ASHRAE

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Seminar 7 Modeling for Carbon and Embodied Energy I

The Circular Home: A Negative-Carbon Modular Residence Designed for Iterative Disassembly and Reuse

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Learning Objectives

- Describe existing guidance and standards around both resilience and decarbonization of the design
- Identify key data sources and methodological approaches used to project building demands for concrete
- Apply a methodology for conducting LCA analysis of HVAC systems
- Describe the steps involved in conducting a whole-building life-cycle assessment (LCA)

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Outline/Agenda

- LCA and Whole-Building LCA Definition
- ISO 14044:2006
- The Circular Home
- LCA Methodology
  - Evaluate Tools
  - Establish Workflow
  - Iterate with Team
- Energy Design Coordination
- Re-use and End-of-Life
- Conclusions

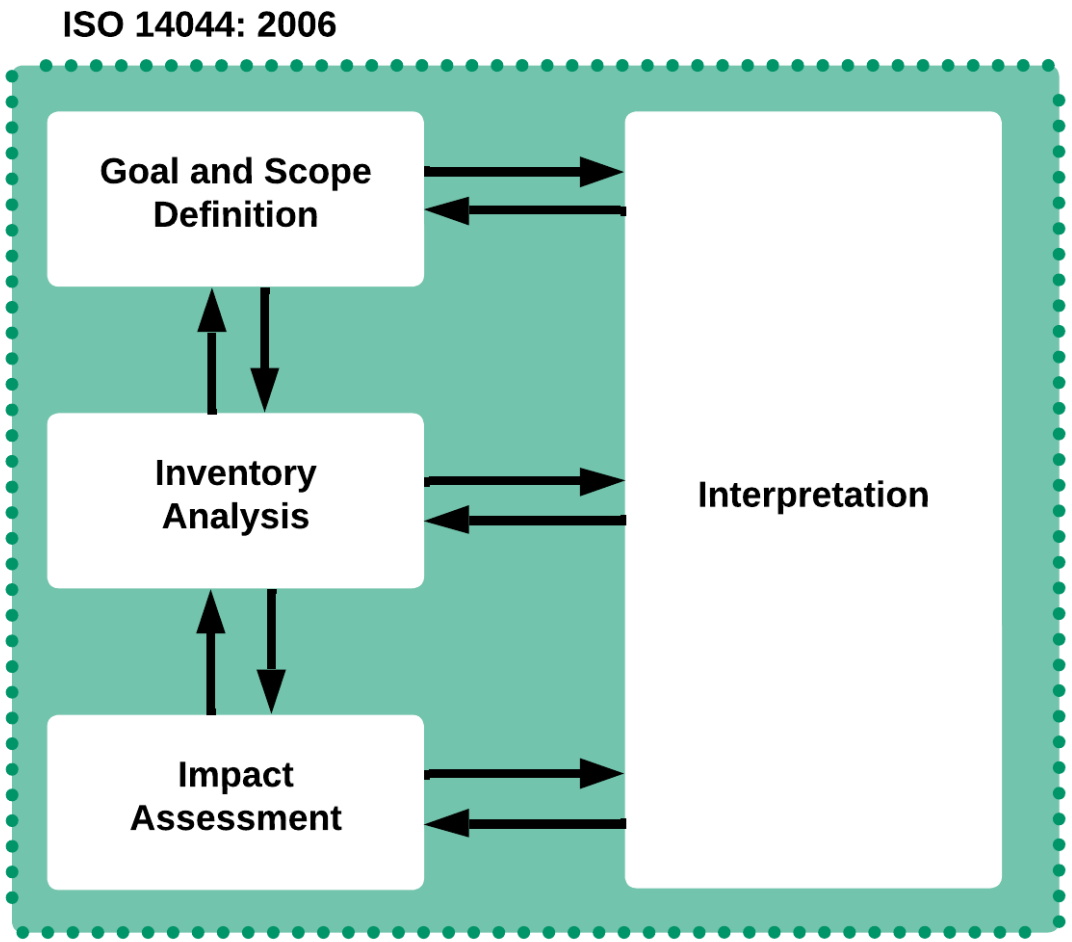
Life Cycle Assessment (LCA) Definition

- Life Cycle Assessment (LCA) involves the “systematic analysis of the potential environmental impacts of products or services during their entire life cycle” (Sphera, 2020)

