole-building LCA tools have either a default system boundary or a customizable system boundary that can be adapted to the LCA goal.

Operational Water & Energy Use

Although modules B6 and B7 – operational water and energy use – are part of the LCA system boundary, the results from these modules are excluded when assessing embodied carbon, since these represent the operational emissions of the building and not the embodied emissions.

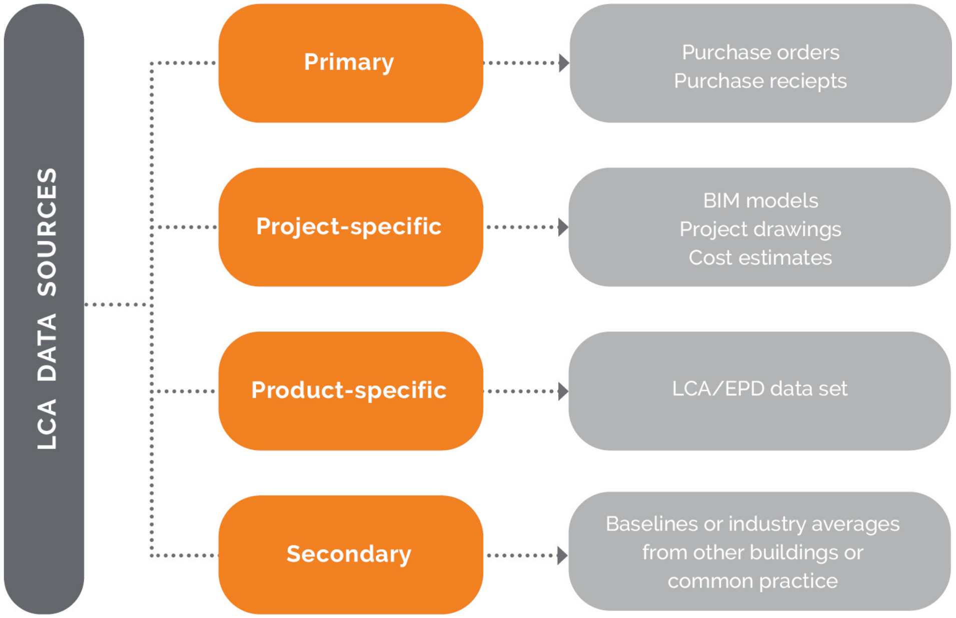


Sourcing the LCA Data

The data source is the point of origin (document, list, model, drawing, etc.) from which information about the building's assemblies and material quantities can be collected and calculated.

Data sources can be classified by their level of accuracy as primary, project-specific, product-specific and secondary. Primary and project-specific data sources usually provide the most detailed information about the quantities and materials in the building, although they usually require interpretation and adaptation since they were not created explicitly for LCA purposes. Product-specific and secondary sources are not project dependent and are based on industry averages, approximations and estimates. The most appropriate data source to use depends on the LCA purpose, the project timing and the availability of information. For example, To conduct LCAs on buildings in the planning and early design phase, it may be necessary to use secondary data as the project-specific materials or quantities may not be specified yet.

Practitioners conducting LCAs can usually rely on project documentation, including drawings, cost estimates and Building Information Models (BIM). Project documentation can be drawn from any point within the design development process, and can be used to assess specific building components or the whole building. The accuracy of the LCA depends on the accuracy and completeness of the data source. In addition, some building LCA tools are only compatible with certain types of data sources.

