Realizing Mass Timber's Benefits: Key Design Decisions and Carbon Analysis

September 16, 2025

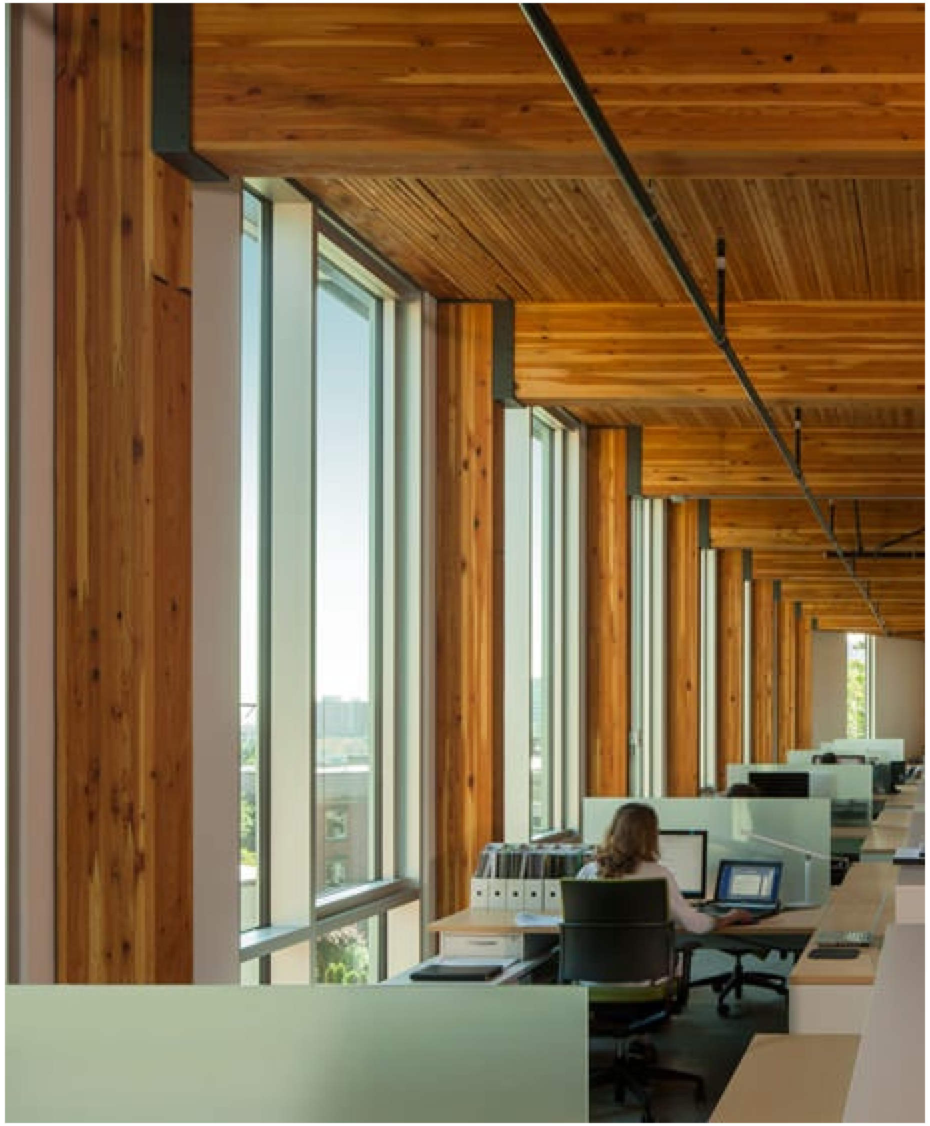
Presented by

John O'Donald, II, PE
WoodWorks

University of Washington Founders Hall, LMN Architects, photo Tim Griffith

Light Wood-Frame
Photo: WoodWorks

Heavy Timber
Photo: Benjamin Benschneider



Mass Timber
Photo: John Stamets

Glue Laminated Timber (Glulam)
Beams & columns

Photo: StructureCraft

Cross-Laminated Timber (CLT)
Solid sawn laminations

Photo: LendLease

Cross-Laminated Timber (CLT)
SCL laminations

Photo: Freres Lumber

Photo: LEVER Architecture

Dowel-Laminated Timber (DLT)

Photo: StructureCraft

Nail-Laminated Timber (NLT)

Photo: Think Wood

Glue-Laminated Timber (GLT)

Plank orientation

Photo: StructureCraft

Photo: StructureCraft

Photo: Ema Peter

Photo: Manasc Isaac Architects/Fast + Epp

Office

Wythe Ave Buildings, NY | Flank Architecture + Development

Hospitality

Lark Hotel, Bozeman | Thinktank Design | Photo: Dan Armstrong

Multi-family

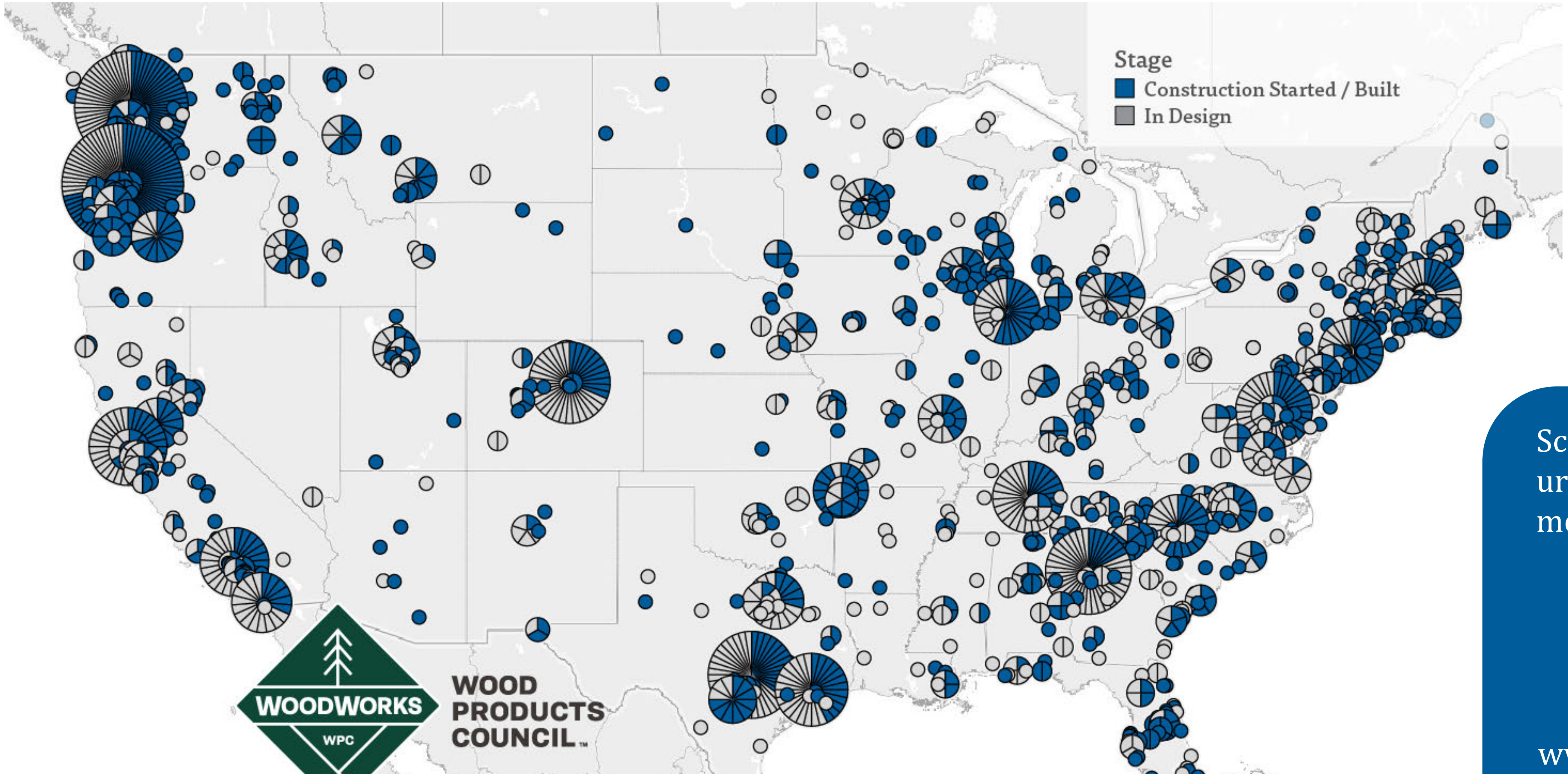
Carbon 12, Portland | Path Architecture | Photo: Andrew Pogue

Industrial

StructureCraft Plant, Abbotsford, BC

Current State of Mass Timber Projects

As of Q2 2025, in the US, **2,524** multi-family, commercial, or institutional projects have been constructed with, or are in design with, mass timber.



Source: WoodWorks, June 30, 2025

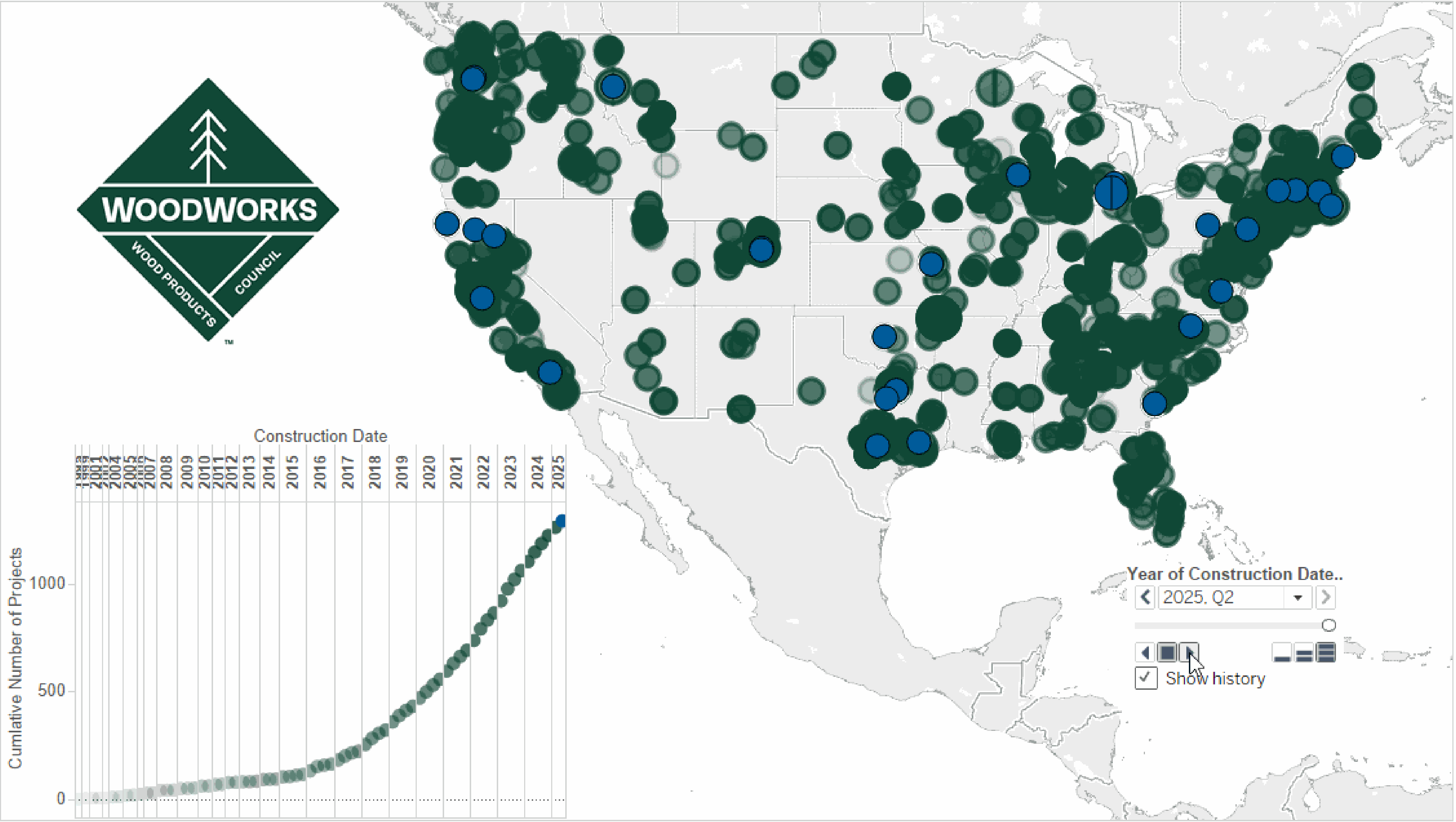
** This total includes modern mass timber and post-and-beam structures built since 2013*

Scan this code or use the url to find the map and more details online.

www.woodworks.org/resources/mapping-mass-timber/

Current State of Mass Timber Projects Over Time

US Market Q2 2025



APEX PLAZA
CHARLOTTESVILE, VA

Office building

CLT panels / glulam frame & braced frames

8 stories (6 mass timber), 187,000 sqft

W|N PROFILE

William McDonough + Partners
Simpson Gumpertz & Heger
Photo Prakash Patel

80M

WASHINGTON, DC

3 story MT vertical addition on top of existing 7 story building

CLT panels / glulam frame

108,000 sqft

16 ft floor to floor

Hickok Cole
Arup
Photo Maurice Harrington

DC SOUTHWEST LIBRARY

WASHINGTON, DC

CREDIT: STRUCTURECRAFT
COURTESY: STRUCTURECRAFT

UNDER ARMOUR GLOBAL HEADQUARTERS

BALTIMORE, MD

CREDIT: SEAGATE
COURTESY: SEAGATE

Johns Hopkins Student Center

Baltimore, MD

Architect: Shepley Bulfinch
Engineer: Knippers Helbig
Contractor: Clark Construction
MT Supplier: StructureCraft
Photos: John O’Donald, Woodworks

STRUCTURAL SOLUTIONS | POST, BEAM + PLATE

STRUCTURAL SOLUTIONS | POST + PLATE

STRUCTURAL SOLUTIONS | HONEYCOMB

Speed of Construction: Franklin Elementary School, WV

- 45,200 sf, 2 story school
- CLT utilized for walls, roof panels, and floor panels
- CLT chosen for its construction schedule benefits, installed in 8 weeks
- Completed January 2015

STRUCTURAL SOLUTIONS | HYBRID LIGHT-FRAME + MASS TIMBER

STRUCTURAL SOLUTIONS | HYBRID STEEL + MASS TIMBER

Key Early Design Decisions

What is the Single Most Important Early Design Decision on a Mass Timber Project? Is it:

- Construction Type
- Fire-Resistance Ratings
- Member Sizes
- Grids & Spans
- Exposed Timber (where & how much)
- MEP Layout
- Acoustics
- Concealed Spaces
- Connections
- Penetrations

The Answer is…They All Need to Be Weighed (Plus Others)

Key Early Design Decisions

Significant Emphasis Placed on the Word Early

Early Because:

» Avoids placing limitations due to construction norms or traditions that may not be efficient with mass timber

» Allows greater integration of all building elements in 3D models, ultimately used throughout design, manufacturing and install

Key Early Design Decisions

Early = Efficient

Realize Efficiency in:

- Cost reduction
- Material use (optimize fiber use, minimize waste)
- Construction speed
- Trade coordination
- Minimize RFIs

Commit to a mass timber design from the start

Key Early Design Decisions

There are a number of project-specific factors that influence how these early decisions are made, and in some cases, the order in which the decisions are made:

- Site (size, orientation, zoning, cost)
- Building needs (size, occupancy(ies), layout, floor to floor, aesthetics, sustainability goals)
- Resulting code options & design implications

Key Early Design Decisions

One *potential* design route:

1. Building size & occupancy informs construction type & grid

2. Construction type informs fire resistance ratings

3. Grid & fire resistance ratings inform timber member sizes & MEP layout

But that's not all…

Architects: The Miller Hull Partnership with Lord Aeck Sargent
Engineer: Uzun + Case
Contractor: Skansa USA
Photo: Jonathan Hillyer

Key Early Design Decisions

Other impactful decisions:

» Acoustics informs member sizes (and vice versa)

» Fire-resistance ratings inform connections & penetrations

» MEP layout informs use of concealed spaces

Miller Hull Partnership, photo: John Sta

Key Early Design Decisions

Other impactful decisions:

- » Grid informs efficient spans, MEP layout
- » Manufacturer capabilities inform member sizes, grids & connections
- » Lateral system informs connections, construction sequencing

And more…

Platte Fifteen, Oz Architecture, KL&A Engineers & Builders, Arch Angle Media

Key Early Design Decisions

Where do we start?

1 De Haro, Perkins & Will, photo Alex Nye

Key Early Design Decisions

Construction Type – Primarily based on building size & occupancy

	Construction Type (All Sprinklered Values)							
	IV-A	IV-B	IV-C	IV-HT	III-A	III-B	V-A	V-B
Occupancies	Allowable Building Height above Grade Plane, Feet (IBC Table 504.3)							
A, B, R	270	180	85	85	85	75	70	60
	Allowable Number of Stories above Grade Plane (IBC Table 505.4)							
A-2, A-3, A-4	18	12	6	4	4	3	3	2
B	18	12	9	6	6	4	4	3
R-2	18	12	8	5	5	5	4	3
	Allowable Area Factor (At) for SM, Feet^2 (IBC Table 506.2)							
A-2, A-3, A-4	135,000	90,000	56,250	45,000	42,000	28,500	34,500	18,000
B	324,000	216,000	135,000	108,000	85,500	57,000	54,000	27,000
R-2	184,500	123,000	76,875	61,500	72,000	48,000	36,000	21,000

Key Early Design Decisions

Construction Type – Primarily based on building size & occupancy

	Construction Type (All Sprinklered Values)							
	IV-A	IV-B	IV-C	IV-HT	III-A	III-B	V-A	V-B
Occupancies	Allowable Building Height above Grade Plane, Feet (IBC Table 504.3)							
A, B, R	270	180	85	85	85	75	70	60
	[illegible]							
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B	18	12	9	[illegible]	6	4	4	3
R-2	18	12	8	5	5	5	4	3
	Allowable Area Factor (At) for SM, Feet² (IBC Table 506.2)							
A-2, A-3, A-4	135,000	90,000	56,250	45,000	42,000	28,500	34,500	18,000
B	324,000	216,000	135,000	108,000	85,500	57,000	54,000	27,000
R-2	184,500	123,000	76,875	61,500	72,000	48,000	36,000	21,000

For low- to mid-rise mass timber buildings, there may be multiple options for construction type. There are pros and cons of each, don't assume that one type is always best.

Key Early Design Decisions

Fire-Resistance Ratings

- » Driven primarily by construction type
- » Rating achieved through timber alone or non-com protection required?