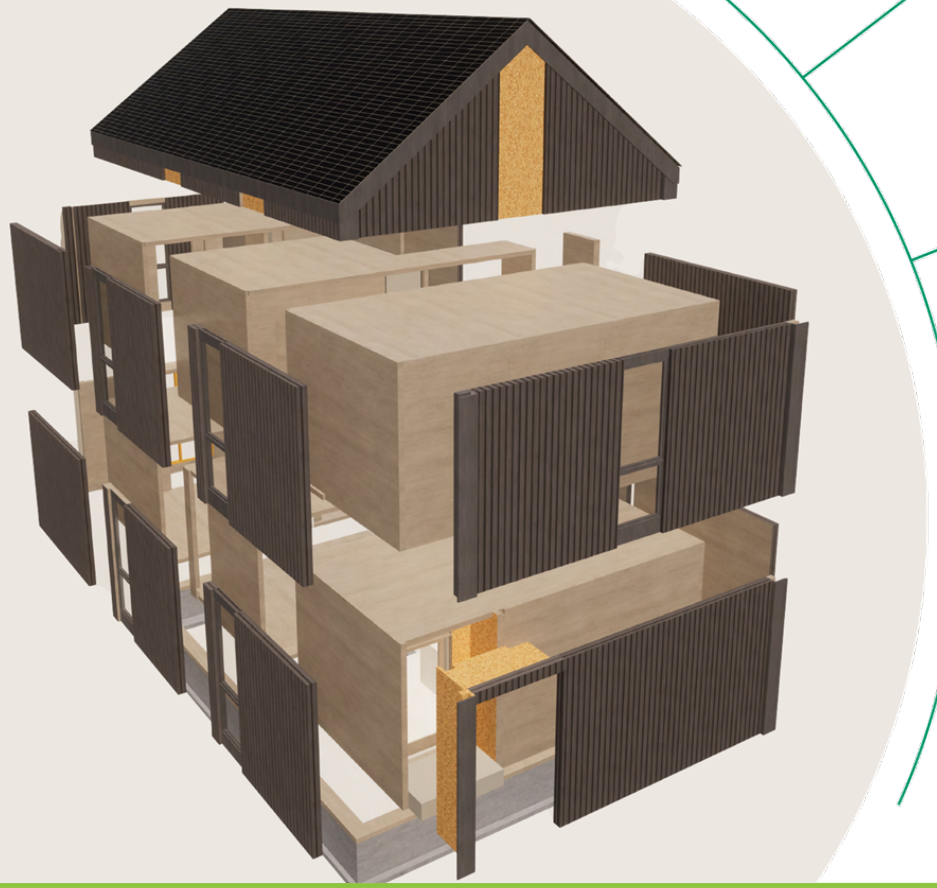
- Whole-Building Life Cycle Assessment (WBLCA) is the application of LCA principles to a building, with its constituent materials and processes (CLF, 2019)

ISO 14044:2006

1. Goal and Scope Definition
    i. Application, purpose, audience, use as comparative analysis
2. Inventory Analysis
    i. Compile and quantify inputs/outputs for entire life cycle
3. Impact Assessment
    i. Magnitudes and relative importance of impact categories
4. Interpretation
    i. Evaluate results, sensitivity analysis



The Circular Home



Offsite modular construction
- Fast Production
- High Quality
- Minimal Waste

Optimized for:
- Sustainability
- Resilience
- Durability
- Life-stages
- Adaptability
- Long use-life

