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Considerations and Worksheet for Structural WBLCA of Mass Timber Buildings

Guidance for mass timber building designers undertaking whole building life cycle assessment (WBLCA)

The design community has embraced the use of whole building life cycle assessment (WBLCA) as a means to quantify, and sometimes compare, the environmental impacts of buildings. While this momentum is exciting, detailed standards for a unified approach to WBLCAs are still in development, leaving designers without clear direction during the assessment process. This document seeks to outline requirements pertaining to life cycle assessment (LCA) found in international standards, and provide guidance on how WBLCAs for mass timber buildings are performed using commercially available LCA tools.

Requirements and guidelines for LCA are provided in the International Organization for Standardization's ISO 14040 *(Principles and framework)* and 14044 *(Requirements and guidelines)*. ISO 14040 Section 4.2.1 outlines four phases of an LCA as shown in Figure 1:

- Goal and scope definition
- Life cycle inventory (LCI) analysis
- Life cycle impact assessment (LCIA)
- Interpretation

As illustrated by the arrows in the figure, these phases are interlinked and performing an LCA is an iterative process. This paper will step through common decisions building designers need to make in each phase of the LCA. It is accompanied by a worksheet—sections of which are included here—to help the designer answer these questions when performing a WBLCA. The worksheet can be downloaded as a fillable PDF at www.woodworks.org/WBLCA_worksheet.

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Image: Monte French Design Studio

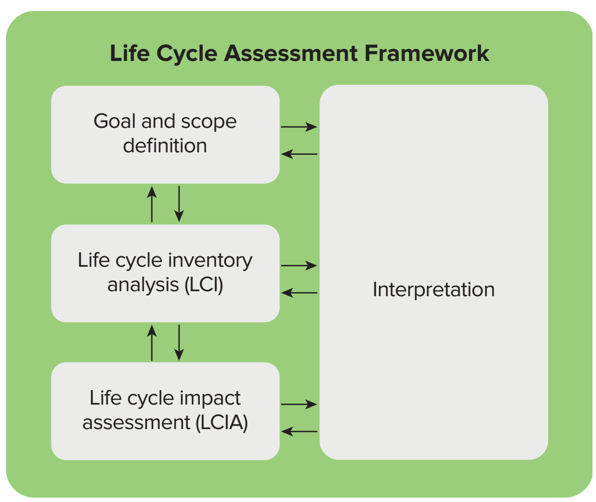

FIGURE 1: Stages of an LCA, adapted from ISO 14040:2006(E) © ISO

Goal and Scope Definition Phase

While seemingly simple, defining the goal and scope of an LCA is an important first step—and one that will likely be revisited throughout the LCA process. The goal and scope each influence one another; having a clear goal in mind will help define the scope, while answering questions about scope will help define the goal.

Goal

To clearly articulate the goals of an LCA study, it is useful to consider the definition of goal in ISO 14044 Section 4.2.2, which says the following must be unambiguously stated:

- *Intended application*
- *Reasons for carrying out the study*
- *Intended audience, i.e., to whom the results of the study are intended to be communicated*
- *Whether the results are intended to be used in comparative assertions to be disclosed to the public*

For a mass timber project, Worksheet Table 1 below shows possible answers to these questions.

An example goal statement based on this table could be:

The goal of this LCA is to understand the potential environmental impacts of a mass timber building for two reasons—1: internal use by our firm to measure and track the impacts of our portfolio of projects, and 2: for the client's use in advertising and marketing. The results are non-comparative.

Alternatively, a comparative study might have this goal statement:

The goal of this LCA is to compare the global warming potential of a mass timber structural system to that of functionally equivalent steel and concrete structural systems for use by the design community for integration into future building designs. The results will be used to make a comparative assertion to be disclosed to the public.

Scope

Specifying the scope of the study ensures that designers focus on intended aspects of the project while conducting the LCA. ISO 14044 Section 4.2.3.1 provides a list of elements to include in the scope. For designers using simplified, commercially available LCA tools, such as Athena, tallyLCA, or One Click LCA, the user's control of the scope will typically be limited to choosing which building components will be included, and which life cycle stages and environmental impacts will be assessed.