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (HOURS)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV				TYPE V	
	A	B	A	B	A	B	A	B	C	HT	A	B
Primary structural frame[f] (see Section 202)	3[a, b]	2[a, b, c]	1[b, c]	0[c]	1[b, c]	0	3[a]	2[a]	2[a]	HT	1[b, c]	0
Bearing walls												
Exterior[a, f]	3	2	1	0	2	2	3	2	2	2	1	0
Interior	3[a]	2[a]	1	0	1	0	3	2	2	1/HT[g]	1	0
Nonbearing walls and partitions Exterior	See Table 705.5											
Nonbearing walls and partitions Interior[d]	0	0	0	0	0	0	0	0	0	See Section 2304.11.2	0	0
Floor construction and associated secondary structural members (see Section 202)	2	2	1	0	1	0	2	2	2	HT	1	0
Roof construction and associated secondary structural members (see Section 202)	1 1/2[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	1 1/2	1	1	HT	1[b,c]	0

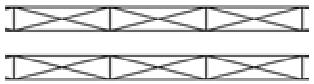
Structural Grid - Panels

» Cost and Construction Type – Panel selection

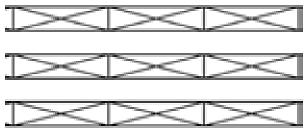
TABLE 601: Fire Resistance Rating Requirements for Building Elements (Hours)

Building Element	I-A	I-B	III-A	III-B	IV-A	IV-B	IV-C	IV-HT	V-A	V-B
Primary Structural Frame	3*	2*	1	0	3*	2	2	HT	1	0
Ext. Bearing Walls	3*	2*	2	2	3*	2	2	2	1	0
Int. Bearing Walls	3*	2*	1	0	3*	2	2	1/HT	1	0
Floor Construction	2	2*	1	0	2	2	2	HT	1	0
Roof Construction	1.5*	1*	1	0	1.5	1	1	HT	1	0
Exposed Mass Timber Elements					None	20-40%	Most	All		

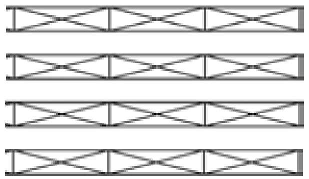
Baseline
0hr & HT



+$10/SF over 3-ply
1hr & maybe 2hr



+$12-15/SF over 5-ply
2hr FRR



Cost Source: Swinerton

*These values can be reduced based on certain conditions in IBC 403.2.1, which do not apply to Type IV buildings.

Construction Types

Where does the code allow MT to be used?

Type IB & II: Roof Decking

Image: DeStafano & Chamberlain, Inc, Robert Benson Photography

Image: StructureCraft Builders

Construction Types

All wood-framed building options:

Type III

Exterior walls non-combustible (may be FRTW)

Interior elements any allowed by code, including mass timber

Type V

All building elements are any allowed by code, including mass timber

Types III and V are subdivided to A (protected) and B (unprotected)

Type IV (Heavy Timber)

Exterior walls non-combustible (may be FRTW OR CLT)

Interior elements qualify as Heavy Timber (min. sizes, no concealed spaces except in 2021 IBC)

Construction Types

Where does the code allow MT to be used?

Type III: Interior elements (floors, roofs, partitions/shafts) and exterior walls if FRT

ICE Block I, RMW Architecture & Interiors, Buehler Engineering, Bernard André Photography

Construction Types

Type IV construction permits exposed heavy/mass timber elements of min. sizes.

Minimum Width by Depth in Inches

Framing		Solid Sawn (nominal)	Glulam (actual)	SCL (actual)
Floor	Columns	8 x 8	6¾ x 8¼	7 x 7½
	Beams	6 x 10	5 x 10½	5¼ x 9½
Roof	Columns	6 x 8	5 x 8¼	5¼ x 7½
	Beams*	4 x 6	3 X 6⅞	3½ X 5½

*3” nominal width allowed where sprinklered

See IBC 2018 2304.11 or IBC 2015 602.4 for Details

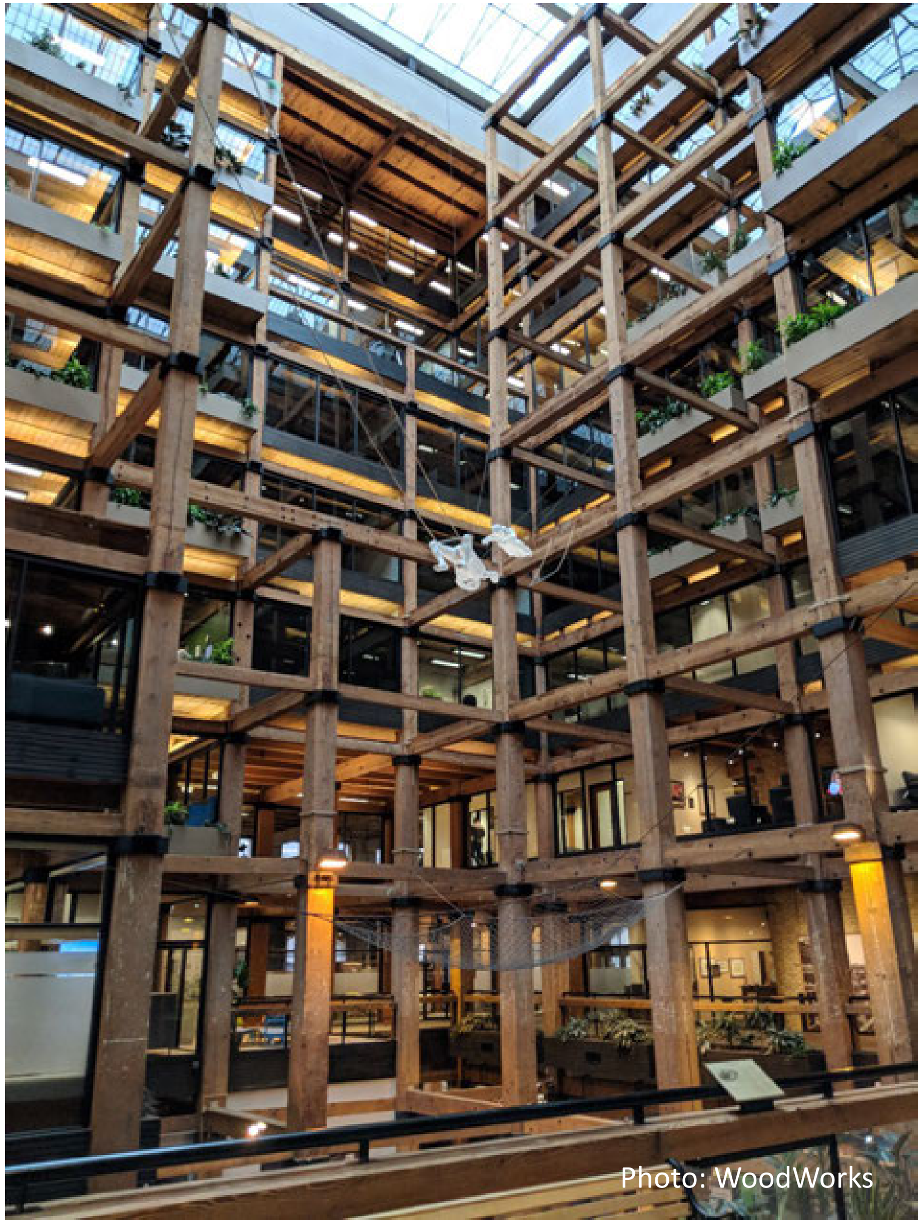


Photo: WoodWorks

Construction Types

Type IV min. sizes:

<u>Floor Panels/Decking:</u>

- 4” thick CLT (actual thickness)
- 4” NLT/DLT/GLT (nominal thickness)
- 3” thick (nominal) decking covered with: 1” decking or 15/32” WSP or ½” particleboard

Photo: StructureCraft

Photo: Aitor Sanchez/ Ewing Cole

Photo: WoodWorks

Construction Types

Type IV min. sizes:

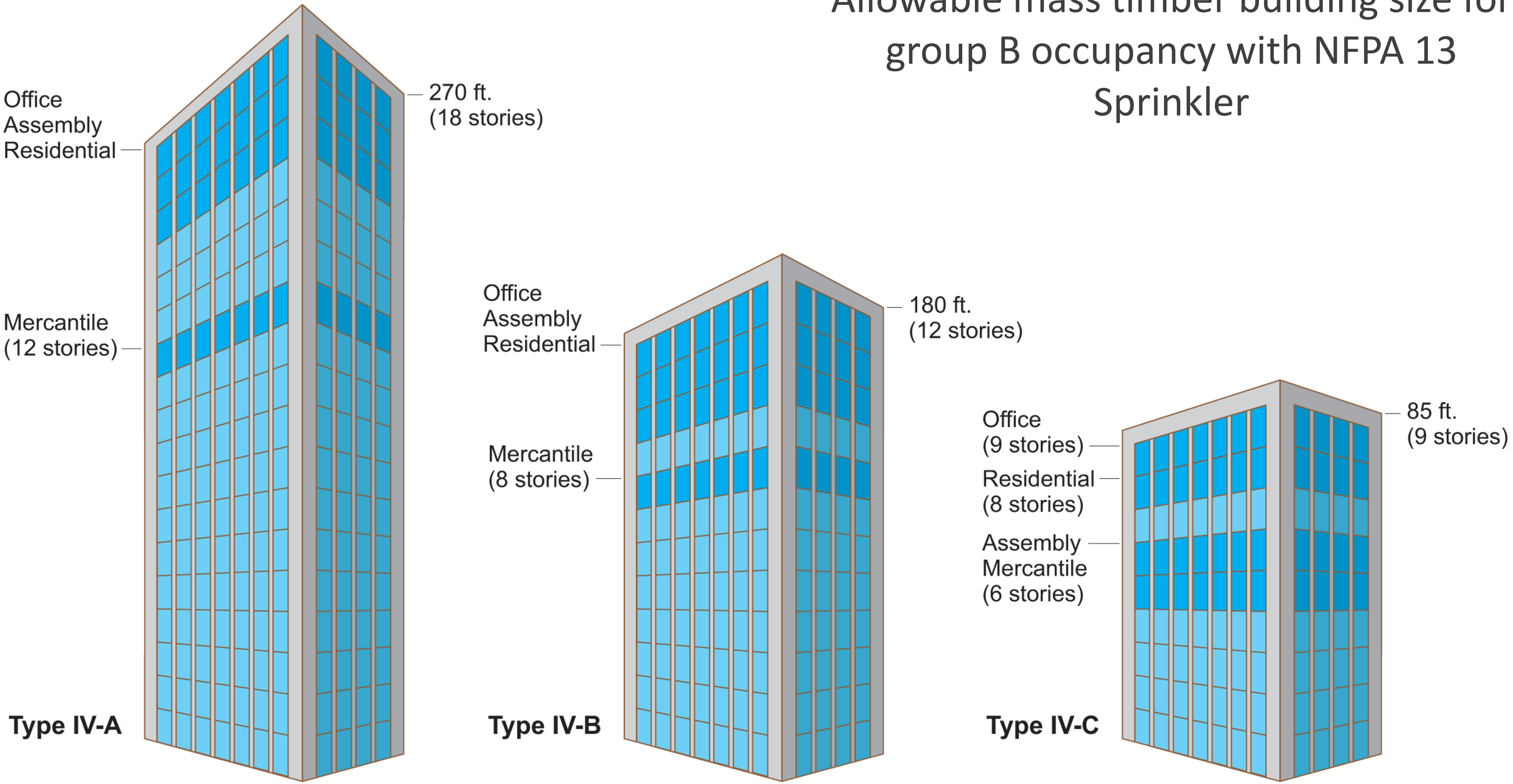
<u>Interior Walls:</u>

- » Laminated construction 4” thick
- » Solid wood construction min. 2 layers of 1” matched boards
- » Wood stud wall (1 hr min)
- » Non-combustible (1 hr min)

Verify other code requirements for FRR (eg. interior bearing wall; occupancy separation)

Construction Types

New Options in 2021 IBC
Allowable mass timber building size for group B occupancy with NFPA 13 Sprinkler



Code Updates to Type IV-B

602.4.2.2.2 Protected Area

Interior faces of mass timber elements, including the inside face of exterior mass timber walls and mass timber roofs, shall be protected in accordance with Section 602.4.2.2.1.

2021 IBC

Exceptions: Unprotected portions of mass timber ceilings and walls complying with Section 602.4.2.2.4 and the following:

1. Unprotected portions of mass timber ceilings and walls comply with one of the following:

   1.1 Unprotected portions of mass timber ceilings, including attached beams, shall be permitted and shall be limited to an area equal to **20 percent** of the floor area in any dwelling unit or fire area.

   1.2 …

2024 IBC

Exceptions: Unprotected portions of mass timber ceilings and walls complying with Section 602.4.2.2.4 and the following:

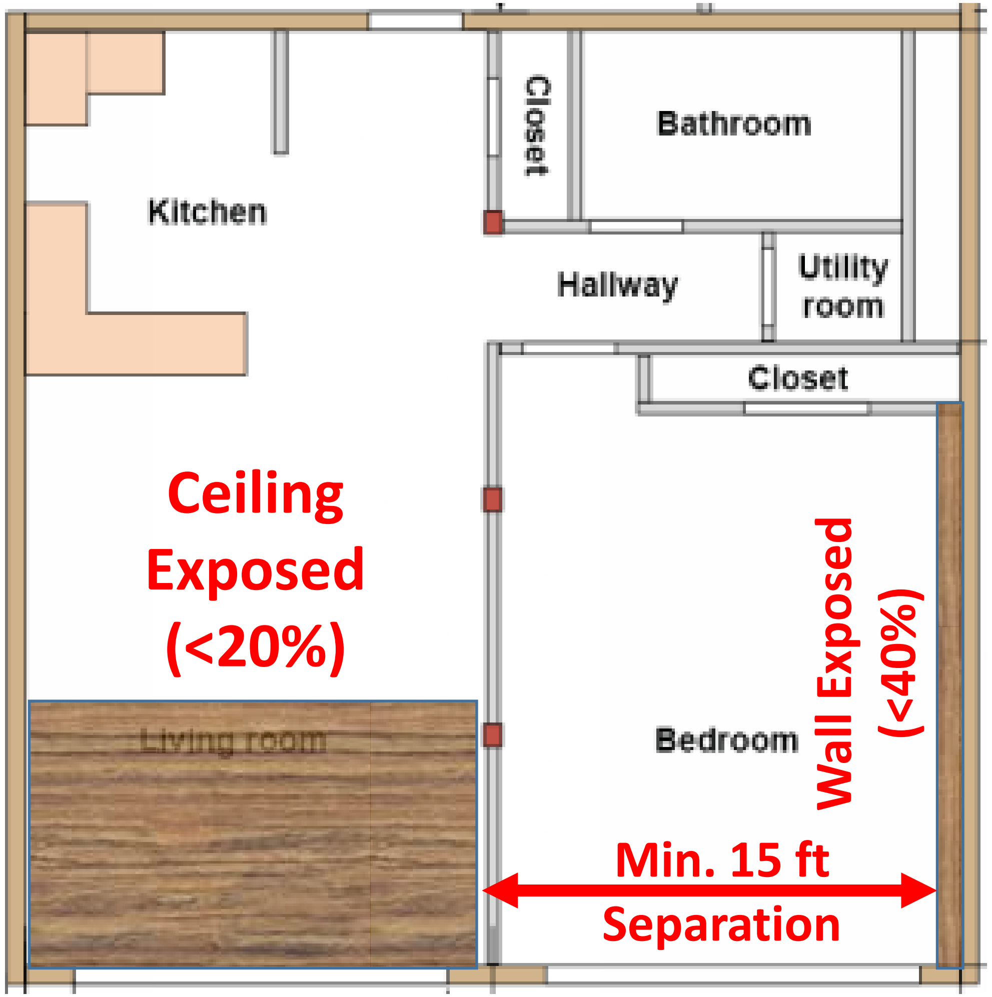
1. Unprotected portions of mass timber ceilings and walls comply with one of the following:

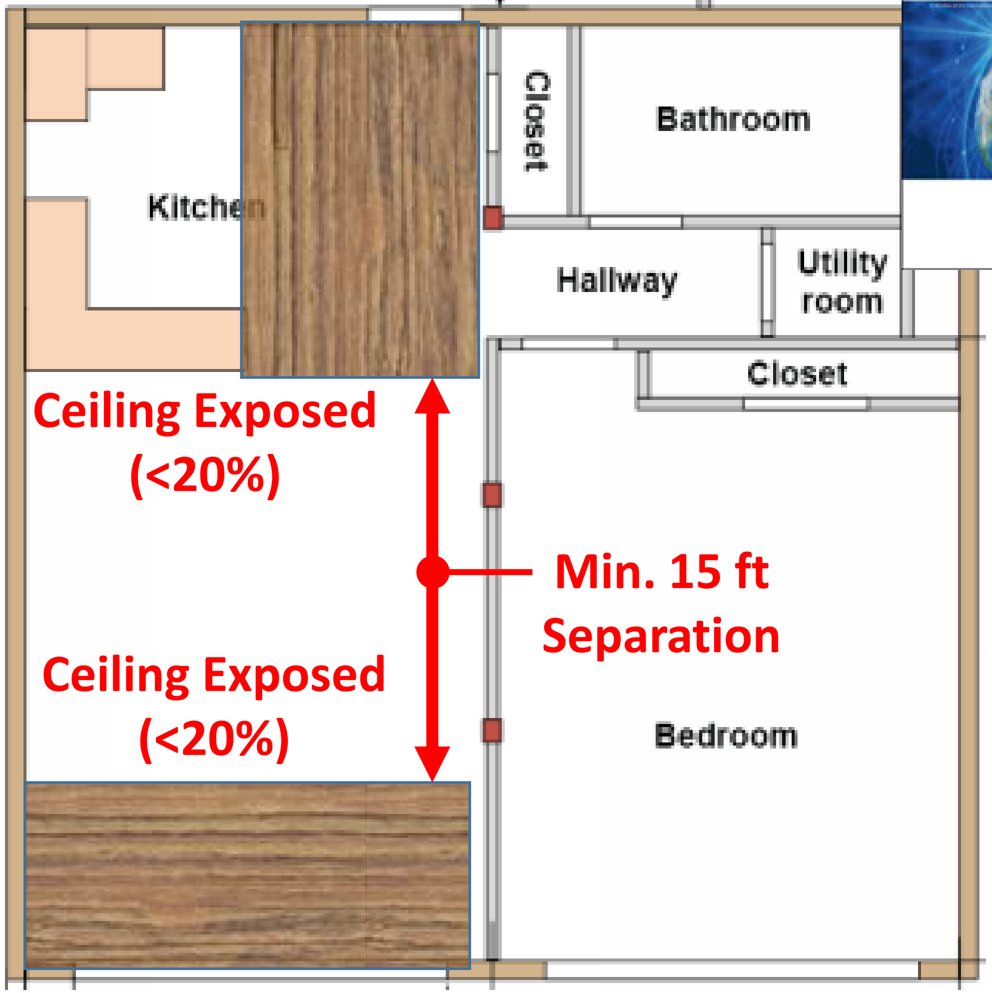
   1.1 Unprotected portions of mass timber ceilings, including attached beams, limited to an area less than or equal to **100 percent** of the floor area in any dwelling unit within a story or fire area within a story.