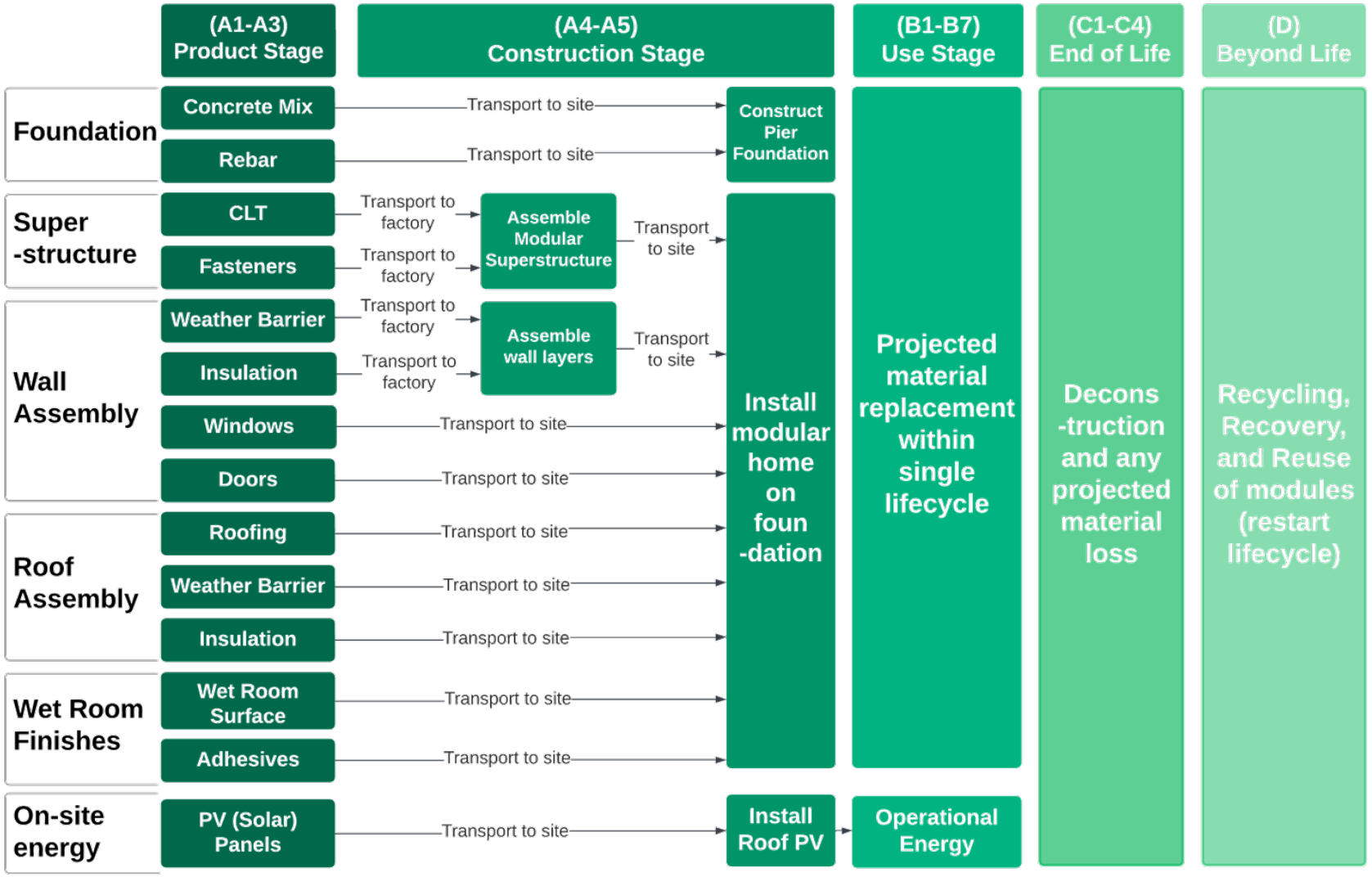
Low embodied carbon and net zero operational carbon
- Plant-based products
- Minimal plastic and concrete
- Climate-tuned envelope
- Efficient equipment
- All-electric systems
- On-site renewables

Value retention for Iterative reuse
- Modules
- Sub-assemblies
- Components
- Materials

Non-destructive connectors add value by improving
- Building Performance
- Fabrication speed
- Ease of assembly/disassembly

	Circular Home Prototype	Traditional Baseline
Materials	CLT structure with non-destructive connectors; Bio-based replacements for insulation, finishes, and accessories	Wood stud framing with standard fasteners; Incumbent materials and products to meet code minimum requirements
Methods	Factory-assembled modules transported to site; intentionally designed for disassembly and re-use	Site-built by a variety of trades, composed of hundreds of individual elements into a permanent whole

The Circular Home



LCA Methodology: Evaluate Tools

- Common WBLCA Tools Include
  (in alphabetical order)
  - Athena Impact Estimator for Buildings
  - One Click LCA
  - Tally