Defining the System

For a structural WBLCA,[1] it is helpful to start with a discussion of which building components to include. This should be closely tied to the goal of the study. In some cases, the scope of interest is limited to the gravity framing (e.g., CLT floor panels supported by glulam beams and columns). However, it is common for a study to include all structural elements—even those that are not mass timber (e.g., the lateral force-resisting system, which may be comprised of concrete shear walls or steel braced frames, or the foundation system, which is typically concrete). Most often, the design team is interested in studying the impacts of choosing a mass timber framing system, including the impacts on nonstructural building systems (e.g., exposed mass timber ceilings reduce the need for finish materials on the underside of a floor-ceiling assembly and may change the type of acoustical treatment required on top).

When making decisions about which elements to include in a WBLCA, consider the following:

- **Structural systems** are comprised of the gravity system (roofs, floors, beams, columns, walls, foundations, etc.) plus the lateral system (shear walls, braced frames, moment frames, etc.). It is common to include all of these elements in a structural WBLCA, although there are times when it might be appropriate to exclude foundations, basements, substructures, etc. to isolate the portion of interest. Note that structural systems also include materials needed to meet serviceability requirements (vibration, deflection, etc.).

WORKSHEET TABLE 1:

Goal Components	Notes
Intended application (What)	*E.g., Building with mass timber structural system*
Reason for study (Why)	*E.g., To measure the potential environmental impacts of all structural materials associated with a mass timber building*
Intended audience (Who)	*E.g., Internal (for tracking) and client (for project promotion)*
Will results be made public?	*E.g., Yes*
Will results be used to make comparative assertions?	*E.g., No*

Download the worksheet as a fillable PDF at www.woodworks.org/WBLCA_worksheet.

- Floor-ceiling assemblies and wall assemblies often include **nonstructural materials** necessary to meet code requirements and performance objectives for:
  - Exterior wall and roof enclosures
  - Fire performance
  - Acoustical performance
  - Thermal performance
  - Other, based on the specific building design

It is common to include all materials relevant to an assembly's performance, whether they are structural or nonstructural.

- **Ancillary structural items** such as stair and elevator framing, rooftop penthouses, elevator overruns, etc. might be included, depending on the goal and scope of the WBLCA and their anticipated contribution to overall building impacts.[2]
- Consideration should be given to whether differences in aesthetic **ceiling or wall finishes** will be included. Mass timber buildings often have exposed structure, whereas additional finish materials may be used to cover the structure in steel and concrete buildings.
- Items such as **nonstructural partition walls** might be included, depending on the scope and goal of the WBLCA and their anticipated contribution to overall building impacts.[2]
- Depending on the desired level of detail, structural **connections** may be included. Every individual fastener could be counted, or connections could be approximated as the weight of material used. Alternatively, connections could be excluded entirely. The decision about whether and how to include connections often depends on the availability of data and anticipated contribution to overall building impacts.[2]
- It is common to exclude mechanical, electrical, plumbing, and fire (MEPF) systems from a structural WBLCA, as well as civil/site work. It is also common to exclude items such as fixtures, furniture, and finishes, except where finishes contribute to the performance requirements as noted above.

WORKSHEET TABLE 2:

Scope Considerations for a Structural WBLCA **Will the LCA include:**	**Yes**	**No**	**Notes**
The entire structural system (gravity, lateral, substructure and foundations)? If no, describe the system(s) to be studied.			
Additional materials needed to meet vibration or other serviceability requirements?			
Nonstructural building enclosures required for moisture protection and thermal performance (exterior walls and roofs)?			
Materials and assemblies needed to meet code-required fire performance?			
Materials and assemblies needed to meet code-required or project-specific acoustical performance?			
Ancillary structural items such as stair framing, elevator overruns, rooftop penthouses, etc.?			
Aesthetic ceiling and/or wall finishes?			
Nonstructural partition walls?			
Connections? If yes, describe the level of detail.			
MEPF? *(This is not common.)*			
Nonstructural elements not indicated above? *(This is not common.)*			

Download the worksheet as a fillable PDF at www.woodworks.org/WBLCA_worksheet.