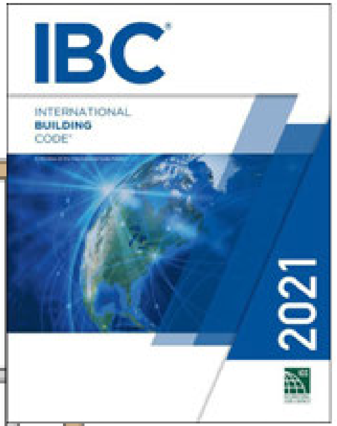
   1.2 …

2019-2022: REFINING THE CODE ROADMAP

2021 IBC Allowances



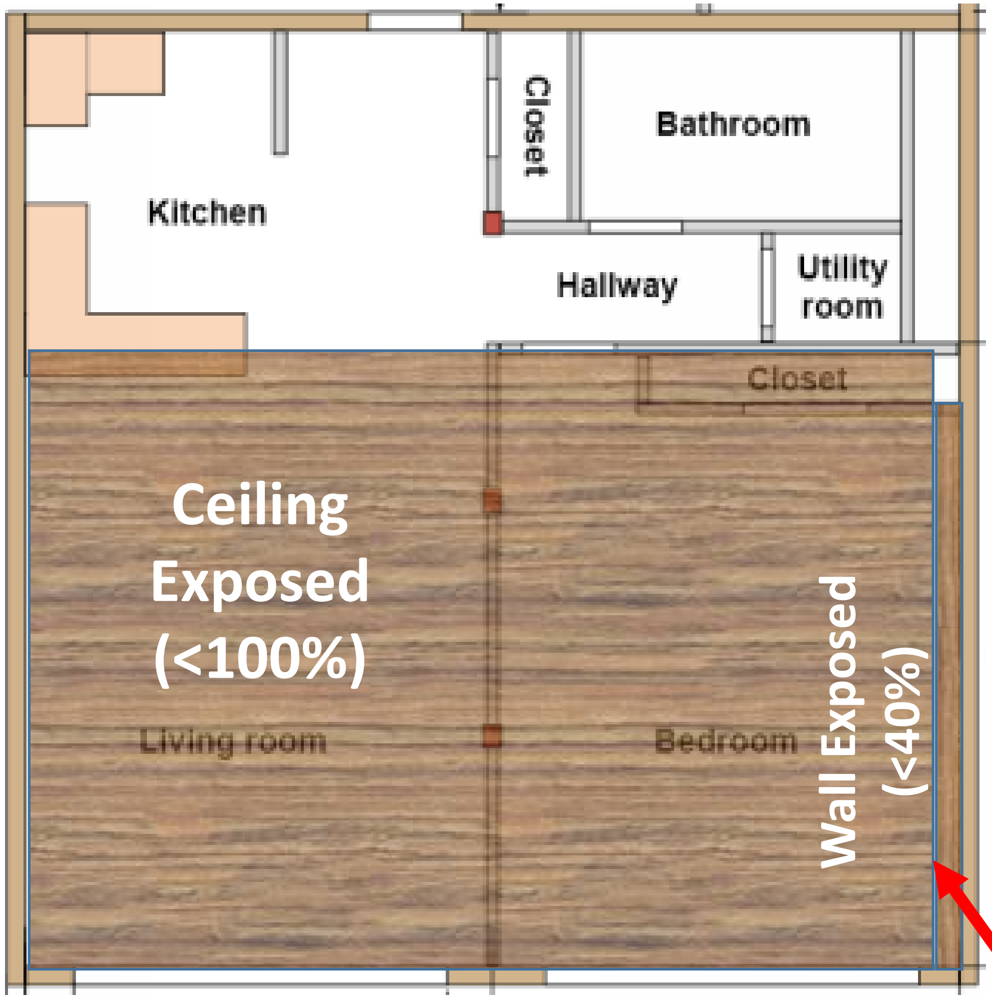


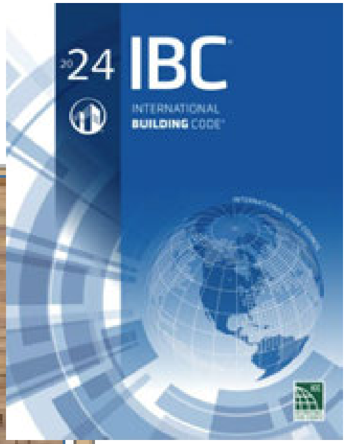


Credit: AWC

2019-2022: REFINING THE CODE ROADMAP

2024 IBC Allowances





No separation req'd between wall & ceiling

Credit: AWC

Richard McLain, PE, SE
Senior Technical Director
Scott Breneman, PhD, PE, SE
Senior Technical Director
WoodWorks – Wood Products Council

Fire Design of Mass Timber Members

Code Applications, Construction Types and Fire Ratings

For many years, exposed heavy timber framing elements have been permitted in U.S. buildings due to their inherent fire-resistance properties. The predictability of wood's char rate has been well-established for decades and has long been recognized in building codes and standards.

Today, one of the exciting trends in building design is the growing use of mass timber—i.e., large solid wood panel products such as cross-laminated timber (CLT) and nail-laminated timber (NLT)—for floor, wall and roof construction. Like heavy timber, mass timber products have inherent fire resistance that allows them to be left exposed and still achieve a fire-resistance rating (FRR). Because of their strength and dimensional stability, these products also offer an alternative to steel, concrete, and masonry for many applications, but have a much lighter carbon footprint. It is this combination of exposed structure and strength that developers and designers across the country are leveraging to create innovative designs with a warm yet modern aesthetic, often for projects that go beyond traditional norms.

This paper has been written to support architects and engineers exploring the use of mass timber for commercial and multi-family construction. It focuses on how to meet fire-resistance requirements in the International Building Code (IBC), including calculation and testing-based methods. Unless otherwise noted, references refer to the 2021 IBC.

Mass Timber & Construction Type

Before demonstrating FRRs of exposed mass timber elements, it's important to understand under what circumstances the code currently allows the use of mass timber in commercial and multi-family construction.

A building's assigned construction type is the main indicator of where and when all wood systems can be used. IBC Section 602 defines five main options (Type I through V); Types I, II, III and V have subcategories A and B, while Type IV has subcategories IV-HT, V-A, IV-B, and IV-C. Types III, IV and V permit the use of wood framing throughout much of the structure and are used extensively for modern mass timber buildings.

Type III (IBC 602.3) – Timber elements can be used in floors, roofs and interior walls. Fire-retardant-treated wood (FRTW) framing is permitted in exterior walls required to have an FRR of 2 hours or less.

Type V (IBC 602.5) – Timber elements can be used throughout the structure, including floors, roofs and both interior and exterior walls.

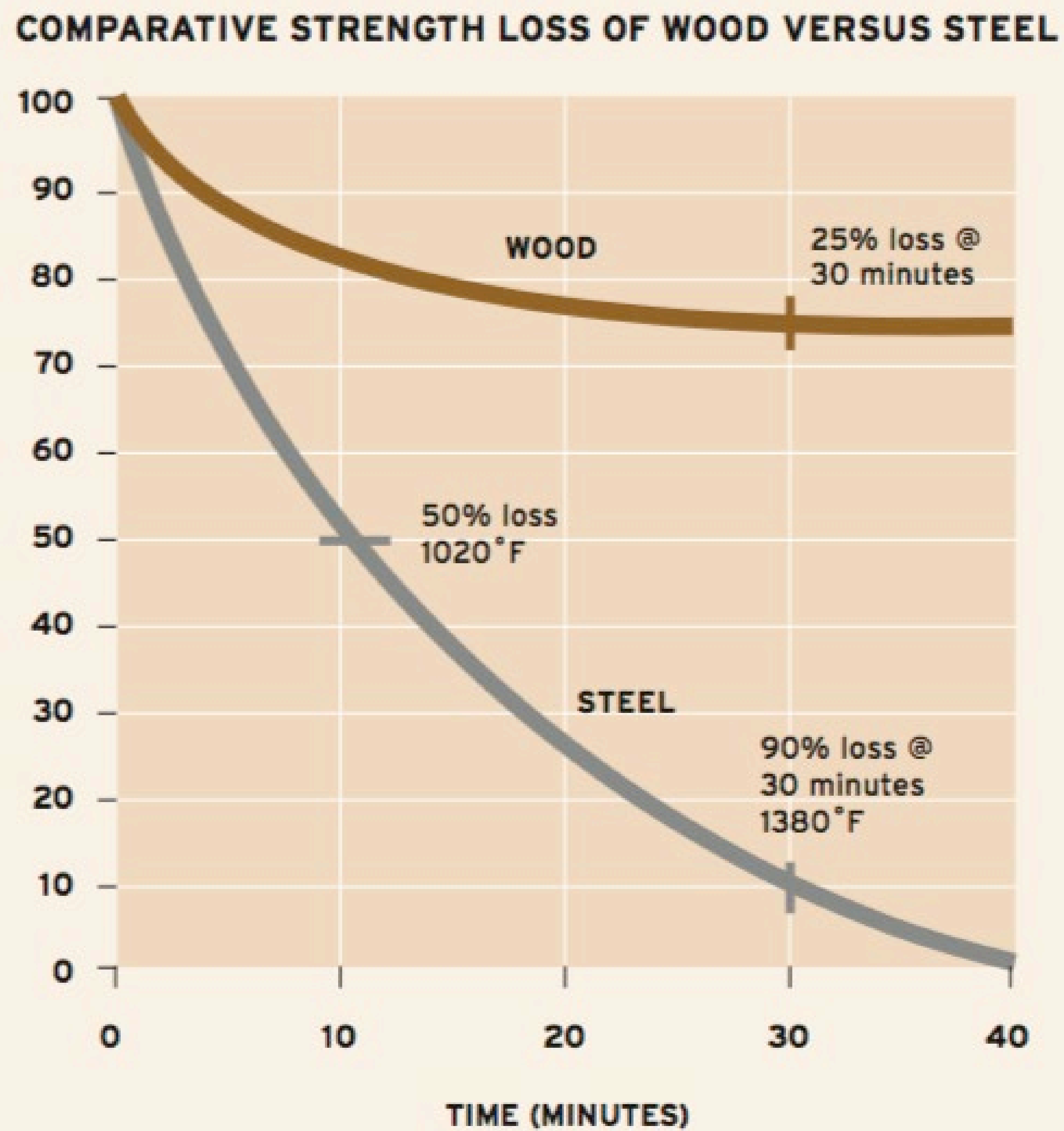
University of Washington Founders Hall
LMN Architects / Magnusson Klemencic Associates

Photo: Tim Griffith

1 De Haro / SKS Partners / Perkins&Will / DCI Engineers
https://www.woodworks.org/resources/fire-design-of-mass-timber-members-code-applications-construction-types-and-fire-ratings/

MASS TIMBER DESIGN

FIRE RESISTANCE



Results from test sponsored by National Forest Products Association at the Southwest Research Institute

SOURCE: AITC

Key Early Design Decisions

Construction type influences FRR

TABLE 601
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BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV				TYPE V	
	A	B	A	B	A	B	A	B	C	HT	A	B
Primary structural frame[f] (see Section 202)	3[a, b]	2[a, b, c]	1[b, c]	0[c]	1[b, c]	0	3[a]	2[a]	2[a]	HT	1[b, c]	0
Bearing walls												
Exterior[e, f]	3	2	1	0	2	2	3	2	2	2	1	0
Interior	3[a]	2[a]	1	0	1	0	3	2	2	1/HT[g]	1	0
Nonbearing walls and partitions Exterior	See Table 705.5											
Nonbearing walls and partitions Interior[d]	0	0	0	0	0	0	0	0	0	See Section 2304.11.2	0	0
Floor construction and associated secondary structural members (see Section 202)	2	2	1	0	1	0	2	2	2	HT	1	0
Roof construction and associated secondary structural members (see Section 202)	$1^1/_2$[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	$1^1/_2$	1	1	HT	1[b,c]	0

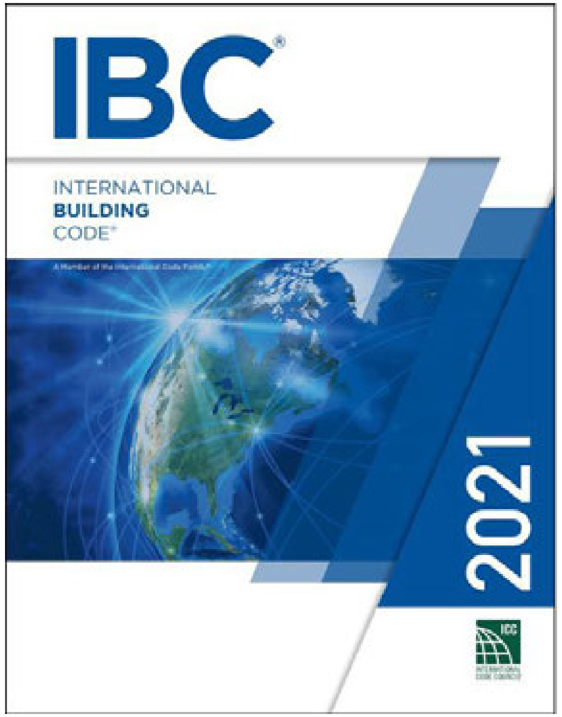
Source: 2021 IBC

Construction type influences FRR

» Type IV-HT Construction (minimum sizes)

» Other than type IV-HT: Demonstrated fire resistance

Method of demonstrating FRR (calculations or testing) can impact member sizing



Fire Testing Laboratory

NGC Testing Services

ACCREDITED Testing Laboratory

TEST REPORT

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for

American Wood Council

222 Catoctin Circle SE, Suite 201
Leesburg, VA 20175

Standard Methods of
Fire Tests of Building Construction and Materials
ASTM E 119 – 11a

Test Report No: WP-1950

Assignment No: K-1089

Subject Material: Cross-Laminated Timber and Gypsum Board Wall Assembly (Load-Bearing)

Test Date: October 4, 2012

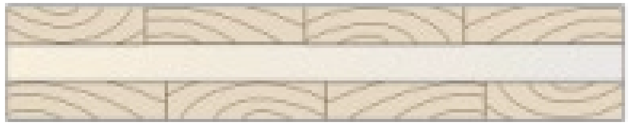
Report Date: October 15, 2012

Prepared by:
Test Engineer

Reviewed by:
Robert J. Menchetti
Director, Laboratory Facilities and Testing Services

Member Sizing

- Impact of FRR on sizing
- Impact of sizing on efficient spans
- Consider connections – can drive member sizing



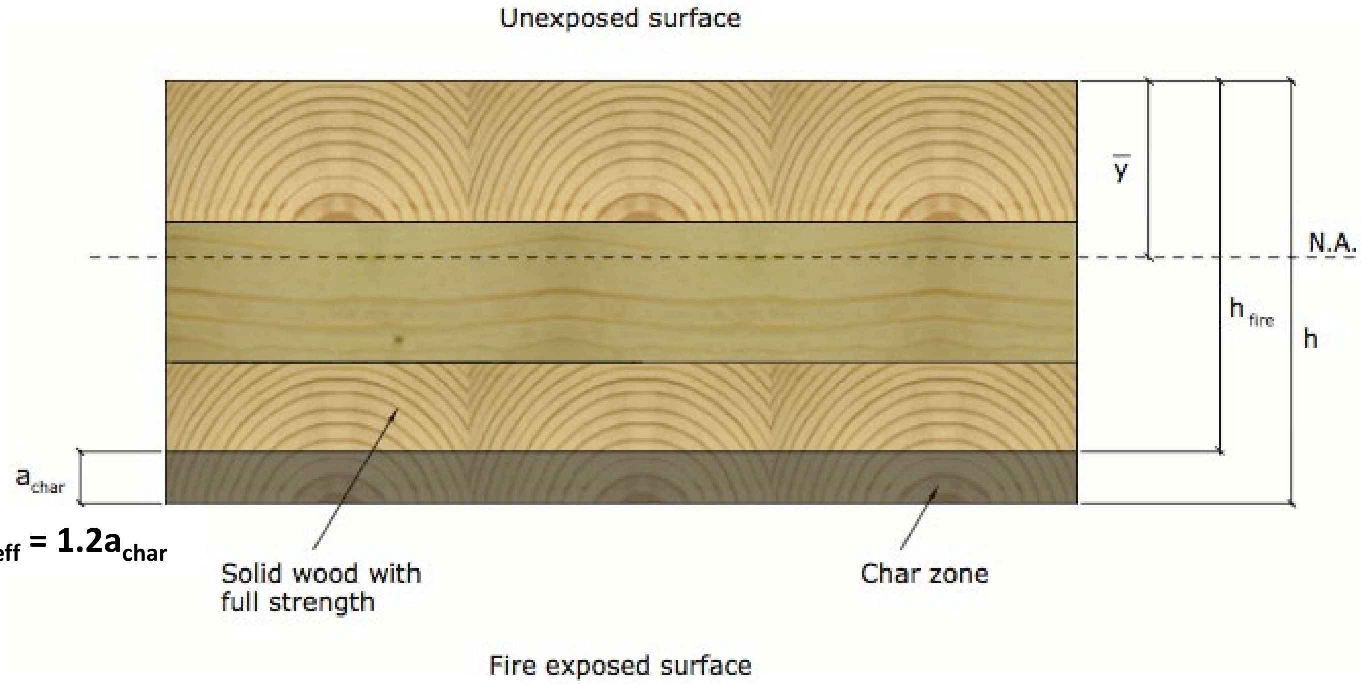
Credit: ARUP

Credit: Kaiser+Path

Construction type influences FRR

Which Method of Demonstrating FRR of MT is Being Used?