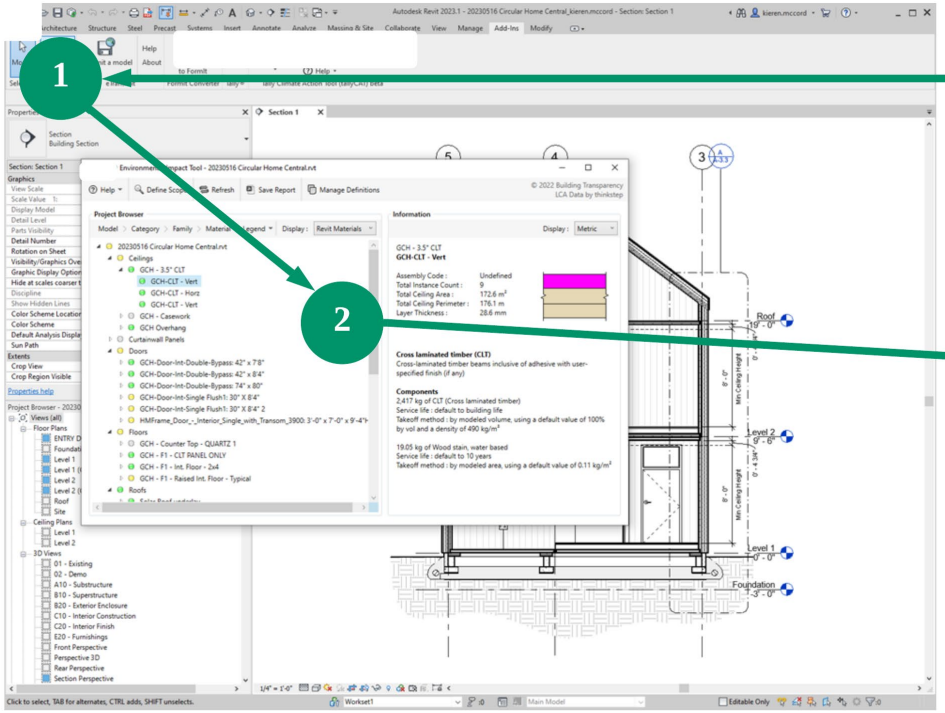
- For this work, Tally (hereafter software 1) was selected due to:
  - Integration with Revit (software 2) as a plugin
  - Transparency and consistency of life cycle inventory (LCI) data, including data sources and end-of-life assumptions

Each of these tools pulls from different databases and sources. **There are many database options that can be used for WBLCA**, just stay consistent with product category rules (PCR)s, which include things like: which processes and stages are considered, use phase and end-of-life considerations, which impact categories are included.

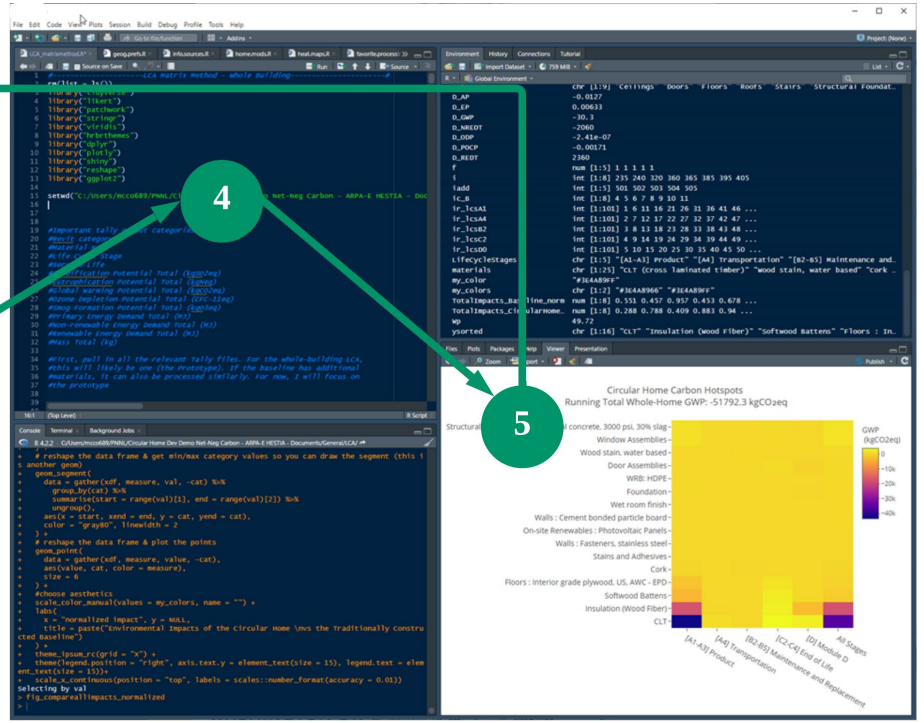
LCA Methodology: Evaluate Tools

- No WBLCA tool has a comprehensive database of building materials
- For projects that use novel materials, external sourcing of data is necessary. Options include:
  - Manufacturer Environmental Product Declarations (EPDs)
  - Industry average EPDs
  - LCI databases
  - LCA literature
- Because sources can use different assumptions, consider the following data characteristics:
  - Specificity (industry average vs. product specific)
  - Quality (reliability)
  - Transparency
  - Comparability (product category rules)
- For the circular home, examples of externally-sourced materials include rigid wood fiber insulation, photovoltaic panels, and foam glass gravel