Establishing Functional Equivalency

When performing a comparative LCA, it is even more important to consider how the choice of structural framing material will impact the items in Worksheet Table 3 to ensure the buildings being compared are *functionally equivalent*. Design teams are often interested in studying the differences between a mass timber building (i.e., a building with a mass timber structural system) and an equivalent steel or concrete building. Because the choice of structural system has cascading impacts on other building systems, there will almost certainly be additional differences between the buildings in order to achieve the same performance. When developing functionally equivalent designs, consider:

- What aspects of the designs will be the same? Typically, this includes project location, building use/occupancy, expected lifespan of the building, total building area, and number of stories.
- Will **grid spacing** remain the same, or is there enough architectural flexibility to allow the framing to be optimized for each building material while still allowing the space to be used as intended?
- Should the **floor-to-ceiling clear height** remain unchanged, which may result in a different overall building height based on the thickness of the floor assembly? Or should the floor-to-ceiling clear height be adjusted so the overall building height remains unchanged?
- Is the design of the **lateral system** affected by the change in building materials and overall structural weight, or is it assumed to remain the same?
- Is the design of **foundations** (and any substructure/basement) affected by the change in superstructure building materials and weights, or is it assumed to remain unchanged?

WORKSHEET TABLE 3:

Developing Functionally Equivalent Designs for a Comparative WBLCA	**Mass Timber**	**Alternative 1**	**Alternative 2**
Describe the alternative structural system(s) that will be compared to mass timber.	*E.g., CLT floor and roof panels with glulam beams and columns*	*E.g., Steel beams and columns with composite concrete on metal deck floor system and metal deck roof*	*E.g., Post-tensioned concrete floors and roofs with reinforced concrete beams and columns*
Project location	*E.g., Anytown, USA*		
Applicable building code(s)	*E.g., 2021 IBC with local amendments*		
Building occupancy/use	*E.g., Mixed-use; R-2 and A-1*		
Expected design life	*E.g., 75 years*		
Total building area	*E.g., 100,000 sf (typically the same for all)*		
Total number of stories	*E.g., 8 stories above grade (typically the same for all)*		
Column grid spacing	*E.g., 20 ft x 20 ft*	*E.g., 30 ft x 30 ft*	*E.g., 30 ft x 30 ft*
Floor-to-ceiling clear height	*E.g., 10 ft clear*	*E.g., 10 ft clear*	*E.g., 10 ft clear*
Overall building height	*E.g., 96 ft*	*E.g., 98 ft*	*E.g., 92 ft*
Construction type	*E.g., Type IV-C*	*E.g., Type II-B*	*E.g., Type II-B*
Lateral system(s)	*E.g., Steel braced frames*	*E.g., Steel braced frames*	*E.g., Reinforced concrete shear walls*
Foundation system(s) and basement/substructure, if applicable	*E.g., Shallow spread footings with mat foundation under lateral elements, no basement*	*E.g., Shallow spread footings with mat foundation under lateral elements, no basement*	*E.g., Pile foundation with pile caps and grade beams throughout, no basement*
Other differences between the design alternatives			

Download the worksheet as a fillable PDF at www.woodworks.org/WBLCA_worksheet.

When developing functionally equivalent designs, it may be that the proposed or as-built design has been further developed than the alternate design(s). It is important that comparative LCAs be performed on designs with the same level of detail so the results are directly comparable, whether this means further development of the alternate(s) or simplification of the primary design. Any differences between the systems being compared should be documented and explained in the LCA report.

Life Cycle Stages

Once the design options are determined, there are some decisions to be made regarding the LCA itself, such as which life cycle stages will be evaluated. Typically, structural WBLCAs include *all four life cycle stages* (production, construction, use and end of life, captured in Modules A1-C4) as outlined in ISO 21930.[3] Known as a *cradle-to-grave* LCA, this approach is recommended as it will provide the most complete results. An LCA may also study a system from cradle-to-gate (A1-A3) or cradle-to-construction gate (A1-A5); however, it is important to consider the goal of the study to ensure that all relevant stages are included. ISO 14044 Section 4.2.3.3.1 states, "the deletion of life cycle stages… is only permitted if it does not significantly change the overall conclusions of the study."