- » Calculations in Accordance with IBC 722 ⟶ NDS Chapter 16
- » Tests in Accordance with ASTM E119

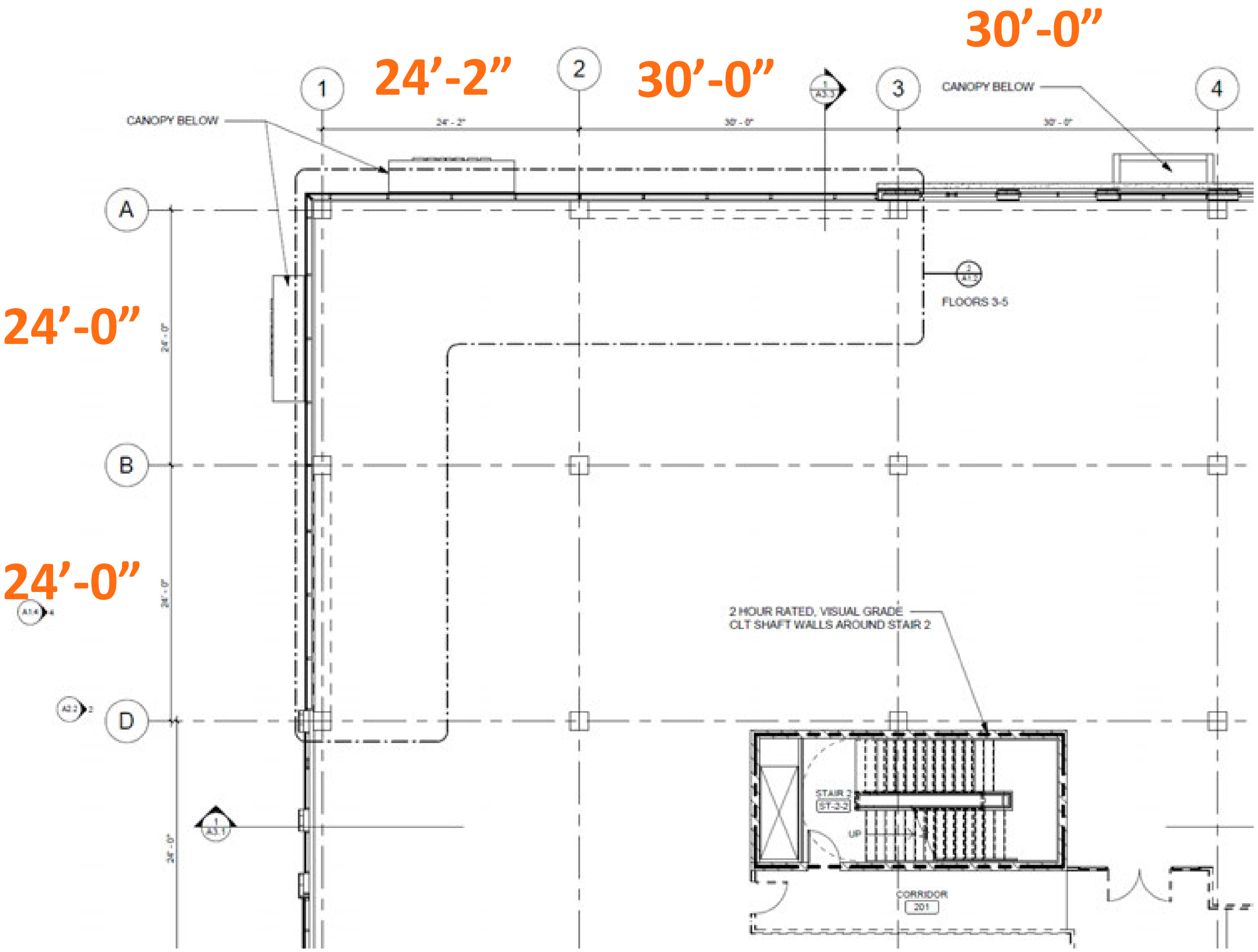


$a_{eff} = 1.2a_{char}$

Structural Grid

Grids & Spans

- Consider Efficient Layouts
- Repetition & Scale
- Manufacturer Panel Sizing
- Transportation



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Grids & Spans

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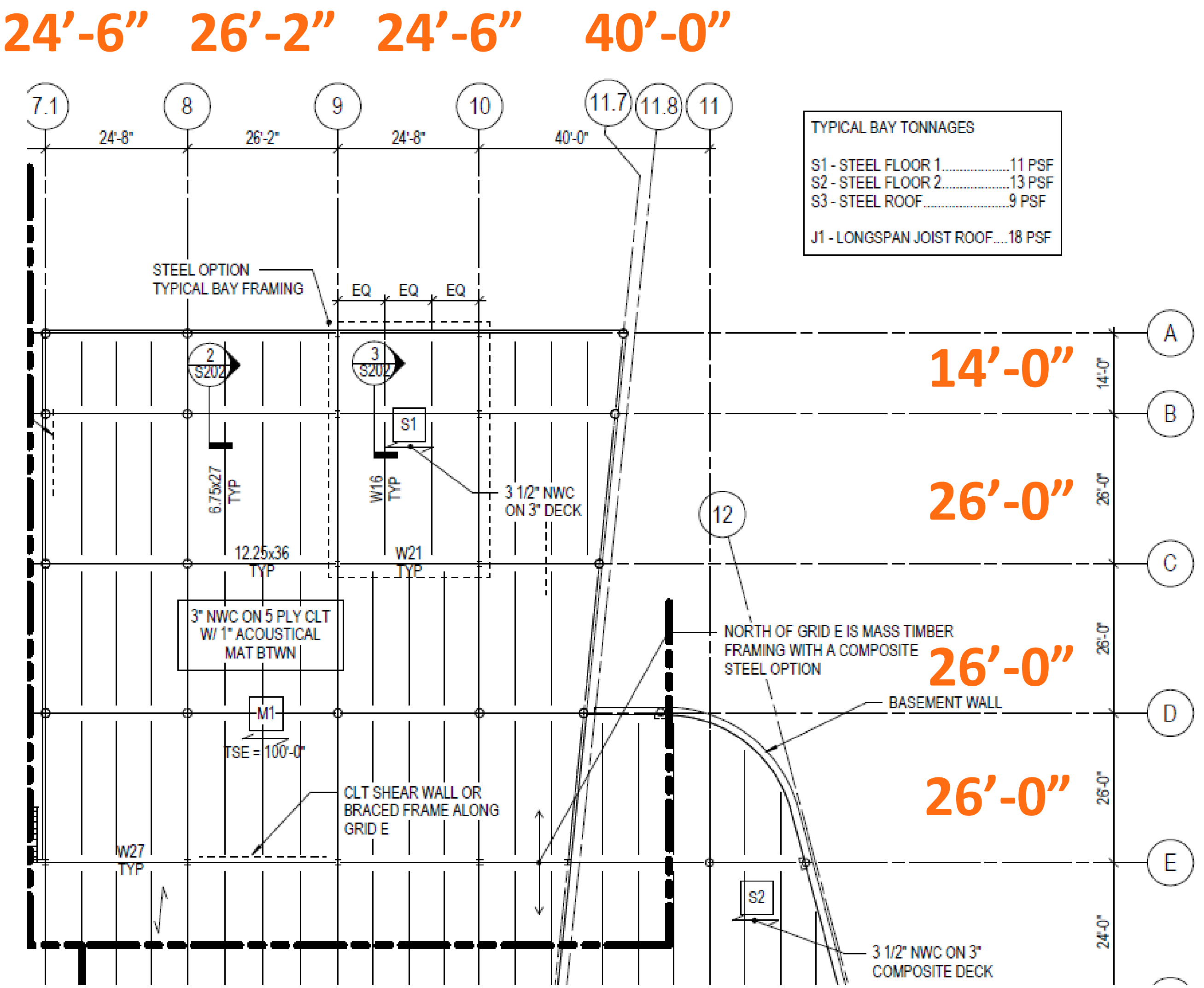


Key Early Design Decisions

Fire-Resistance Ratings (FRR)

» Thinner panels (i.e. 3-ply) generally difficult to achieve a 1+ hour FRR

» 5-ply CLT / 2x6 NLT & DLT panels can usually achieve a 1- or 2-hour FRR

» Construction Type | FRR | Member Size | Grid (or re-arrange that process but follow how one impacts the others)

Panel	Example Floor Span Ranges
3-ply CLT (4-1/8" thick)	Up to 12 ft
5-ply CLT (6-7/8" thick)	14 to 17 ft
7-ply CLT (9-5/8")	17 to 21 ft
2x4 NLT	Up to 12 ft
2x6 NLT	10 to 17 ft
2x8 NLT	14 to 21 ft
5" MPP	10 to 15 ft

Photo: David Barber, ARUP

Structural Grid

Member Sizes

- Impact of FRR on Sizing
- Impact of Sizing on Efficient Spans
- Consider connections – can drive member sizing

0 HR FRR: Consider 3-ply Panel

- Efficient Spans of 10-12 ft
- Grids of 20x20 (1 purlin) to 30x30 (2 purlins) may be efficient

Platte Fifteen, Denver, CO
30x30 Grid, 2 purlins per bay
3-ply CLT
Image: JC Buck

Structural Grid

Member Sizes

» Impact of FRR on Sizing
» Impact of Sizing on Efficient Spans
» Consider connections – can drive member sizing

1 or 2 HR FRR: Likely 5-ply Panel

» Efficient spans of 14-17 ft
» Grids of 15x30 (no purlins) to 30x30 (1 purlin) may be efficient

First Tech Credit Union, Hillsboro, OR
12x32 Grid, One-Way Beams
5-ply (5.5”) CLT
Image: Swinerton

Structural Grid

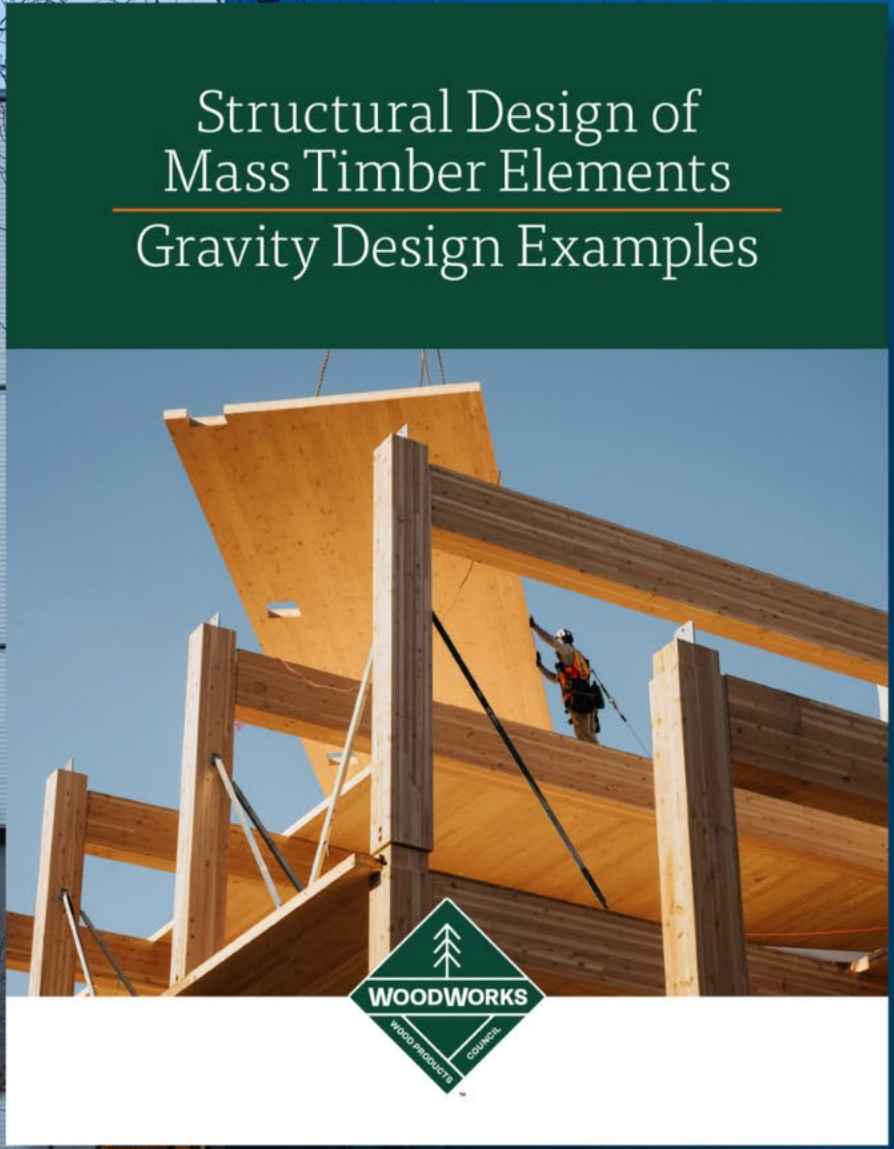
Member Sizes

- Impact of FRR on Sizing
- Impact of Sizing on Efficient Spans
- Consider connections – can drive member sizing

1 or 2 HR FRR: Likely 5-ply Panel

- Efficient spans of 14-17 ft
- Grids of 15x30 (no purlins) to 30x30 (1 purlin) may be efficient

Clay Creative, Portland, OR
30x30 Grid, 1 purlin per bay
2x6 NLT
Image: Mackenzie



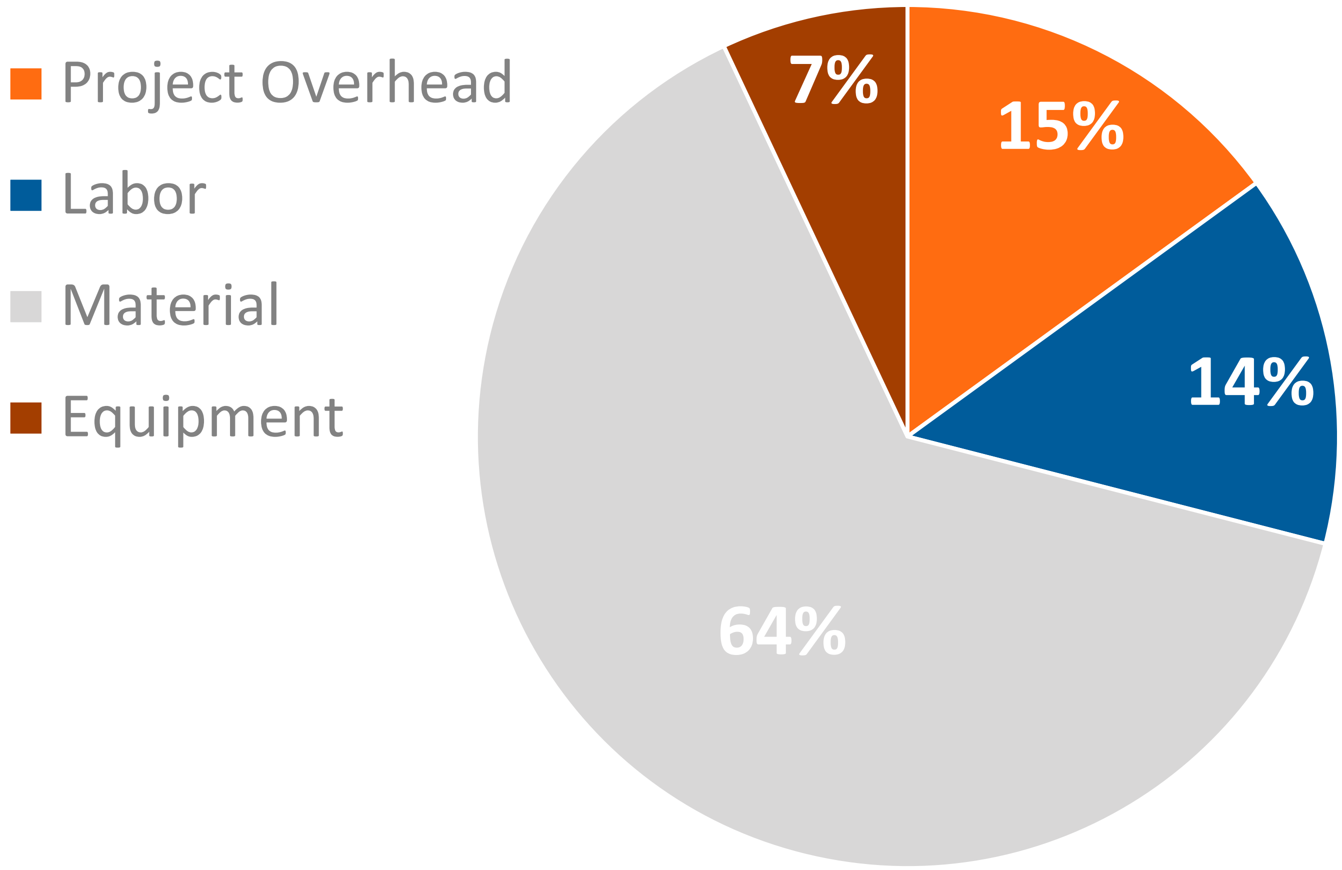
Thesis / LEVER Architecture / Holmes / Swinerton
Photo: Lara Swimmer

https://www.woodworks.org/resources/structural-design-of-mass-timber-elements-gravity-design-examples/

Key Early Design Decisions

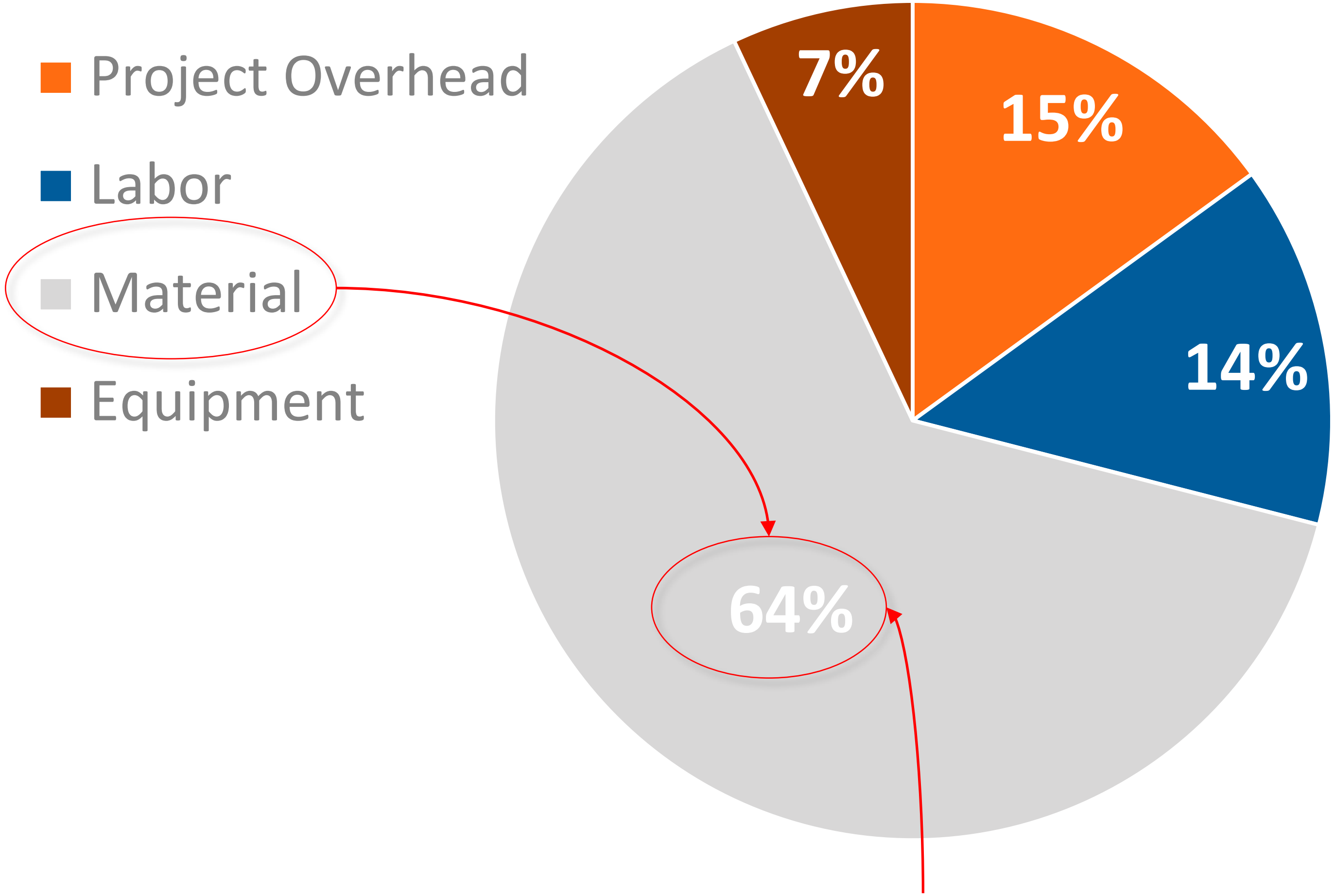
Why so much focus on panel thickness?