LCA Methodology: Establish Workflow



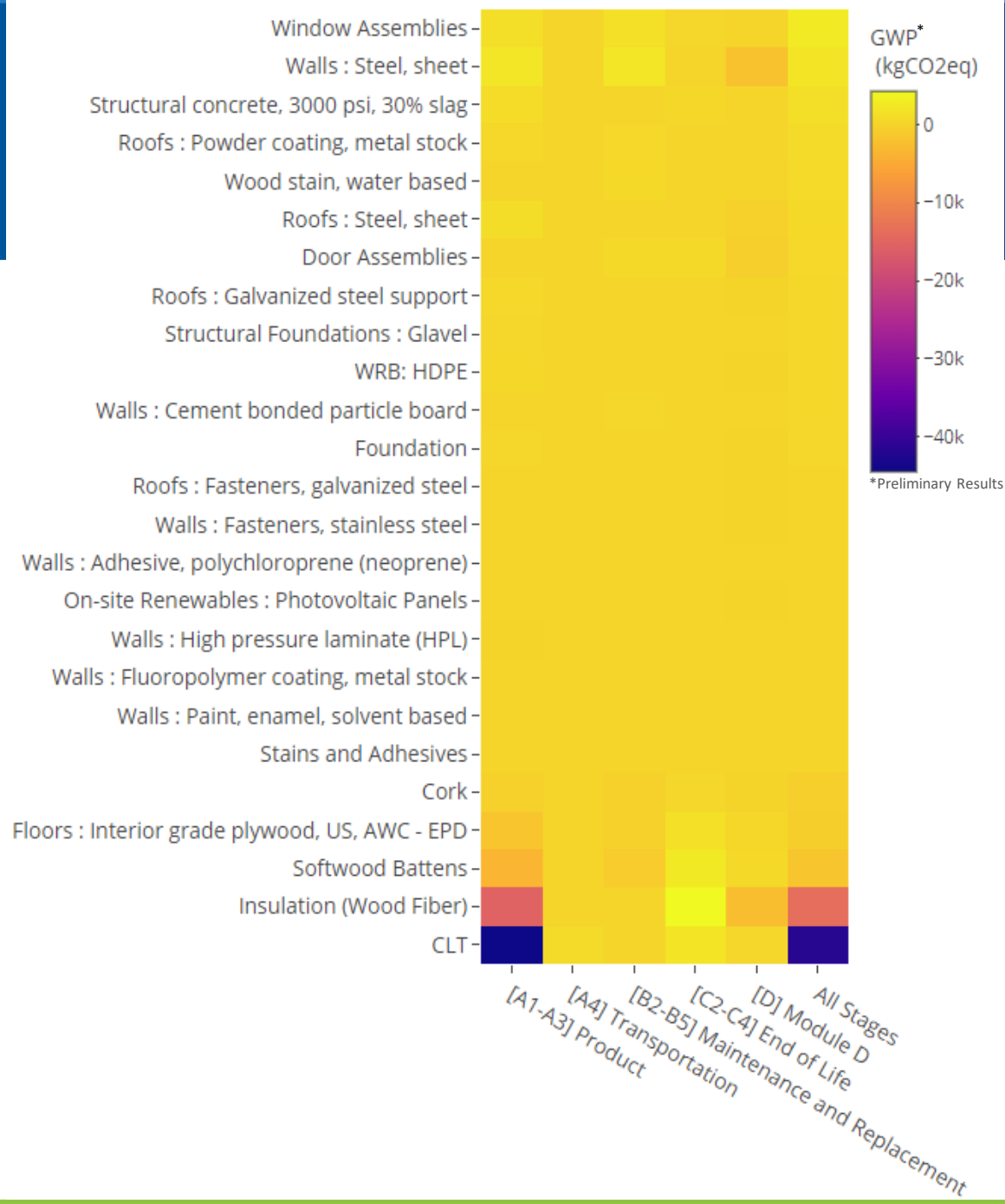
CSV Spreadsheet



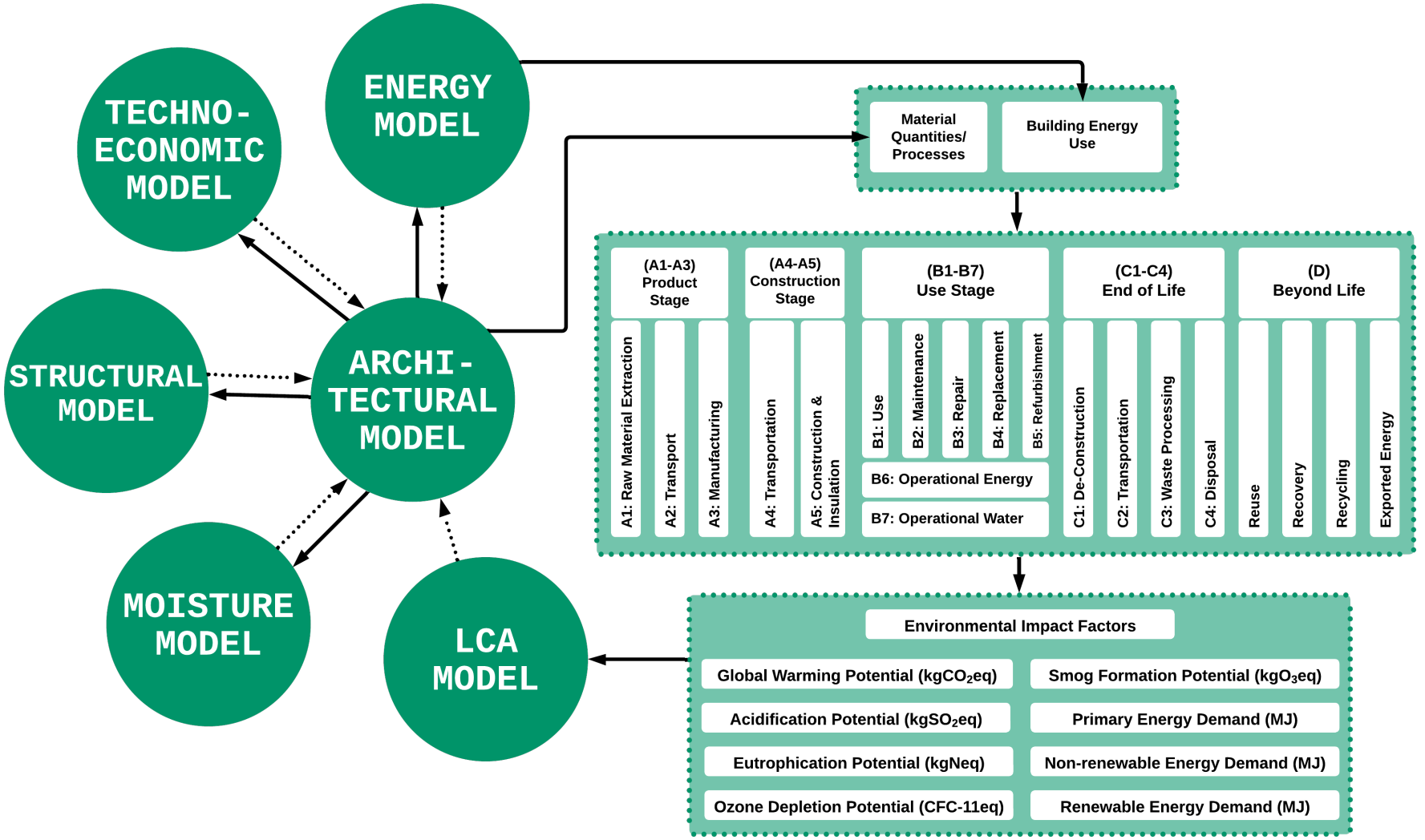
1	2	3	4	5
Receive Software 2 model from design team	Use Software 1 plugin for available materials/processes	Export quantities/ impacts to spreadsheet	Import spreadsheet to R (Software 3) and add missing flows	Review heat map for inital results/impacts, inform design

LCA Methodology: Establish Workflow

- Hotspot analysis provides digestible, efficient feedback.
- Global warming potential (GWP) [$kgCO_2eq$] is of particular interest to the project sponsor
- Most data is sourced from WBLCA tool, but missing data comes from manufacturer EPDs and existing literature, applied in alignment with existing data sources