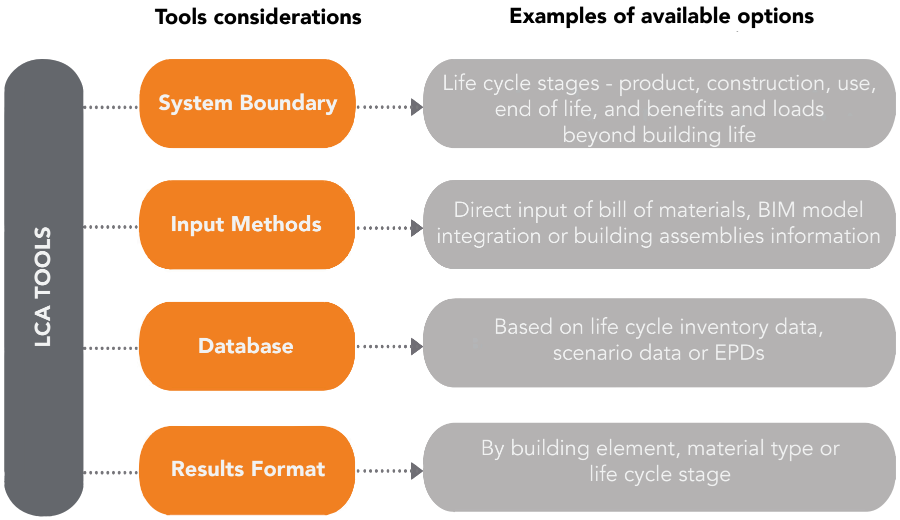


EXAMPLES:

BIM models that are only used for visualization purposes might not have all the relevant information to conduct an accurate assessment, as important assembly and component details may have been omitted for ease of modeling.

The LCA tool Tally® is a Revit plug-in and is designed to assess a building's material quantities based on the geometry of its BIM model only.

Choosing an Assessment Tool



Tools considerations	Examples of available options
System Boundary	Life cycle stages - product, construction, use, end of life, and benefits and loads beyond building life
Input Methods	Direct input of bill of materials, BIM model integration or building assemblies information
Database	Based on life cycle inventory data, scenario data or EPDs
Results Format	By building element, material type or life cycle stage

A number of software tools for building LCAs are available in Canada and other parts of the world. The selection of a specific tool should be based on the assessment parameters, such as the LCA goal, timing, scope and data source. It is also important to consider a specific tool's attributes, such as the system boundary, the data input method and the format of the results. In addition, each tool draws on its own database of environmental impact information, which will influence the accuracy and applicability of results.

System Boundary

Whole-building LCA software tools estimate a building's environmental impacts over its projected lifetime. They include detailed impact information for all (or most) life cycle stages and a range of environmental impact categories. Some tools allow for the practitioner to select the system boundary according to their needs.

Recently, embodied carbon calculators have been developed that focus solely on upfront embodied carbon (i.e. from production only).These software tools are not intended to perform a whole-building LCA, but rather to provide a streamlined approach for assessing design and procurement decisions based on the embodied carbon for specific products or materials.

> *Athena Impact Estimator for Buildings™, One Click LCA® and Tally® are examples of whole-building LCA software tools.*
>
> *The Embodied Carbon in Construction Calculator (EC3) and Gestimat are examples of embodied carbon calculators.*

Input Methods

Whole-building LCA typically requires the creation of a building's bill of materials (BoM), which can be defined as the estimated quantity of materials required to construct the building. Each software tool has its own user interface and process for inputting these material quantities into the tool. The different data input methods offer a range of benefits and tradeoffs depending on the LCA goal, scope and data source.

Most LCA tools allow or require the direct input of a building's BoM. In these cases, the practitioner uploads or manually enters the compiled list of material types, quantities, categories and other relevant data into the tool's interface. While each tool may require different levels of material specificity, this input method is relatively simple provided the data processing has been completed prior to input. Some tools may be able to create a BoM from information about the building's assemblies only. This is useful for projects in early design development where detailed data about material quantities is not available.

As the use of BIM and other 3D computer models becomes more common, some LCA tools are offering BIM software plugins that allow for integration between the modeling software and LCA software. Material quantities can be extracted directly from a BIM model to the tool with little intermediate data processing. The practitioner specifies material parameters for each element in the BIM model to create the BoM. The level of complexity for this method depends on the complexity, organization and completeness of the BIM model.