Typical MT Package Costs



Source: Swinerton

Typical MT Package Costs



Panels are the biggest part of the biggest piece of the cost pie

Source: Swinerton

Construction Type Early Decision Example

7-story building on health campus

- Group B occupancy, NFPA 13 sprinklers throughout
- Floor plate = 22,300 SF
- Total Building Area = 156,100 SF

MT Construction Type Options:

- If Building is < 85 ft
  - 7 stories of IV-C
  - 6 stories of IIIA or IV-HT over 1 story IA podium
- If Building is > 85 ft
  - 7 stories of IV-B

Panel volume usually 65-80% of MT package volume

Type IIIA option 1

1-hr FRR

Purlin: 5.5”x28.5”

Girder: 8.75”x33”

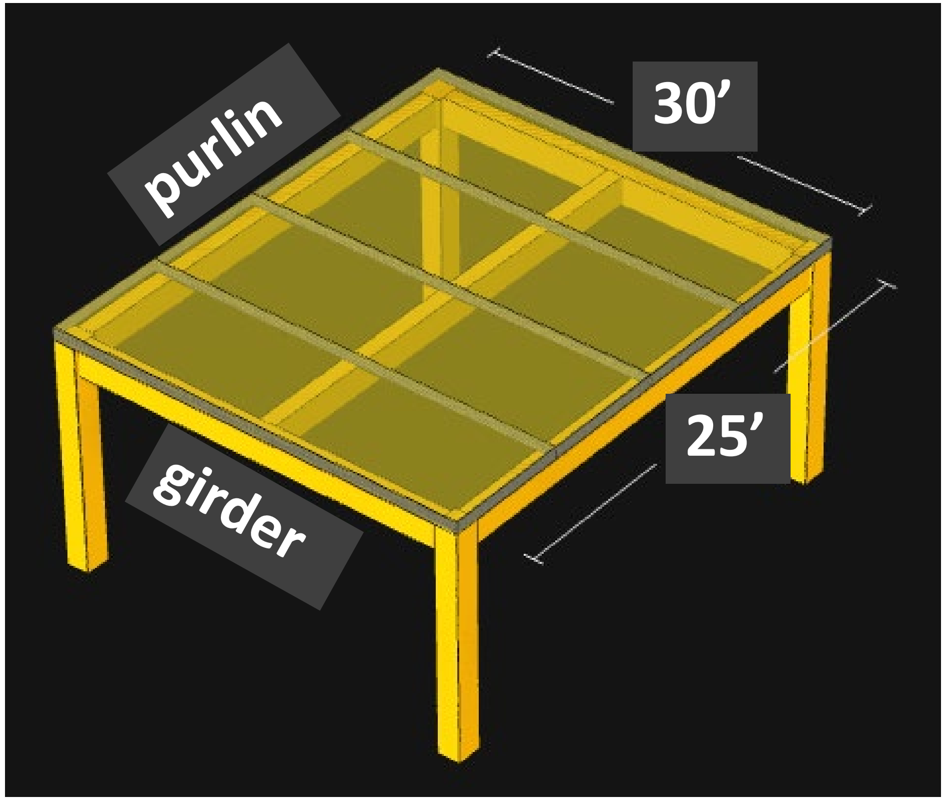
Column: 10.5”x10.75”

Floor panel: 5-ply

Glulam volume = 118 CF (22% of MT)

CLT volume = 430 CF (78% of MT)

Total volume = 0.73 CF / SF



Source: Fast + Epp, Timber Bay Design Tool

Panel volume usually 65-80% of MT package volume

Type IIIA option 2

1-hr FRR

Purlin: 5.5”x24”

Girder: 8.75”x33”

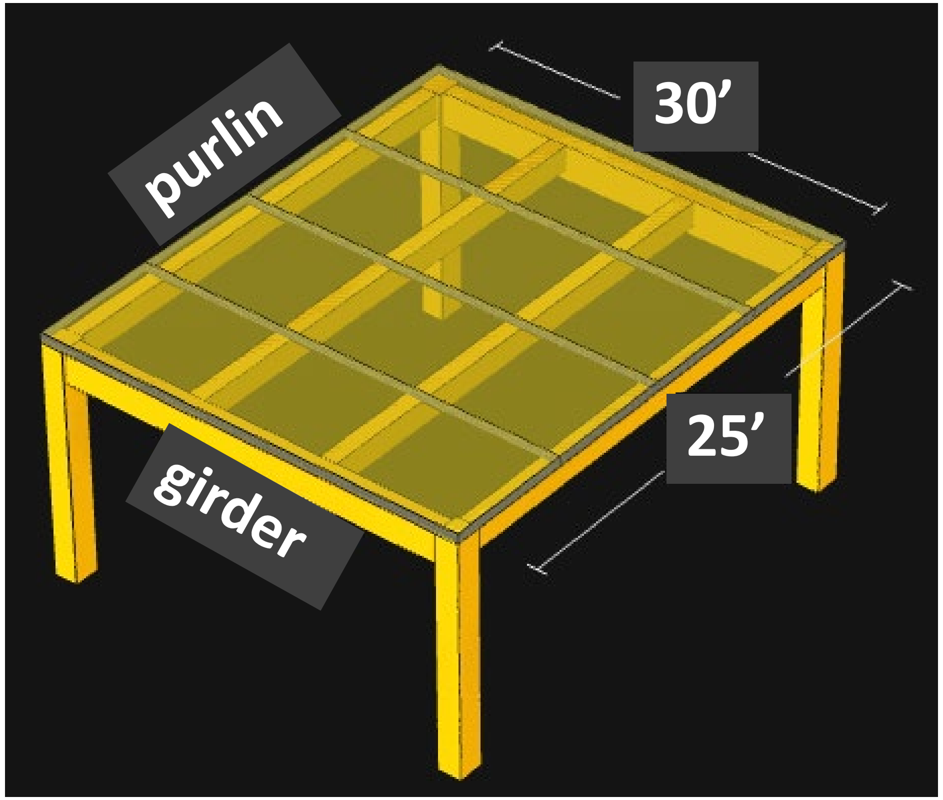
Column: 10.5”x10.75”

Floor panel: 5-ply

Glulam volume = 123 CF (22% of MT)

CLT volume = 430 CF (78% of MT)

Total volume = 0.74 CF / SF



Source: Fast + Epp, Timber Bay Design Tool

Cost considerations: One additional beam (one additional erection pick), 2 more connections

Panel volume usually 65-80% of MT package volume

Type IV-HT

0-hr FRR (min sizes per IBC)

Purlin: 5.5”x24” (IBC min = 5”x10.5”)

Girder: 8.75”x33” (IBC min = 5”x10.5”)

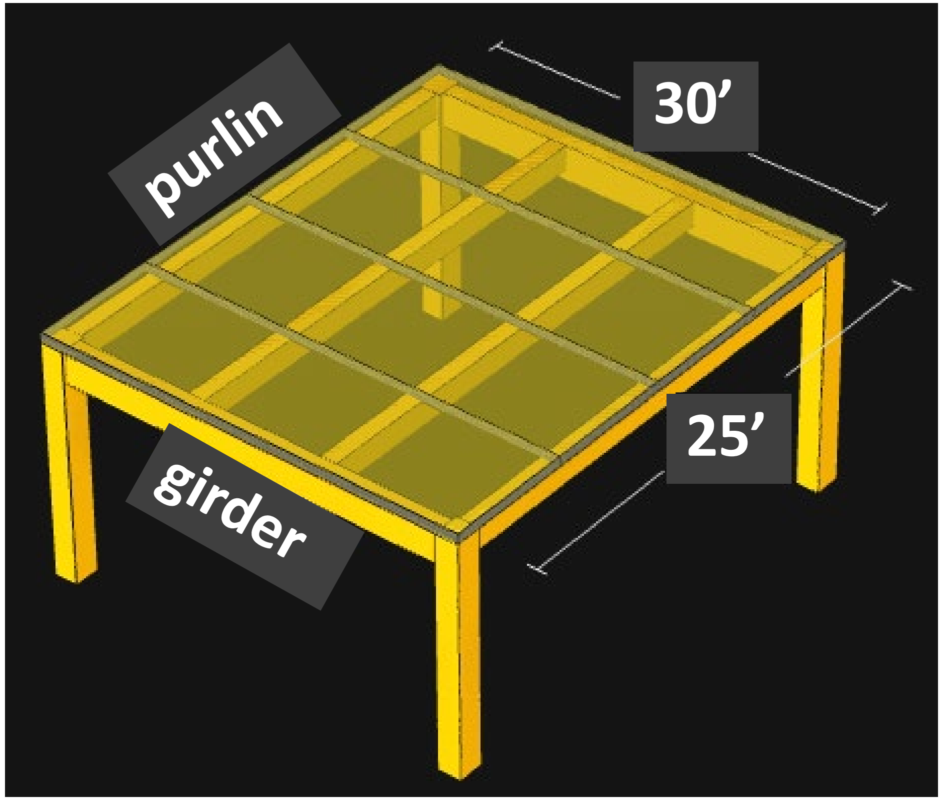
Column: 10.5”x10.75” (IBC min = 6.75”x8.25”)

Floor panel: 3-ply (IBC min = 4” CLT)

Glulam volume = 120 CF (32% of MT)

CLT volume = 258 CF (68% of MT)

Total volume = 0.51 CF / SF



Source: Fast + Epp, Timber Bay Design Tool

Panel volume usually 65-80% of MT package volume

Type IV-C

2-hr FRR

Purlin: 8.75”x28.5”

Girder: 10.75”x33”

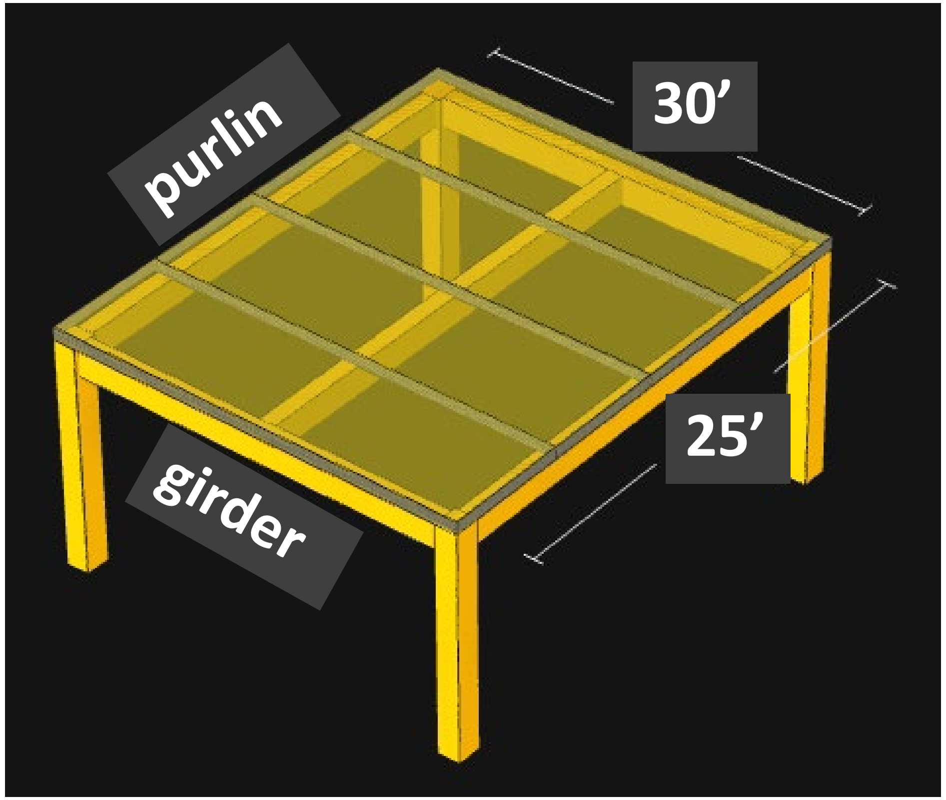
Column: 13.5”x21.5”

Floor panel: 5-ply

Glulam volume = 183 CF (30% of MT)

CLT volume = 430 CF (70% of MT)

Total volume = 0.82 CF / SF

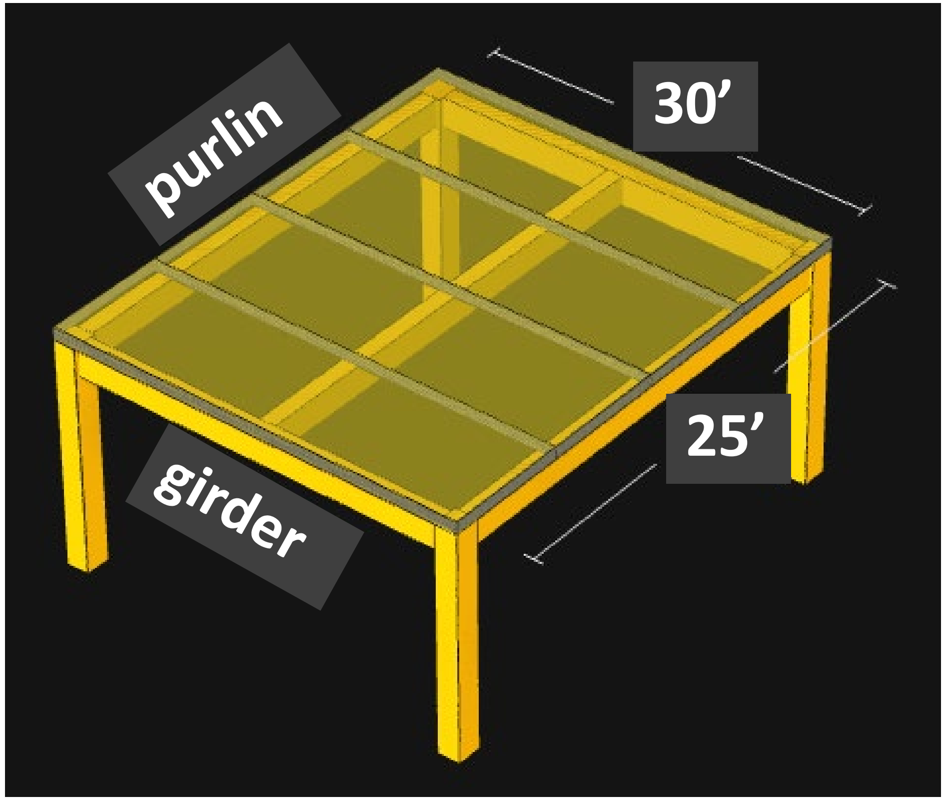


Source: Fast + Epp, Timber Bay Design Tool

Which is the most efficient option?

A general rule of thumb for efficient mass timber fiber volume is no higher than 0.75 CF per SF. Ratios in the 0.85 to 1.0 CF / SF range tend to become cost prohibitive.

	Timber Volume Ratio	Podium on 1st Floor?
IIIA – Option 1	0.73 CF / SF	Yes
IIIA – Option 2	0.74 CF / SF	Yes
IV-HT	0.51 CF / SF	Yes
IV-C	0.82 CF / SF	No



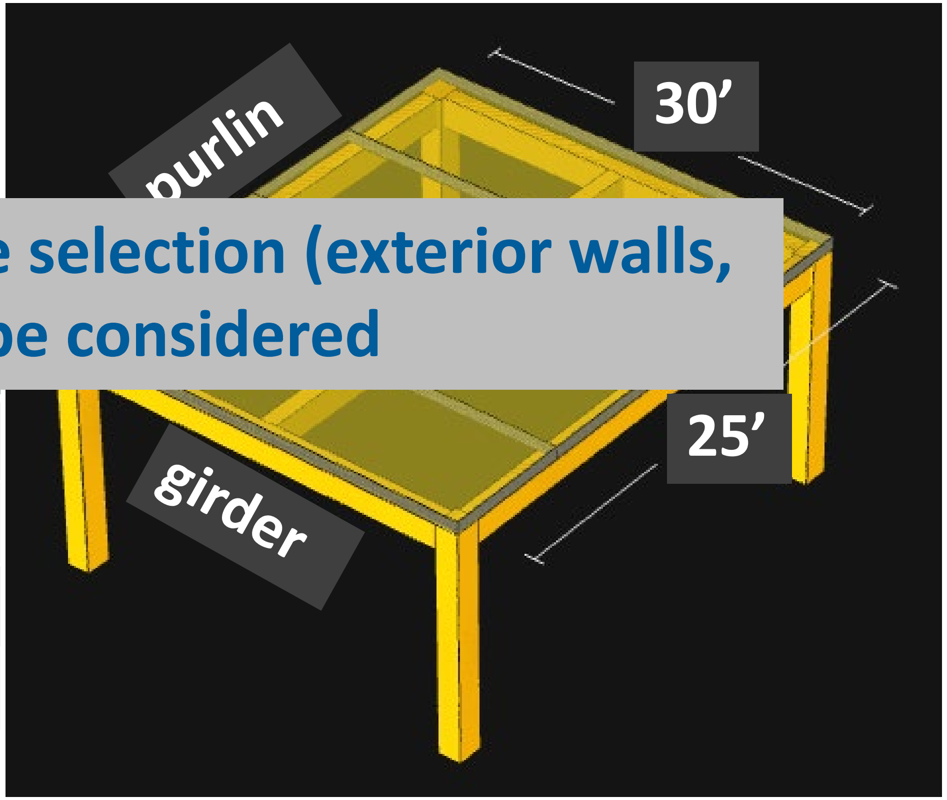
Source: Fast + Epp, Timber Bay Design Tool

Which is the most efficient option?

A general rule of thumb for efficient mass timber fiber volume is no higher than 0.75 CF per SF. Ratios in the 0.85 to 1.0 CF / SF range tend to become cost prohibitive.