LCA Methodology: Iterate with Team

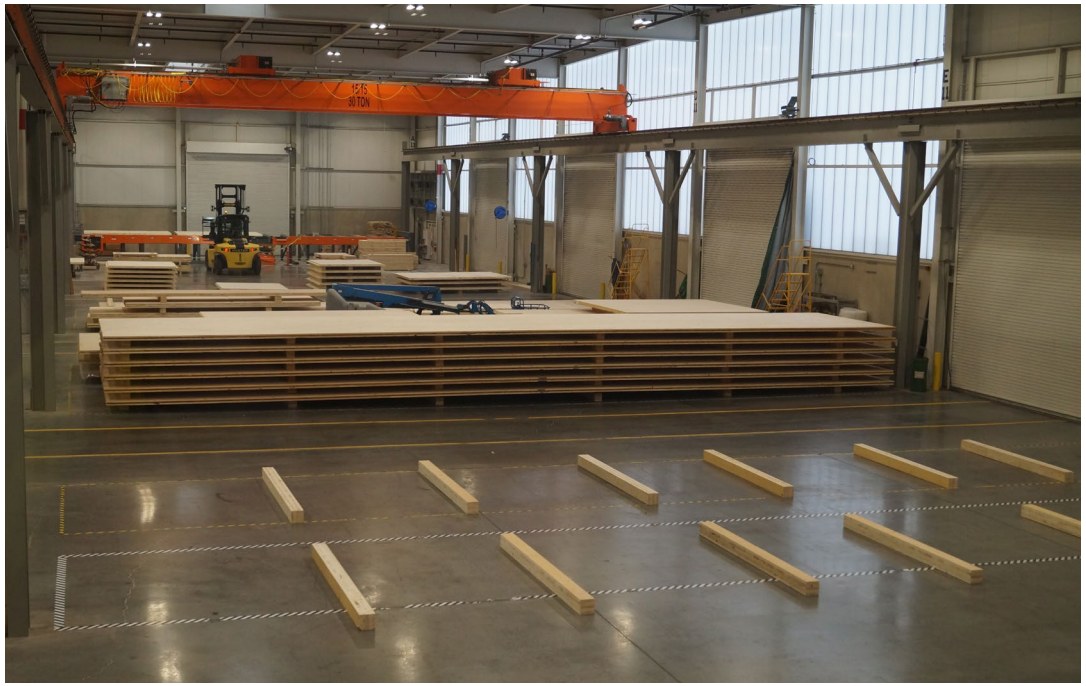


- Design model provides quantities for embodied impacts
- Energy model provides quantities for operational impacts
- Iterative feedback optimizes environmental impacts

LCA Methodology: Iterate with Disciplines

Net-negative carbon is the driving target, but the project includes many other performance criteria – these are just a few:

- Techno economic
  - Market rate
  - Constructability
- Structural
  - Performance targets for gravity, shear, wind, snow, seismic
  - Efficient use of CLT billets
- Architectural
  - Factory fabrication, desirable aesthetic
  - Off-the-shelf materials and components, where possible



CLT Billets
photo courtesy Mercer Mass Timber

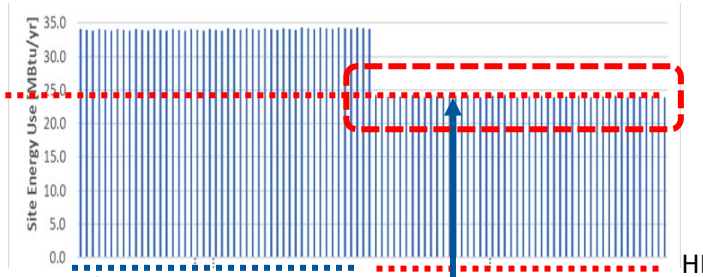
Energy Design Coordination: Initial Energy Simulation Plan

- Migrate the prototype building design to energy modeling software
- Choose an above-code starting point for assemblies & equipment
- Develop an input matrix for both energy use and production, test higher values
- Run parametric analysis
- Determine which load/production configurations achieve net-neg goal
- Solicit input from other teams and make adjustments
- Rinse and repeat
- Be conservative!
- Leave for later fine-tuning: Other climate zones, reference model, unique assemblies

Demand Simulation v.1

parametric options	range	# cases
Wall WF Insul thickness, in.	8" - 11"	3
Wall R-assembly	35.6 - 46.6	
Roof WF Insul thickness, in.	13.25" - 14.75"	2
Roof R-assembly	54.9 - 60.6	
Floor WF Insul thickness, in.	8" - 9.5"	2
Floor R-assembly	35.6 - 41.1	
Infiltration, ACH@50Pa	0.8 - 2.0	2
Mechanical Ventilation		2
Water heater	Elec tankless (UEF:0.99), Elec HPWH (UEF:3.5)	2
	total no. of cases for v.1	**96**
v.2 Reduce wall/roof insulation, more insulation increments, add bldg. orientations		**15,360**
v.3 Better windows and heat pump efficiencies, add window size options		**8,192**

Energy Design Coordination: Iteration



25 Mbtu/yr

Elec resistance WH

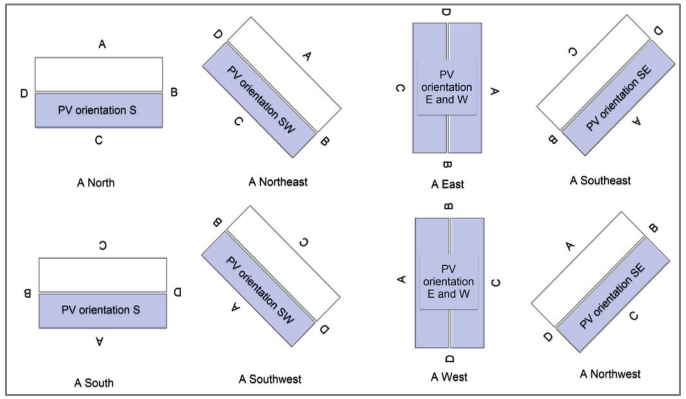
HPWH

Need HPWH to get there

2

How much PV capacity can we fit on the roof?