Results Format

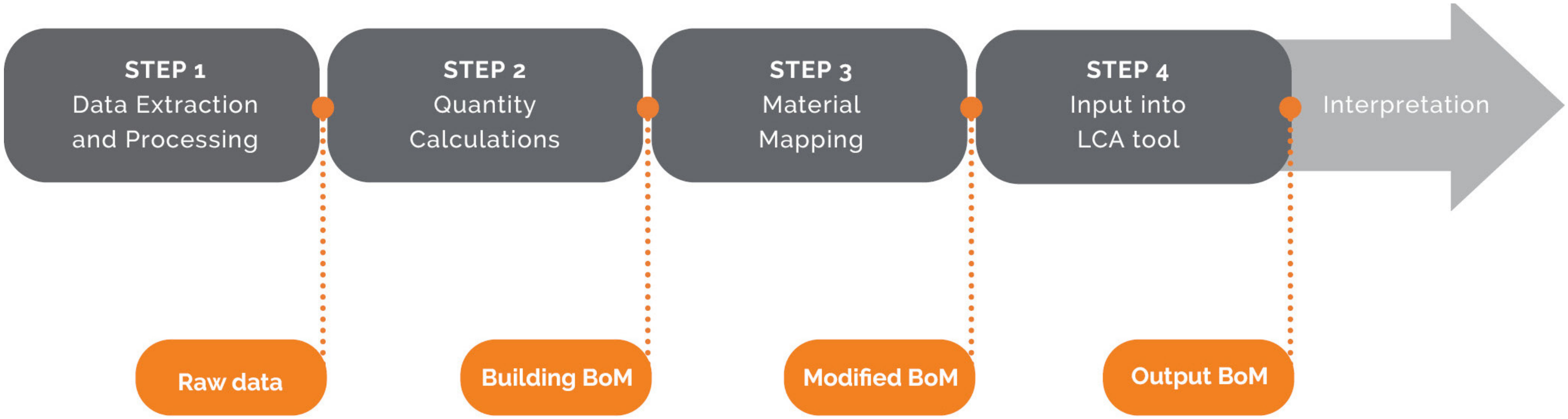
Each tool has its own way of displaying the LCA results. These may be broken down by building element, material type, life cycle stage, etc., and may be displayed in an online portal, exported in various file formats, and/or shown in tabular or graphical forms. Attention should be given as to how the tool generates the output reports to ensure it will provide the results in the format and level of granularity that is useful for the purpose of the LCA.

Databases

Life cycle databases exist in the background of LCA software tools, allowing them to deliver sophisticated results without requiring users to be LCA experts. Every tool uses different databases, which may be proprietary or public and are ideally kept up to date as new information becomes available. Databases may be based on life cycle inventory data, scenario data and environmental product declarations (EPDs). EPDs are independently verified documents that provide a summary of LCA results of a specific product.

Life cycle inventory data is a compilation of the input and output flows for flows for many products, processes and materials. Scenario data is used in combination with inventory data to cover assumptions about the future such as transportation distances and delivery modes of products to the construction site, product replacement cycles, or disposition of building materials at end of life. Databases can be based on EPDs. Most EPDs focus on the product life cycle stage (i.e. material extraction, manufacturing and transportation in-between these stages). EPDs can also be product-specific or industry-average.

Conducting the Assessment



The methodology outlined here is for LCAs based on the building's BoM. The process to conduct an LCA generally includes the following four steps:

Data Extraction and Processing

Quantity Calculations

Material Mapping

Input/Output from the LCA Tool

The sequence in which these steps happen, as well as the specific tasks included in each one, can vary and overlap depending on the tool and data sources chosen for the assessment.

STEP 1 Data Extraction and Processing

Project data extraction is the process of converting information from the project data sources into a preliminary list of materials, referred to as raw data. The raw data list should include information about the building assemblies within the LCA scope only. This step involves different tasks depending on the data source, and can be supported by different software tools.

> *EXAMPLE:*
>
> *Extracting data from architectural and structural drawings requires quantity takeoffs, which can be done by hand or with the help of quantity takeoff software tools; BIM software may support the generation and export of material takeoff schedules directly from the virtual model; cost estimates can be imported into data processing software to organize, separate and classify materials.*

STEP

2 Quantity Calculations

In this step, the raw data is used to estimate material quantities in the appropriate units of measure. It also includes consolidating identical materials across the same assembly group to achieve one single quantity for each material. This consolidated list constitutes the building BoM.

The creation of a BoM requires a thorough accounting of the relevant elements and components in the project, and a consistent approach to data preparation to ensure reliability of results. The BoM should be organized using a classification system such as UniFormat, Master Format or Omni Class. It can also follow the classification system of the chosen LCA tool, which may be different than the commonly used construction classification systems.