There are other impacts of constriction type selection (exterior walls, concealed spaces) that should be considered

IIIA – Option 1	0.73 CF / SF	Yes
IIIA – Option 2	0.74 CF / SF	Yes
IV-HT	0.51 CF / SF	Yes
IV-C	0.82 CF / SF	No

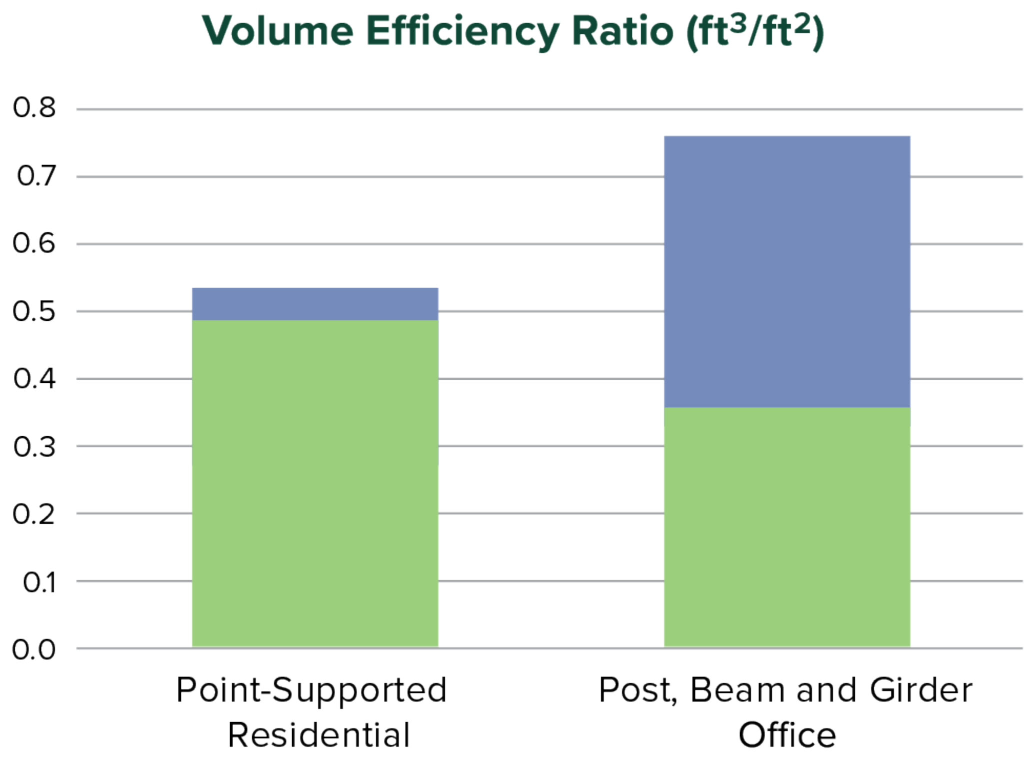


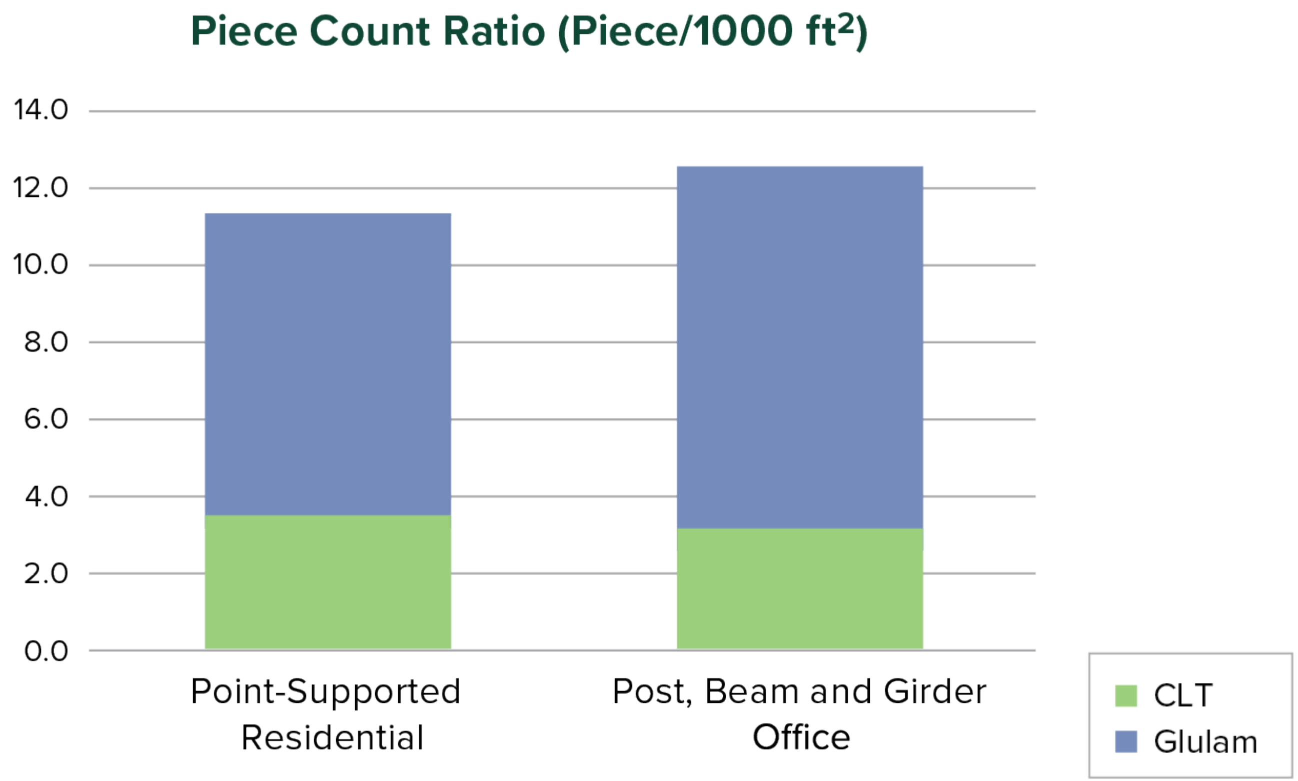
Source: Fast + Epp, Timber Bay Design Tool

Manage Project Costs

Cost Benchmarking

- Volume efficiency ratio: ft^3/ft^2 provides a simple rule of thumb for estimating future projects
- Piece count: cost/piece and piece count/nK ft^2 "What is the estimated number of pieces in relation to the installation cost?"
- Others





Connections

Many ways to demonstrate connection fire protection:

calculations, prescriptive NC, test results, others as approved by AHJ


Photo: John Stamets


Photo: Josh Partee

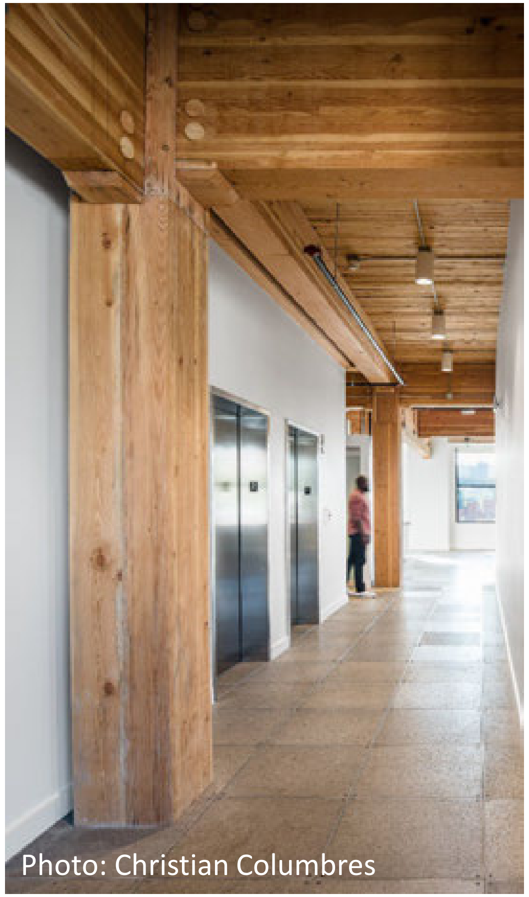


Photo: Christian Columbres

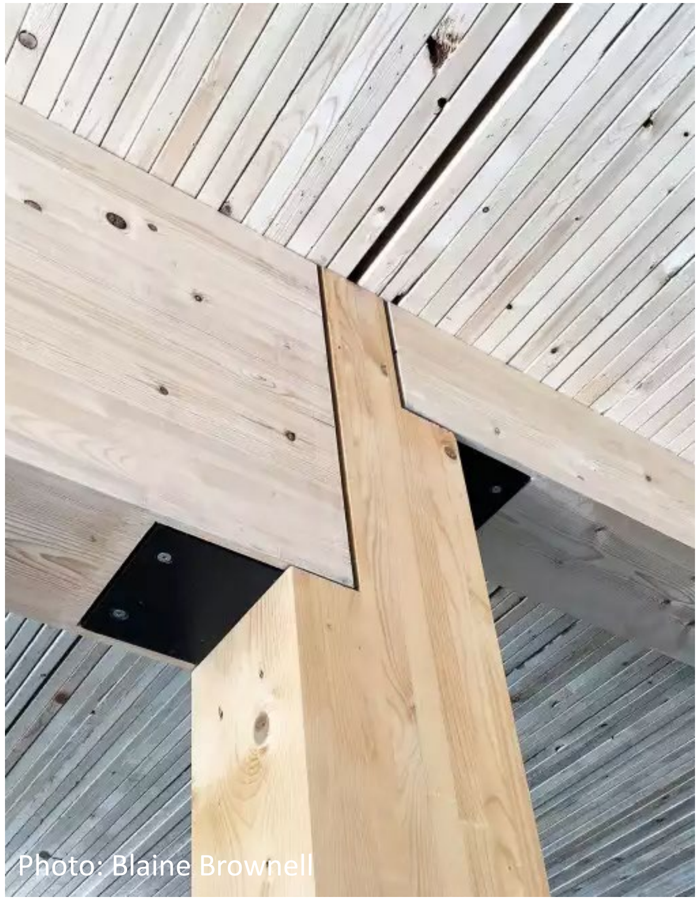
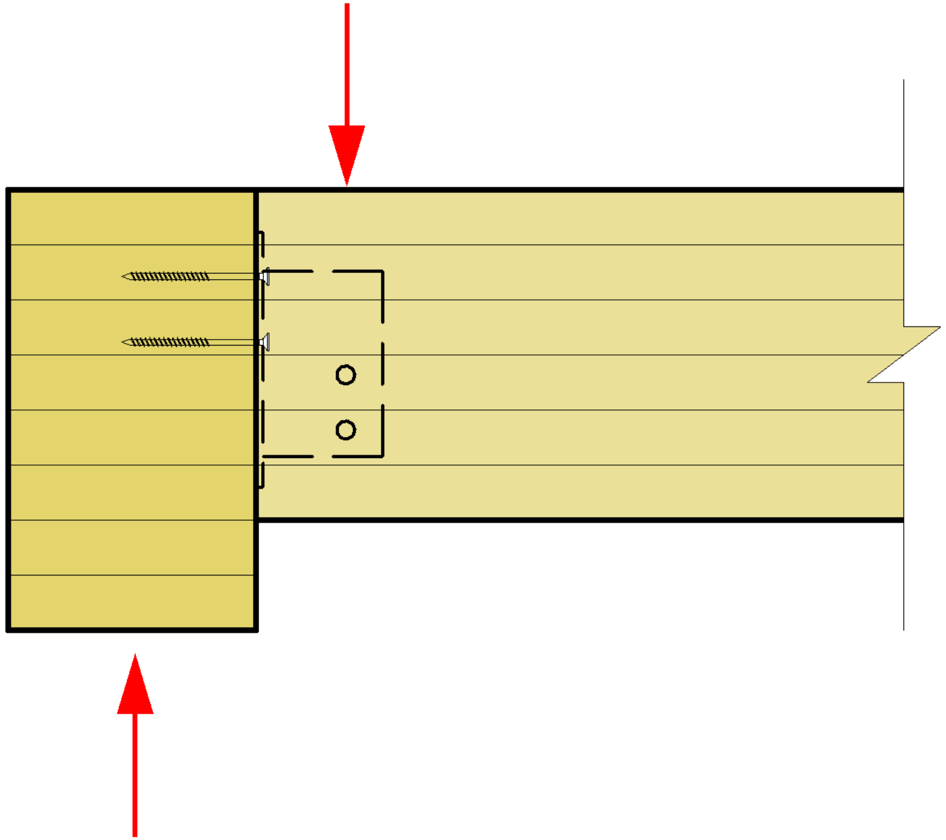


Photo: Blaine Brownell

Connections

Steel hangers/hardware fully concealed within a timber-to-timber connection is a common method of fire protection



Connections

Member to member bearing also commonly used, can avoid some/all steel hardware at connection

Style of connection also impacts and is impacted by grid layout and MEP integration

Connections

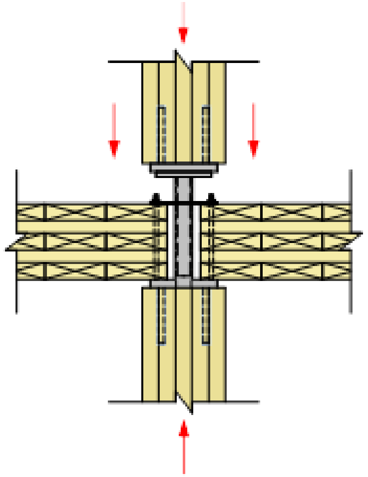
Other connection design considerations:

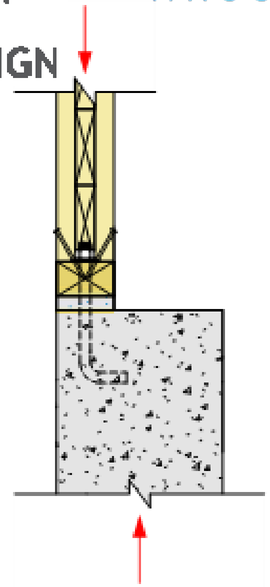
- Structural capacity
- Shrinkage
- Constructability
- Aesthetics
- Cost

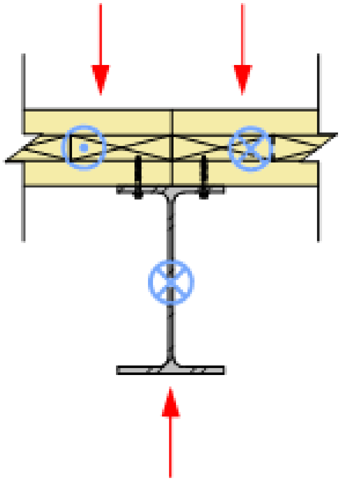
Credit: Alex Schreyer

Mass Timber Connections Index

A library of commonly used mass timber connections with designer notes and information on fire resistance, relative cost and load-carrying capacity.







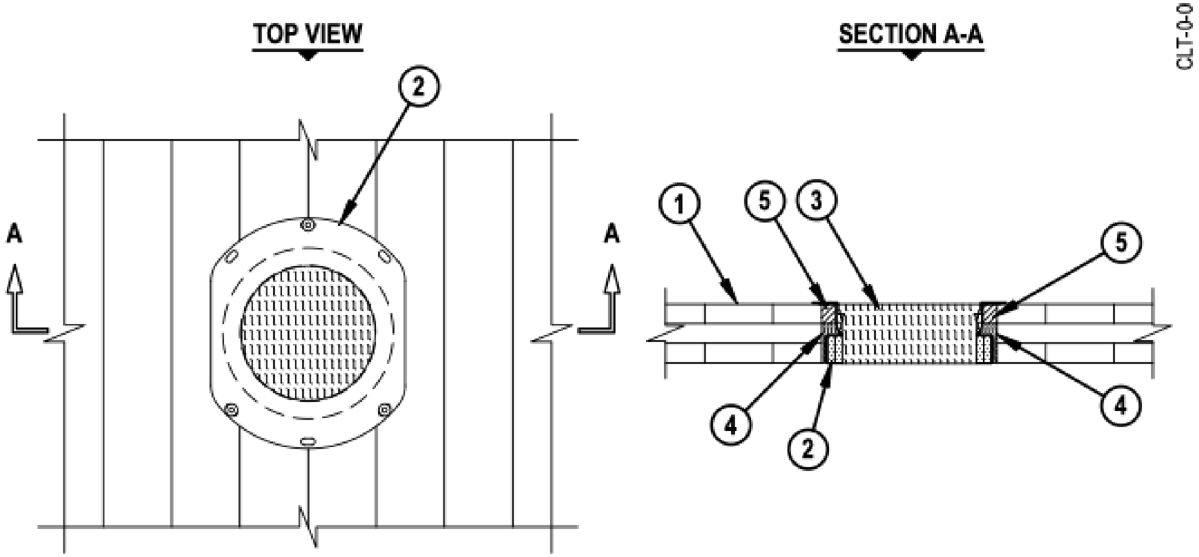
Penetrations & Firestopping

Option 1: MT penetration firestopping via tested products

Photos: AWC/FPInnovations

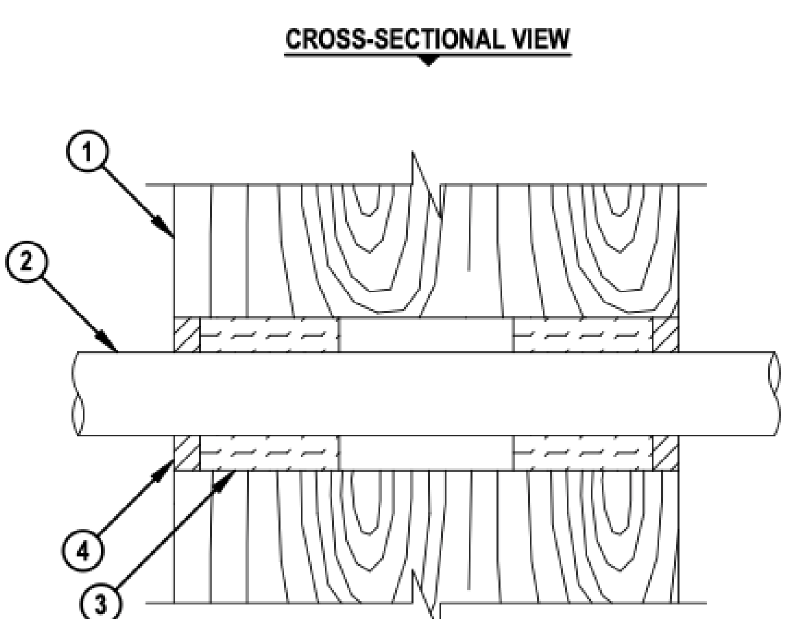
Penetrations & Firestopping

Option 2: MT penetration firestopping of penetrations via engineering judgement details (contact firestop manufacturer)



1. 3-PLY CROSS LAMINATED TIMBER FLOOR ASSEMBLY (MINIMUM 3" THICK) (1-HR. FIRE-RATING).
2. HILTI CFS-DID FIRESTOP DROP-IN DEVICE INSERTED INTO OPENING (SEE TABLE BELOW) AND SECURED TO TOP SURFACE OF CROSS LAMINATED TIMBER FLOOR ASSEMBLY WITH THREE 1/4" x 1" LONG STEEL WOOD SCREWS WITH WASHERS.
3. MINIMUM 3" THICKNESS MINERAL WOOL (MIN. 4 PCF DENSITY) TIGHTLY PACKED, AND FLUSH WITH TOP AND BOTTOM SURFACE OF CFS-DID FIRESTOP DROP-IN DEVICE.
4. MINERAL WOOL (MIN. 4 PCF DENSITY) TIGHTLY PACKED, RECESSED TO ACCOMMODATE SEALANT, AND COMPLETELY FILLING SPACE BETWEEN CFS-DID FIRESTOP DROP-IN DEVICE AND PERIPHERY OF OPENING.
5. MINIMUM 1" DEPTH HILTI FS-ONE MAX INTUMESCENT FIRESTOP SEALANT BETWEEN CFS-DID FIRESTOP DROP IN DEVICE AND PERIPHERY OF OPENING.