Environmental Impacts

The scope should define which environmental impact categories will be assessed. In a structural WBLCA, global warming potential (GWP) is commonly included, in recognition of various policies, initiatives and goals to reduce greenhouse gas emissions and slow climate change. It is also common to include acidification potential, eutrophication potential, ozone depletion potential, smog formation potential, and fossil fuel depletion (or nonrenewable energy use). Other impact categories exist[4] and can be included as desired to meet the goal of the LCA. Most LCA tools have the ability to report on a preset list of impact categories.

Keep in mind that answers to all of these questions may not be apparent at the beginning of the project. The scope can be revisited and revised throughout the LCA process.

LCI Phase

The LCI phase is where the majority of data collection occurs and results in a complete inventory of inputs and outputs for the materials included in the LCA.[5] For example, in this phase we can see how much nonrenewable energy is used for each unit of product that goes into a building. These outputs will be used to quantify environmental impacts in the LCIA phase (discussed next).

When using one of the simplified LCA tools previously mentioned, most of the work in the LCI phase, such as decisions about data sourcing and methodological approaches, is built into the tool.[6] For the user, the main work during this phase consists of choosing appropriate materials from the dataset available. Although these tools typically have built-in LCI datasets that cannot be manipulated, some allow input of unique data. Alternatively, the user might make modifications to data outside the tool. In either of these cases, the user should be familiar with the source and quality of the data being used, consider its compatibility with predefined data used by the tool, and understand the potential impact on the LCA results. This type of manual adjustment should be well documented in the LCA report for transparency and replicability.

A note on product availability within LCA tools: Selecting appropriate materials within an LCA tool is a key step in the process. However, limited data availability within the tools can require the use of proxy materials. For example, assume a particular CLT product from a specific manufacturer has been chosen for a project. The manufacturer has a product-specific environmental product declaration,[7] but that product and its EPD data are not available within the tool. In this case, a user might need to select a "generic" CLT product within the tool, typically representing an average of several different products. In other cases, a material might simply be unavailable—in which case the tool user needs to decide whether to substitute a different material in the analysis or omit the product altogether. These types of discrepancies should be clearly documented in the LCA report along with a discussion of how these assumptions are expected to affect the overall results.

WORKSHEET TABLE 4:

Additional Scope Considerations	Notes
Which life cycle stages will be included?	*E.g., A1-C4, cradle-to-grave, excluding Module D*
Which environmental impact categories will be assessed?	*E.g., Global warming potential, acidification potential, eutrophication potential, ozone depletion potential, smog formation potential, fossil fuel use*
Other scope items not already addressed	

Download the worksheet as a fillable PDF at www.woodworks.org/WBLCA_worksheet.

LCIA Phase

The LCIA phase is where inputs and outputs from the LCI phase are converted into the environmental impacts that will be reported.[8] For example, the nonrenewable energy use that was inventoried in the LCI phase is converted into an equivalent carbon dioxide (CO_{2e}) emission that is then reported in the GWP indicator. The LCI and LCIA phases are where the bulk of analysis occurs. Again, when using a simplified LCA tool, most of the methodological decisions in these phases have been set by the tool's developers. The assumptions are documented in the output report and/or user manuals and typically cannot be changed within the tool. Building designers should be familiar with the methods used and assumptions made within each tool, and may want to provide additional commentary about how those assumptions impact the results. If the tool user makes any additional modifications outside of the tool, those changes should also be well documented in the LCA report.

A note about biogenic carbon:
One significant methodological difference between LCA tools is the handling of biogenic carbon. Biogenic carbon should be included in an LCA,[9] but some tools report it *separately* while others include it *in the reported GWP value*. Adding complexity, some tools report the amount of biogenic carbon stored *for the life of the building* while others report the amount of carbon *permanently stored at the end-of-life stage*. See the WoodWorks article, Biogenic Carbon Accounting in WBLCA Tools, for more information.