3



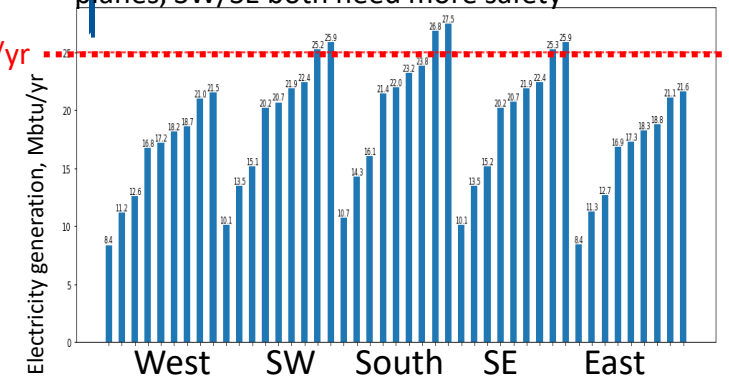
Available roof area, assume ~20W/sf

We need all the real estate we can get!

4

What's the carbon penalty for PV arrays? Not too bad, it turns out: *Maximize PV!*

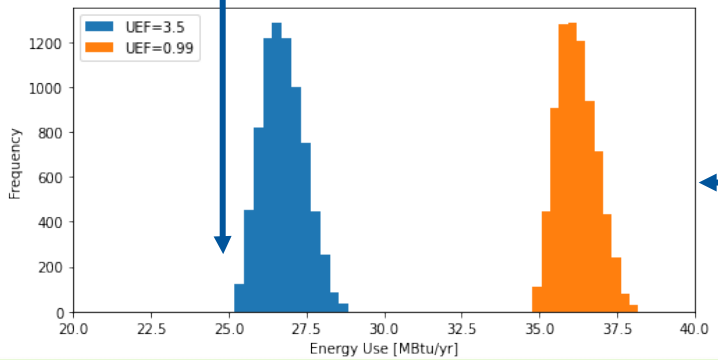
Production of 25 Mbtu/yr: S is safe with the largest array that fits. E or W need both roof planes, SW/SE both need more safety



Array capacities from 2.4 kW to 6.15 kW

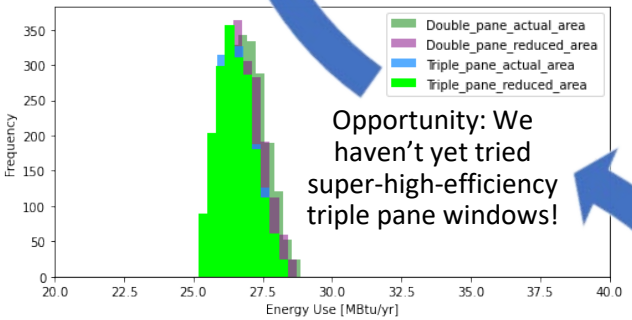
5

Architecture – Let's "skinny-up" the walls and roof for constructability



We can no longer hit 25 Mbtus

6



Opportunity: We haven't yet tried super-high-efficiency triple pane windows!

?

1

~ 25 Mbtu is the best we can do with starting assumptions

Re-use and End-of-Life

- For this project, re-use drives design decisions
  - Easy disassembly (e.g. non-destructive fasteners)
  - Durable enclosure to lengthen material lifespan
- LCI data sources have default end-of-life assumptions for most materials
- Software 1 provides a breakdown of impacts by material and by life cycle stage and it lists end-of-life assumptions, such as percent reuse (vs. landfill/incineration)
- To understand the environmental impacts involved in a second iterative re-use of existing materials, consider the actual percent reuse and modify the default assumptions using ratios

Conclusion

- Providing LCA input during the design (and not after completion) can minimize the harmful environmental impacts of a building, both embodied and operational, and ensure ample opportunity to meet design goals.
- Existing whole-building LCA tools provide a great starting point, but do not have exhaustive material lists, necessitating creative approaches for sourcing data, and then applying them to the model consistently.
- Hotspot analysis provides an efficient feedback mechanism for design and other disciplinary teams.
- While embodied carbon may be the primary performance goal, it's likely not the only consideration. Pragmatic issues like material dimensions, product availability, and constructability can force choices whose carbon impact must be made up elsewhere.

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Questions

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