F-RATING = 1-HR. OR 2-HR. (SEE NOTE NO. 3 BELOW)

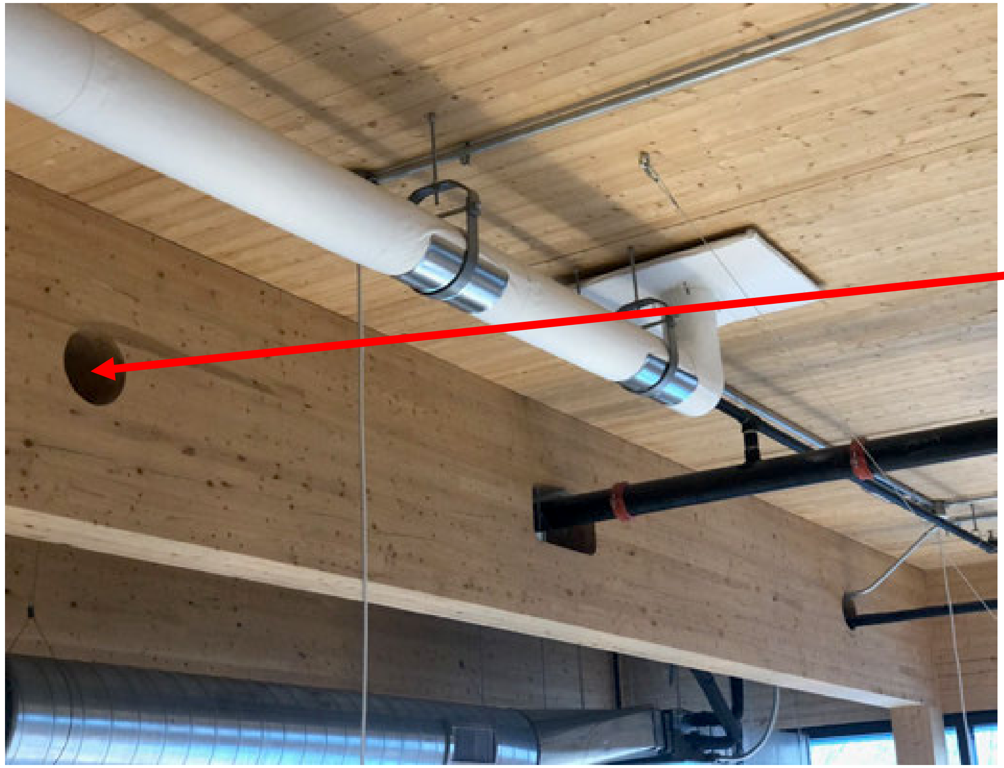


1. MASS TIMBER WALL ASSEMBLY (MINIMUM 12" THICK) (1-HR. OR 2-HR. FIRE-RATING).
2. MAXIMUM 2" NOMINAL DIAMETER PVC PLASTIC PIPE (SCH 40).
3. MINIMUM 4" THICKNESS MINERAL WOOL (MIN. 4 PCF DENSITY) TIGHTLY PACKED AND RECESSED TO ACCOMMODATE SEALANT.
4. MINIMUM 3/4" DEPTH HILTI FS-ONE MAX INTUMESCENT FIRESTOP SEALANT.

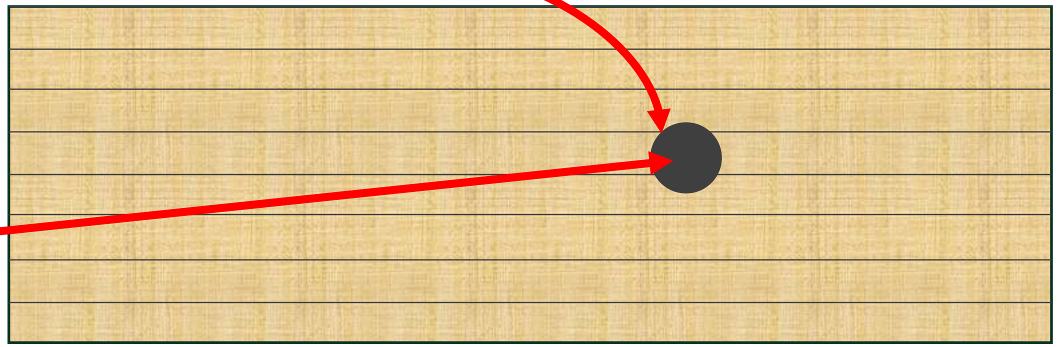
Penetrations & Firestopping

Beam penetrations:

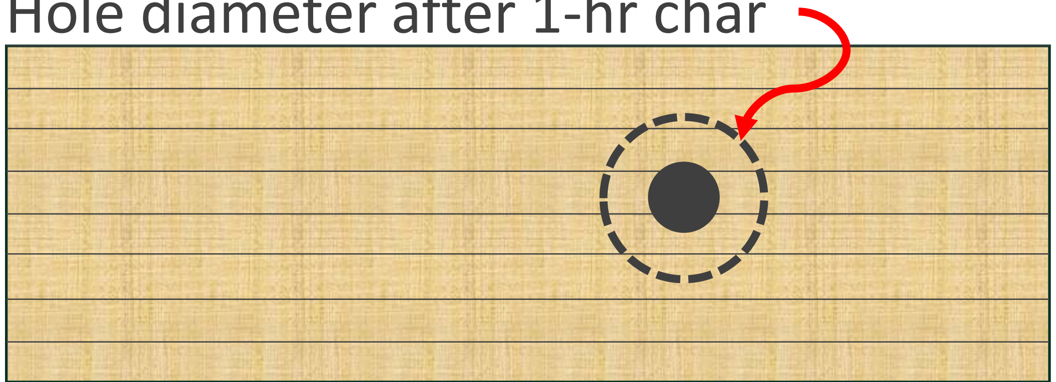
- » If FRR = 0-hr, analyze structural impact of hole diameter only
- » If FRR > 0-hr, account for charred hole diameter or firestop penetration



Hole diameter



Hole diameter after 1-hr char



MEP Layout & Integration

Key considerations:

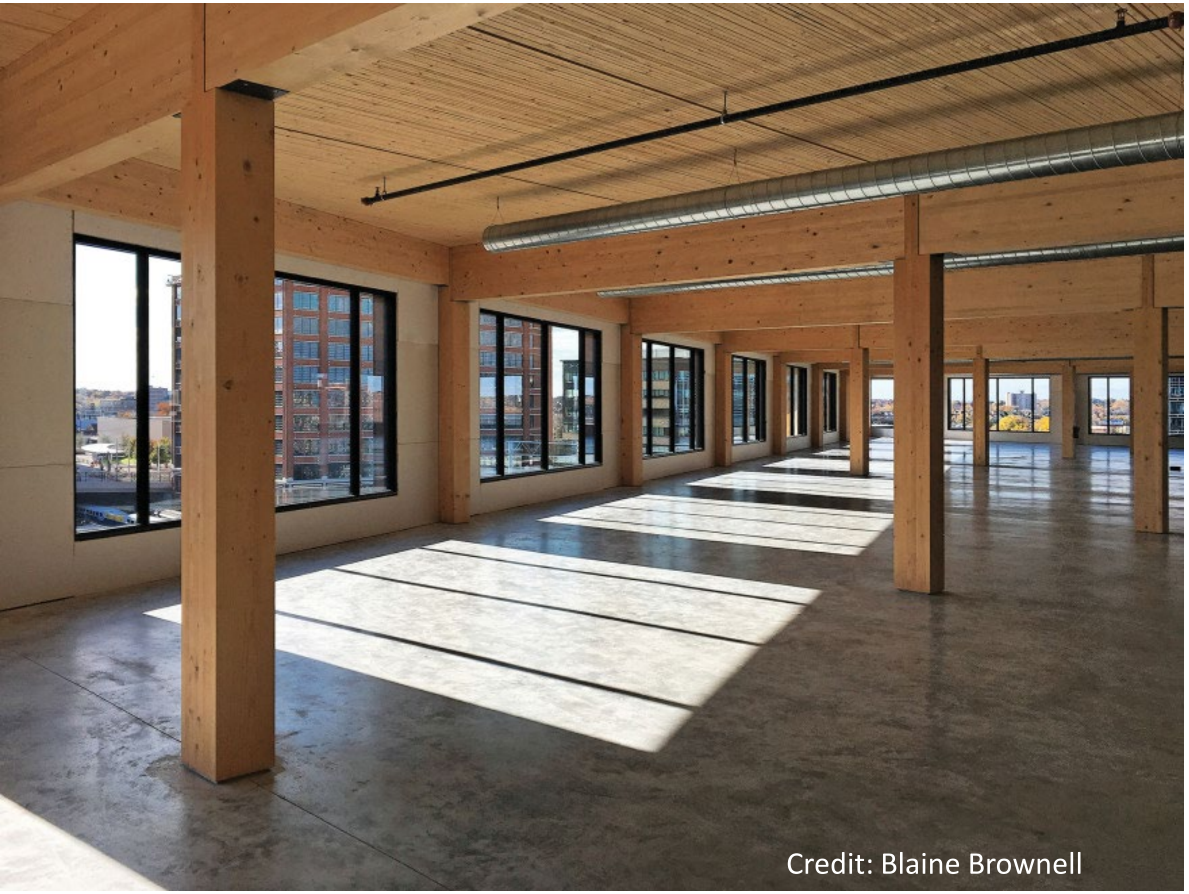
- Level of exposure desired
- Floor to floor, structure depth & desired head height
- Building occupancy and configuration (i.e. central core vs. double loaded corridor)
- Grid layout and beam orientations
- Need for future tenant reconfiguration
- Impact on fire & structural design: concealed spaces, penetrations

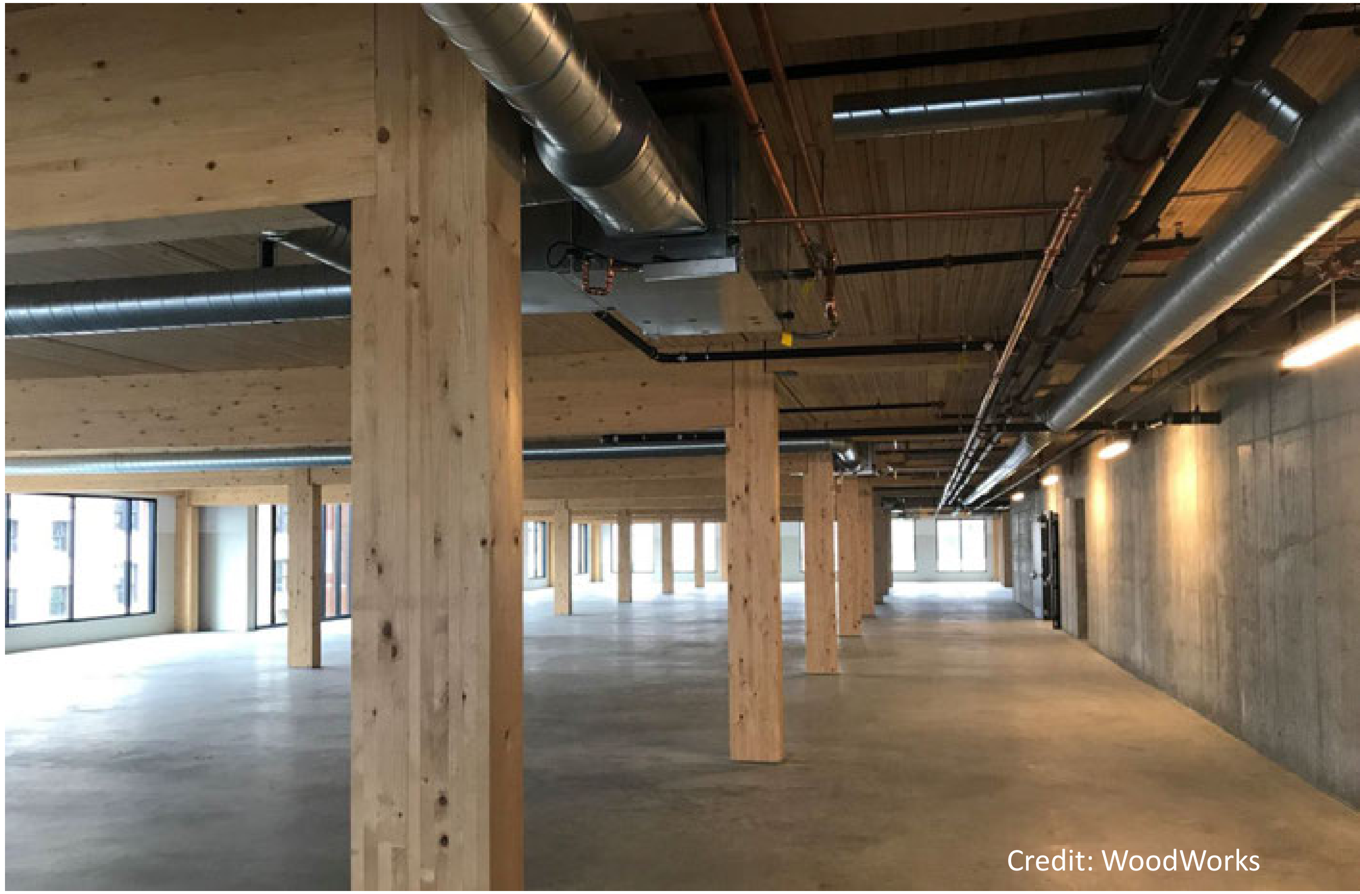
Credit: WoodWorks

MEP Layout & Integration

Smaller grid bays at central core (more head height)

» Main MEP trunk lines around core, smaller branches in exterior bays

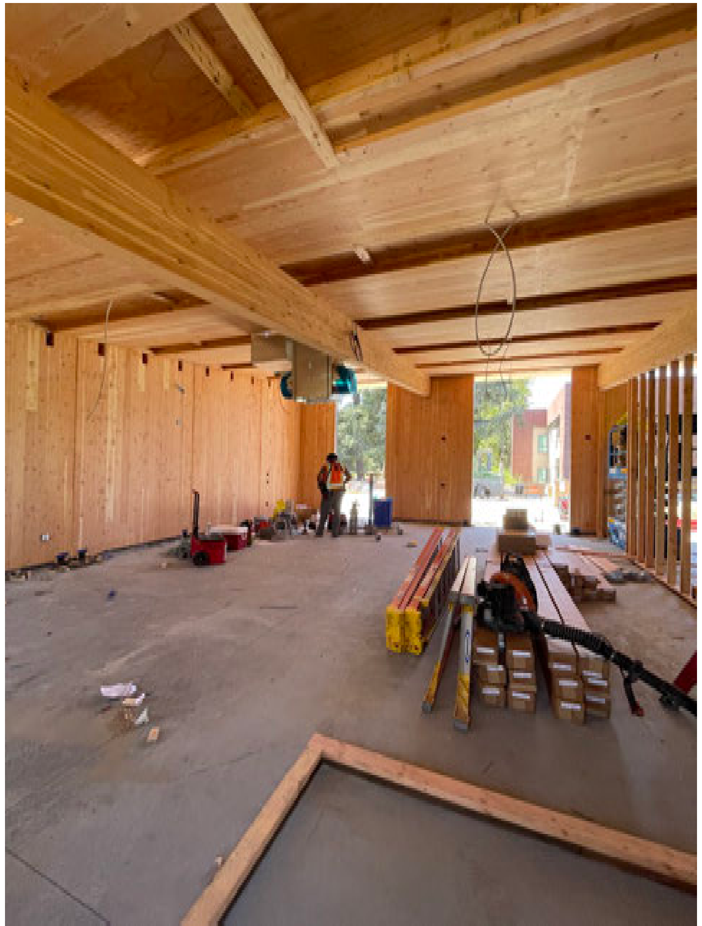

Credit: Blaine Brownell


Credit: WoodWorks

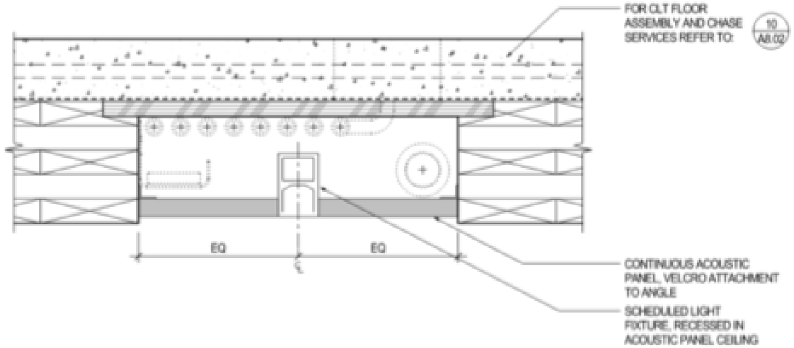
MEP Layout & Integration

In gaps between MT panels

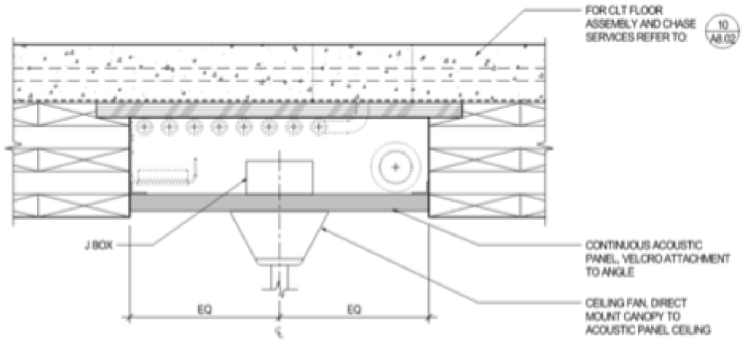
» Greater flexibility in MEP layout



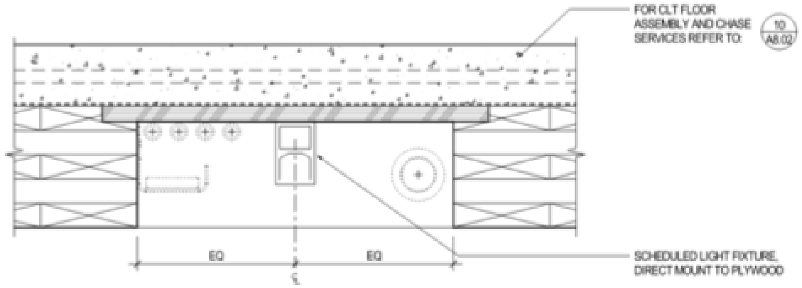
Credit: WoodWorks



2 A8.22 SECTION - RECESSED LIGHTING AT ACOUSTIC FELT CEILING
3" = 1'-0"



3 A8.22 SECTION - CEILING FAN AT ACOUSTIC FELT CEILING
3" = 1'-0"



1 A8.22 SECTION - LIGHTING IN EXPOSED CLT CHASE
3" = 1'-0"

Credit: PAE Consulting Engineers

MEP Layout & Integration

In gaps between MT panels

- Aesthetics: often uses ceiling panels to cover gaps
- Acoustic impacts: rely more on topping