> *EXAMPLE:*
>
> *The raw data might include the building's walls surface areas. Calculations need to be made to estimate the number of wood studs within each wall based on the spacing and dimensions of the studs in each wall assembly, the number and dimension of each wall assembly in the building, and with this information, calculate the total volume of wood studs in the entire building.*

STEP

3 Material Mapping

Material mapping is the process of matching the materials in the building's BoM with the materials available in the LCA tool's database.

In this step, materials should be categorized based on the tool's classification system. This new list is referred to as the modified BoM.

For materials and products without an exact match, the practitioner must determine an acceptable substitution. This typically involves finding the closest similar product or material. Likewise, the units of the material quantities must be converted to match the units in the LCA tool's database.

The assumptions and adjustments in material choices and units of measure made in this step should be documented as they will impact the results. If a work-around cannot be found and the material must be excluded, the LCA's object of assessment should be adjusted and the issues documented.

STEP

4 Input/Output from the LCA Tool

Conducting the assessment using the selected LCA tool involves a process of uploading or manually entering the modified (input) BoM using the tool interface. The environmental impact results and the corresponding output BoM, are then exported from the tool. The output BoM is different from the modified BoM in that it might include extra materials and construction waste factors accounted for by the tool when running the LCA.

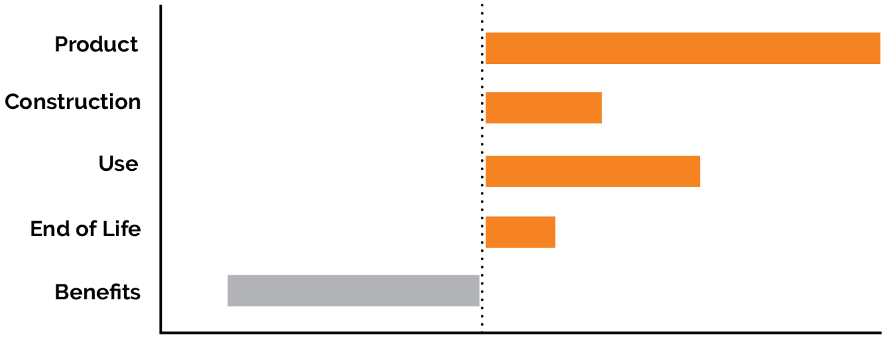
It is important to conduct a preliminary review of the results by checking for discrepancies in material quantities or errors in calculations. If the LCA results are unexpected or seem incorrect, the practitioner should review these steps and re-calculate the LCA.

Interpreting and Reporting the Results

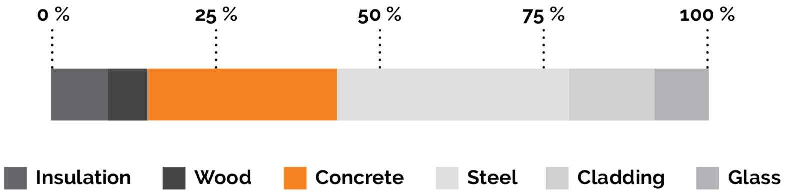
After conducting an LCA, the outputs and results should be presented and interpreted in accordance with the LCA goal and scope. This may involve an iterative process of reviewing the LCA inputs, process and results to ensure that they align with the LCA goal. Interpreting the results allows the practitioner to reach conclusions, explain data limitations, provide recommendations to project decision-makers and/or demonstrate achievement of performance targets.

When interpreting the LCA results, practitioners should recognize that they are estimates only, despite the high degree of precision with which the impacts are usually displayed. LCA results indicate potential environmental effects and do not predict actual impacts on human health, resource availability and ecosystem quality. Results are also dependent on the LCA goal and scope, which in turn influences decisions on data inputs, tools, databases, and assumptions. The same building can be assessed using different parameters or tools and get different LCA results.