A short list of considerations for both the LCI and LCIA phases is summarized in Worksheet Table 5. Due to the complex nature of LCA, it is not advised to make adjustments to a tool's results without a comprehensive understanding of LCA practices in general, the specific tool being used, and the background data and assumptions associated with the modification. Consult the additional references listed at the end of this article for more detailed information.

Interpretation Phase

After the previous phases have been completed, the results must be interpreted in order to draw conclusions and share outcomes of the LCA. As noted, this may need to be done several times due to the iterative nature of LCA. ISO 14044 Section 4.5.1.1 outlines three elements of the interpretation phase:

- Identification of the significant issues based on the results of the LCI and LCIA phases of the LCA
- An evaluation that considers completeness, sensitivity and consistency checks
- Conclusions, limitations, and recommendations

Specifically, the results should be interpreted based on their compatibility with the goal and scope of the study. Many of these items (identification of significant issues, completeness and consistency checks, limitations of the study) have been discussed in the previous sections and outlined in the worksheet. The remaining items are discussed below.

A sensitivity analysis tests how varying the assumptions and data by some amount influences the results. This step helps to ensure reliability of the results and helps the designer understand which material choices have more or less impact overall.[2] Because LCA tools do not typically allow manual adjustments of the underlying data and assumptions, the user may choose to adjust and test the sensitivity of their inputs (i.e., the material quantities), especially for building elements where quantities had a higher degree of uncertainty (e.g., the exact weight of steel used in connections was not known and had to be estimated based on rules of thumb).

Results from LCA tools typically include several reporting options. For example, results might be separated by life cycle stage (A1-A3, A4-A5, B1-B7, C1-C4, and D). They might be grouped by material (e.g., wood, steel, concrete, glass, plastics) or according to the material's function within the building (e.g., foundations, beams and columns, floors and

WORKSHEET TABLE 5:

Methodology and Data	Notes
Which LCA tool is being used?	*E.g., Athena IE4B, tallyLCA, or One Click LCA*
Is biogenic carbon reported separately or as part of the GWP?	*E.g., As part of GWP*
Additional explanation of biogenic carbon reporting, as necessary	*E.g., The tool reports biogenic carbon at each life cycle stage. The total GWP reported includes the amount of biogenic carbon permanently stored in the landfill at the end of life.*
Explanation of other methodological choices defined by the tool, as necessary	*E.g., The tool assumes an end-of-life mix of x% landfilled, x% recovered and x% incinerated. [Explain of implications to the project results.]*
Explanation of data gaps or assumptions	*E.g., The tool uses glulam as a proxy for CLT. Based on cradle-to-gate EPD data from the specific CLT manufacturer, this is expected to have [anticipated impact] in the A1-A3 stage. [Include any anticipated impacts in the A4-C4 stages.]*

Download the worksheet as a fillable PDF at www.woodworks.org/WBLCA_worksheet.

WORKSHEET TABLE 6:

Interpretation and Conclusions	Notes
Identify any gaps, inconsistencies, errors or limitations not previously noted.	
Results of sensitivity check, if applicable	
Reporting of results	*E.g., Results by life cycle stage, results by material, results by building system or function*
Conclusions and recommendations	
Third-party review, if required	*E.g., A critical review was provided by [name(s)]. [Include results of review.]*

Download the worksheet as a fillable PDF at www.woodworks.org/WBLCA_worksheet.

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roofs, walls). This granularity can help both the author and audience understand the significance of the data so conclusions and recommendations can be more easily made.

Note that environmental impacts are often reported two ways: on a per unit area basis (e.g., kg CO_{2e}/m^2) or total impact for the building (e.g., kg CO_{2e}). Results per unit area can help with comparisons to benchmark studies while totals for the building might better convey the impacts of the specific design. The decision to report one or both sets of results likely depends on the goal of the LCA.

Conclusions can be drawn from the above work, while recommendations are made on the basis of these conclusions and should relate to the goal and scope of the LCA study. Results and conclusions should be reported in an unbiased and transparent manner such that the study can be replicated, and similar conclusions reached.