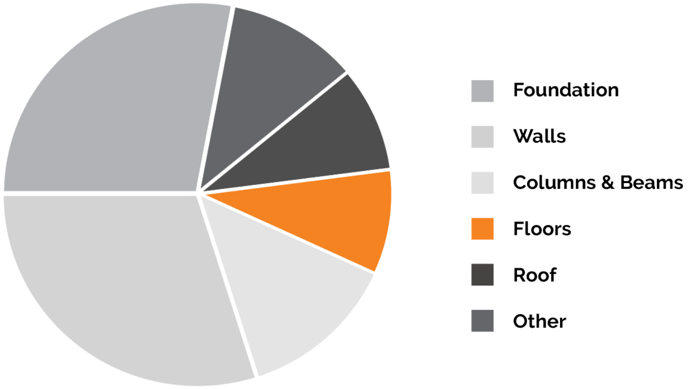
The reporting strategy is an integral part of an LCA. An effective report should describe the methodology for conducting the assessment, as well as report the results and conclusions of the LCA addressing the data, methods and assumptions applied in the study, and the limitations thereof.[5,6]



GWP by Life Cycle Stage ($kgCO_2eq/m^2$)



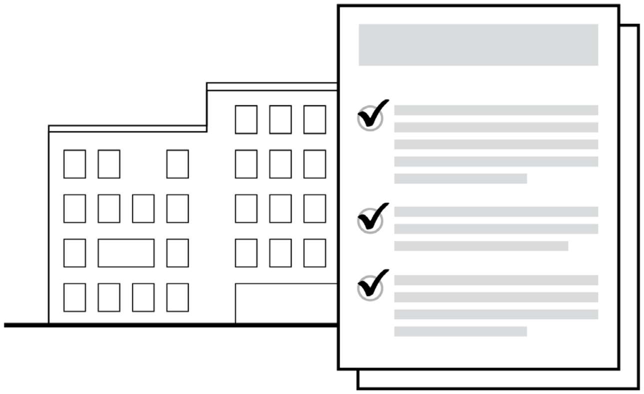
GWP by Material Type ($kgCO_2eq/m^2$)



GWP by Assembly ($kgCO_2eq/m^2$)

Strategies to Reduce Embodied Carbon in Buildings

The collective industry experience of professionals who have worked on LCAs is rapidly expanding as the field continues to mature. The body of knowledge gained through experience is being developed into design and construction strategies to reduce the environmental impact of buildings.



Some of the strategies for reducing the embodied carbon in building materials include[7]:

- Using less material in a building
- Rehabilitating existing buildings rather than building new
- Selecting materials with lower manufacturing emissions
- Substituting products with a low-carbon version
- Selecting durable materials with lower replacement rates
- Designing buildings that enable durability through adaptability
- Designing systems and components for ease of maintenance to extend their useful life
- Planning and designing for deconstruction and product capture for reuse
- Minimizing and reusing construction and operational waste

The proactive integration of LCA into the building design process can help project teams determine the most appropriate strategies for their project and how to best implement them.

Additional Resources

This playbook is intended to provide an overview of the processes and considerations for conducting LCA to estimate a building's embodied carbon emissions. The reader is encouraged to review more in-depth reports, studies and standards.

- In Canadian regulations, whole-building LCA and embodied carbon reduction in construction is not yet a general requirement, although it is starting to permeate in some jurisdictions and government entities. Some examples include the City of Vancouver's Zero Emissions Building Plan & Climate Emergency Action Plan, and the Federal Government's Greening Government Strategy.
- The National Research Council's low-carbon assets through lifecycle assessment initiative (LCA²) is leading a national effort to develop and launch a centralized Canadian LCI database to standardize LCA results across the country. For more information, please visit: https://nrc.canada.ca/en/research-development/research-collaboration/programs/low-carbon-assets-through-life-cycle-assessment-initiative
- The number of certifications addressing embodied carbon in construction sector has been growing rapidly. The most popular in Canada include: CaGBC Zero Carbon Building Standard, LEED Certification, ILFI Living Building Challenge & Zero Carbon Certification.
- The Athena Sustainable Materials Institute is a non-profit research collaborative that has published a number of resources for construction LCA practitioners. For a complete list of their publications, please visit: http://www.athenasmi.org/resources/publications/
- Bionova published in 2018 a review of how embodied carbon is addressed in certifications and regulations globally. To access this comprehensive study, please visit: https://www.oneclicklca.com/embodied-carbon-review/

Endnotes

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