Note that ISO 14044 outlines additional requirements for two situations. First, "when results of the LCA are to be communicated to any third party… a third-party report shall be prepared."[10] This report may be prepared by an internal or external expert, as long as they were not part of the preparation of the LCA report.[11] There are additional requirements "when the results are intended to be used to support a comparative assertion intended to be disclosed to the public."[12] This type of critical review must be carried out by an external independent review panel that may include "interested parties affected by the conclusions drawn from the LCA, such as government agencies, non-governmental groups, competitors and affected industries."[13] In keeping with this requirement, product-level LCAs, which feed into WBLCAs, are third-party verified, but are not meant for comparison with other product-level LCAs. Similarly, it is advisable that WBLCAs also be third-party verified, though, in practice, the extent to which this occurs varies. Verification performed by someone with expertise in LCA who was not directly involved in the study will increase the credibility of the results. However, when performing comparative WBLCAs, it might not be feasible to engage all competitors and affected industries in a productive manner. At a minimum, should the design team choose to address this critical review, it might be possible to get consensus on the appropriateness of the design comparisons and confirm that the scope and methodology support the goal of the LCA.

Summary

Although LCA is a complex process, simplified LCA tools specifically developed for use by building designers eliminate many of the challenges related to data collection and methodological assumptions. The worksheet that accompanies this document is meant to guide designers through the steps and decisions required outside of these tools so comparative LCAs can be more easily completed. It is still important for tool users to be familiar with the potential limitations of the chosen LCA tool and document the anticipated effects on the overall results.

Additional information, particularly about the LCI and LCIA phases, can be found in the documents referenced on page 8. For questions or assistance with the LCA process, please reach out to help@woodworks.org.

Photo: Monte French Design Studio

Additional Resources:

For more WoodWorks sustainability resources, including articles on WBLCA, biogenic carbon and environmental product declarations, visit Why Wood/Sustainability at www.woodworks.org.

ASTM International. (2022). ASTM E2921-22 Standard Practice for Minimum Criteria for Comparing Whole Building Life Cycle Assessments for Use with Building Codes, Standards, and Rating Systems.

International Organization for Standardization. (2006). ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework.

International Organization for Standardization. (2006). ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines.

International Organization for Standardization. (2017). ISO 21930:2017 Sustainability in buildings and civil engineering works – Core Rules for Environmental Product Declarations of Construction Products and Services.

Simonen, K. (2014). *Life Cycle Assessment*. (1st ed.). Routledge, Taylor & Francis Group.

ZEBx. (June 2021). *Life Cycle Assessment Process to Estimate Embodied Carbon in Buildings*.

[1] The term “WBLCA” is often used to describe the *entire* building, including *all* of its contents for the full lifetime of the building. However, in this article, the term “structural WBLCA” is used to refer to a wholistic and whole life perspective of the building systems impacted by the choice of structural system, while elements that are not affected by this choice might be excluded.

[2] This is the concept of “cut-off criteria.” Items expected to have minimal contribution to the overall results may be reasonably excluded from the analysis. This decision could be made on the basis of mass, energy requirements, or environmental significance of the item and typically relies on prior LCA experience and/or an iterative LCA process. Any decisions to omit materials from the study should be well documented in the LCA report.

[3] While Module D is not considered part of the life cycle, reporting methods used by different LCA tools sometimes require its inclusion to capture all aspects of the life cycle. Learn more in the WoodWorks article, Biogenic Carbon Accounting in WBLCA Tools.

[4] EPA’s Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI 2.1) lists dozens of impact categories, which are also noted in their User’s Guide.

[5] ISO 14044 Section 4.3

[6] Background data sources and assumptions are outlined in the WoodWorks article, Carbon Accounting Tools for Structural Systems.

[7] See the WoodWorks article, Current EPDs for Wood Products.

[8] ISO 14044 Section 4.4

[9] Per ISO 21930 for wood sourced from sustainably managed forests. Note that this includes all wood products sourced from North America. See the WoodWorks article, When to Include Biogenic Carbon in an LCA, for more information.

[10] ISO 14044 Section 5.2

[11] ISO 14044 Section 6.2

[12] ISO 14044 Section 5.3

[13] ISO 14044 Section 6.3

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