Credit: Ema Peter/MGA

MEP Layout & Integration

In raised access floor (RAF) above MT

- Impact on head height
- Concealed space code provisions


Credit: Global IFS

MEP Layout & Integration

In raised access floor (RAF) above MT

- Aesthetics (minimal exposed MEP)
- Acoustic impacts (usually thinner topping req'd)

RAF

NON-RAF

Credit: BOKA Powell

Lateral System Choices

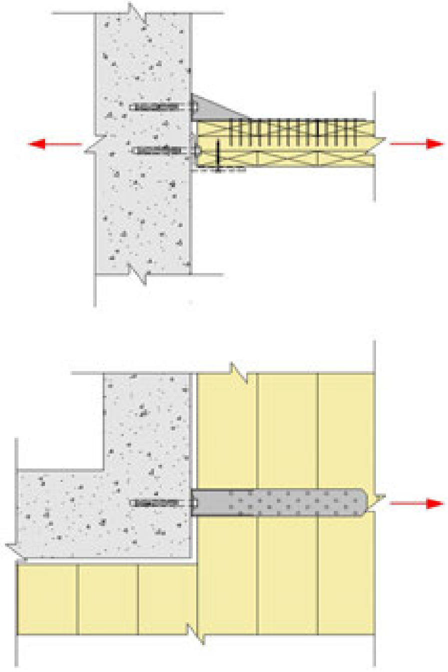
Concrete Shear walls

Lateral System Choices

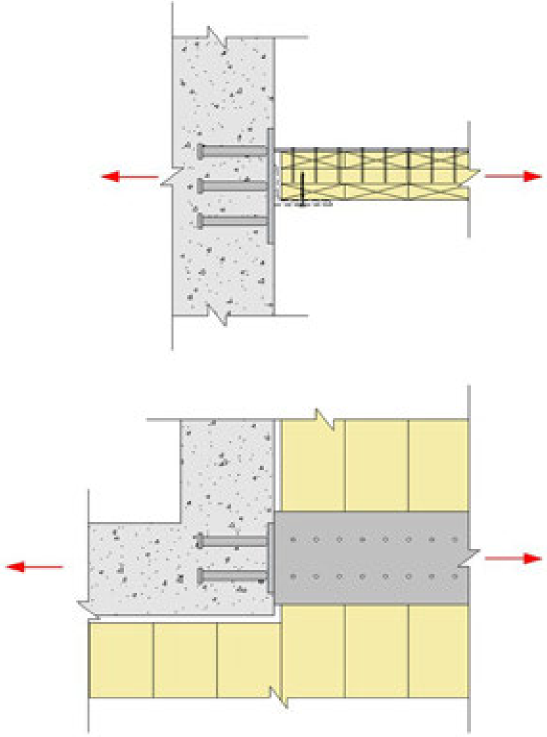
Connections to concrete core

» Tolerances & adjustability

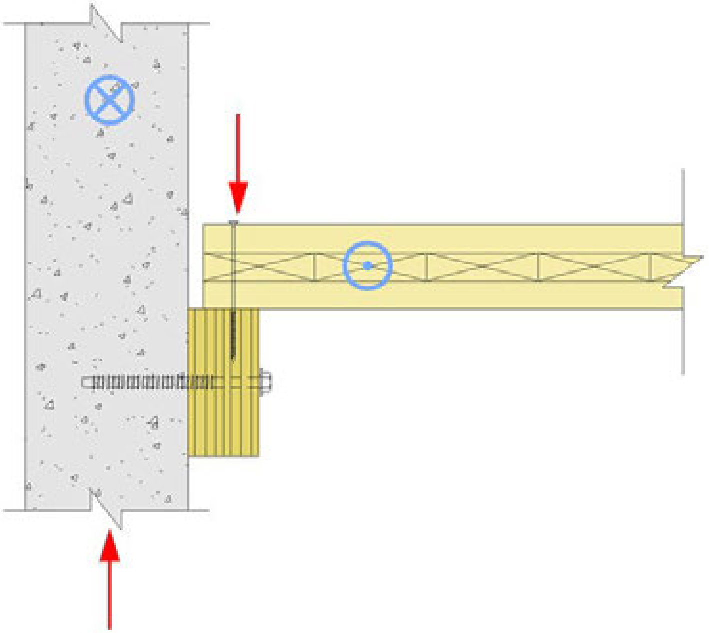
» Drag/collector forces



PLAN VIEW



PLAN VIEW



Lateral System Choices

Connection to concrete core

Lateral System Choices

Steel Braced Frame

Photos: Marcus Kauffmann, ODF

Lateral System Choices

Connections to steel frame

- Tolerances & adjustability
- Consider temperature fluctuations
- Ease of installation

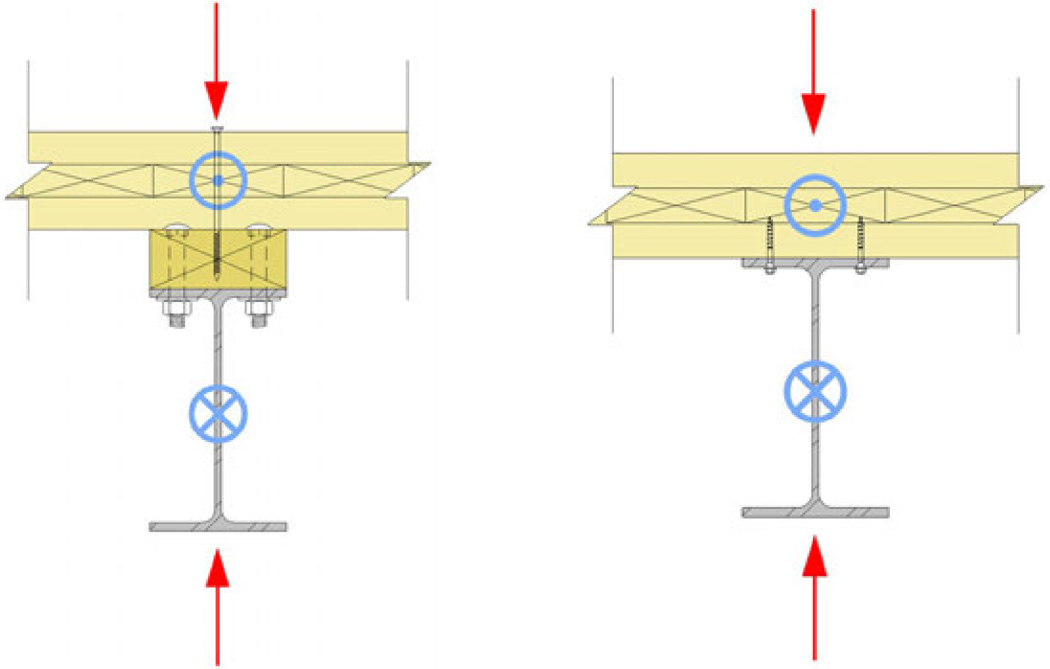


Photo: Marcus Kauffmann, ODF

Lateral System Choices

Wood-frame Shear walls:

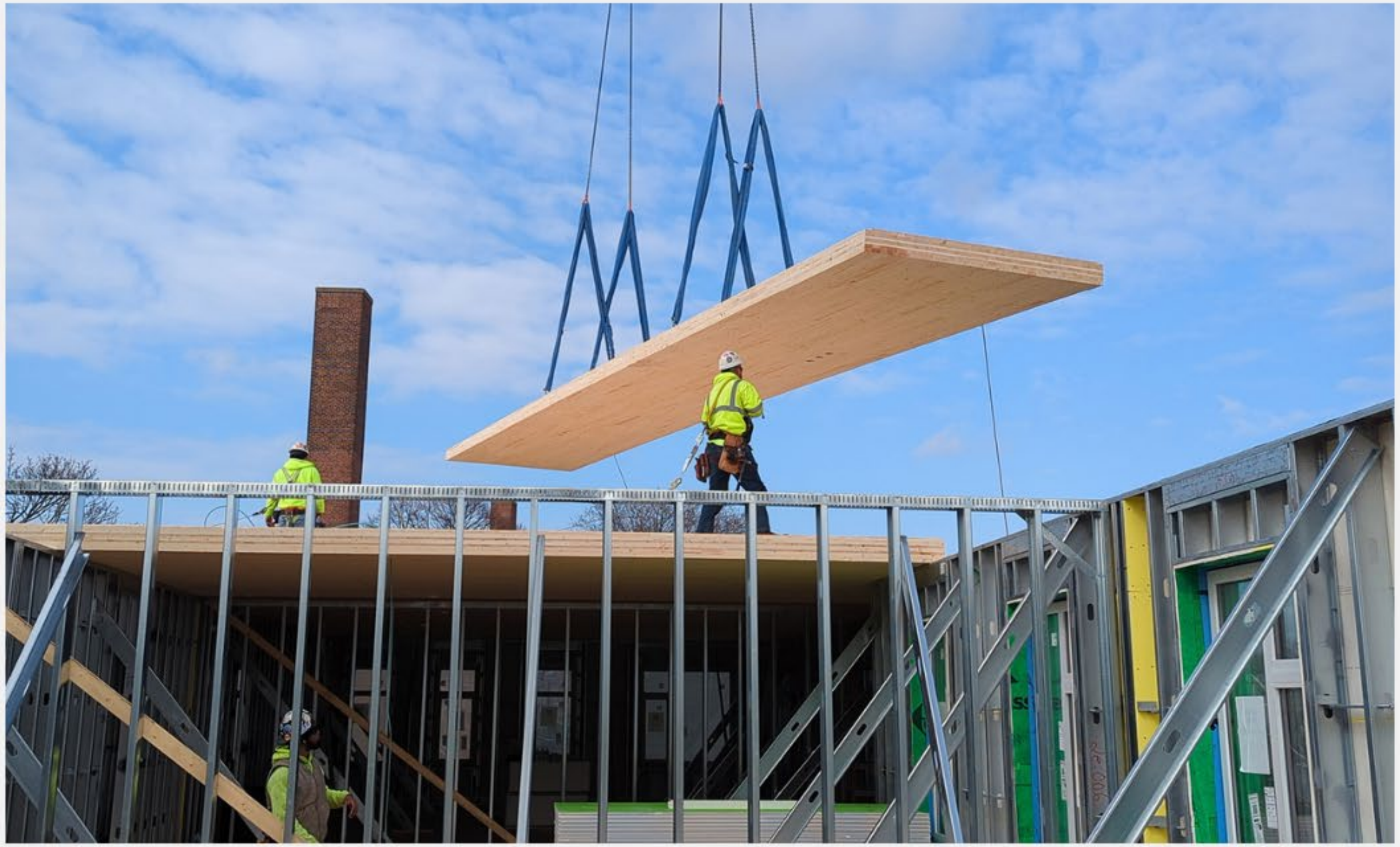
- Code compliance
- Standard of construction practice well known
- Limited to 65 ft shear wall height, 85 ft overall building height

  (Type IIIA construction)

Credit: Jeremy Bittermann & Kaiser + Path

EXPERT TIP

CLT on Cold-Formed Steel Stud Bearing Walls: Engineering Tips for Hybrid Construction



Bunker Hill Housing Redevelopment – Stellata, Stantec, McNamara / Salvia, Leggat McCall Properties
Photo Bryan Maltais

Considerations for mass timber floor and roof panels on cold-formed steel (CFS) stud bearing walls

https://www.woodworks.org/resources/clt-on-cold-formed-steel-stud-bearing-walls/

CLT Shear Wall Options in the U.S.

https://www.woodworks.org/resources/clt-shear-wall-options-in-the-u-s/

Covers cross-laminated timber (CLT) and light-frame wood shear wall systems available for use now and in development

Peavy Hall / Oregon State University Forest Science Complex
Photo Equilibrium

Lateral System Choices

Timber Braced Frame

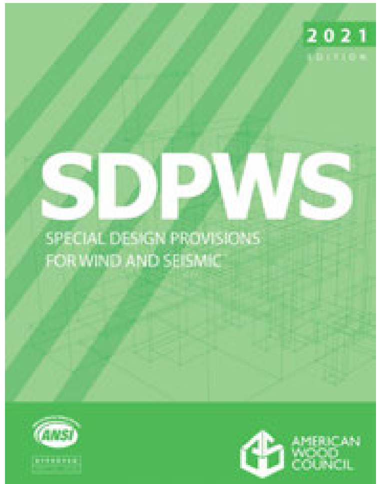
Credit: Alex Schreyer

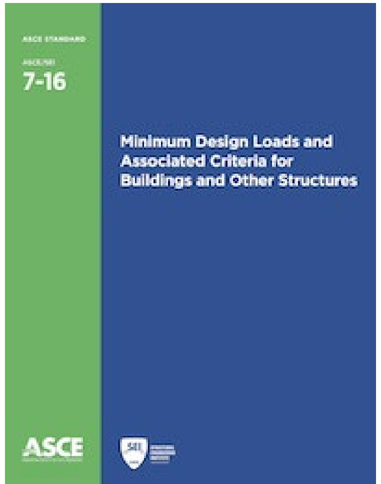
Lateral System Choices

Prescriptive Code Compliance

- Concrete Shear walls ✓
- Steel Braced Frames ✓
- Light Wood-Frame Shear walls ✓
- CLT Shear walls ✓
- CLT Rocking Walls ✗
- Timber Braced Frames ✗

2021 SDPWS
ASCE 7-22





CLT Diaphragm Design for Wind and Seismic Resistance

Using SDPWS 2021 and ASCE 7-22

Cross-laminated timber (CLT) has become increasingly prominent in building construction and can be seen in buildings throughout the world. Specifically, the use of CLT floor and roof panels as a primary gravity force-resisting component has become relatively commonplace. Now, with availability of the 2021 *Special Design Provisions for Wind and Seismic* (SDPWS 2021) from the American Wood Council (AWC), U.S. designers have a standardized path to utilize CLT floor and roof panels as a structural diaphragm. Prior to publication of this document, projects typically had to receive approval to use CLT as a structural diaphragm on a case-by-case basis from the local Authority Having Jurisdiction (AHJ).

This paper highlights important provisions of SDPWS 2021 for CLT diaphragm design and recommendations developed by the authors in the more extensive *CLT Diaphragm Design Guide*, based on SDPWS 2021, published by WoodWorks – Wood Products Council.

AWC SDPWS 2021

SDPWS 2021 is the first edition to provide direct provisions for CLT to be used as an element in a diaphragm or shear wall. To differentiate between CLT and light-frame lateral force-resisting systems, it adopts the terminology *sheathed wood-frame* for light-frame diaphragms (SDPWS §4.2) and shear walls (SDPWS §4.3), and includes new sections for CLT diaphragms (SDPWS §4.5) and shear walls (SDPWS §4.6). SDPWS 2021 is referenced in the 2021 International Building Code (IBC).

Shear Capacity

SDPWS 2021 has a single nominal shear capacity for each set of construction details, v_n, defined in §4.1.4 for use with both wind and seismic design. From this nominal shear capacity, the Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD) wind and seismic design capacities are determined by dividing by the ASD reduction factor, Ω_D, or multiplying by a resistance factor, ϕ_D, for LRFD design as summarized in Table 1. For sheathed wood-frame diaphragms, the SDPWS

Photo: KPFF

Catalyst in Spokane Washington

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Harbor Bay Real Estate Advisors / Hartshorne Plunkard Architecture / Forefront Structural Engineers / Fast+Epp
https://www.woodworks.org/resources/clt-diaphragm-design-for-wind-and-seismic-resistance/

Acoustics & Sound Control

<u>Concrete Slab:</u>
6” Thick
80 PSF
STC 53

<u>CLT Slab:</u>
6-7/8” Thick
18 PSF
STC 41

Acoustics & Sound Control

TABLE 1:

Examples of Acoustically-Tested Mass Timber Panels

Mass Timber Panel	Thickness	STC Rating	IIC Rating
3-ply CLT wall[4]	3.07"	33	N/A
5-ply CLT wall[4]	6.875"	38	N/A
5-ply CLT floor[5]	5.1875"	39	22
5-ply CLT floor[4]	6.875"	41	25
7-ply CLT floor[4]	9.65"	44	30
2x4 NLT wall[6]	3-1/2" bare NLT 4-1/4" with 3/4" plywood	24 bare NLT 29 with 3/4" plywood	N/A
2x6 NLT wall[6]	5-1/2" bare NLT 6-1/4" with 3/4" plywood	22 bare NLT 31 with 3/4" plywood	N/A
2x6 NLT floor + 1/2" plywood[2]	6" with 1/2" plywood	34	33

Source: Inventory of Acoustically-Tested Mass Timber Assemblies, WoodWorks[7]

Acoustics & Sound Control

Consider Impacts of:

- » Timber & Topping Thickness
- » Panel Layout
- » Gapped Panels
- » Connections & Penetrations
- » MEP Layout & Type

Credit: Rothoblaas

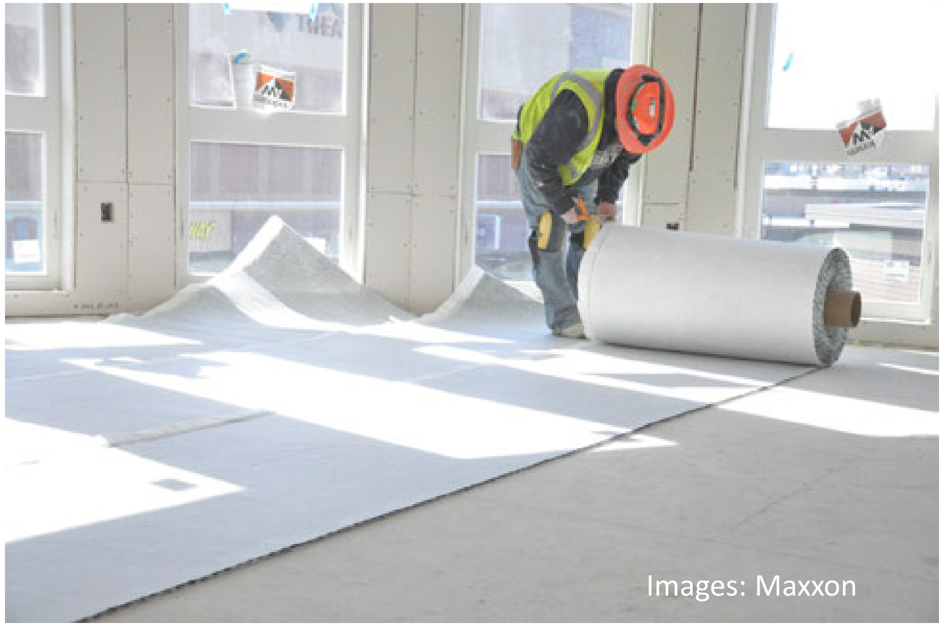
Acoustics & Sound Control

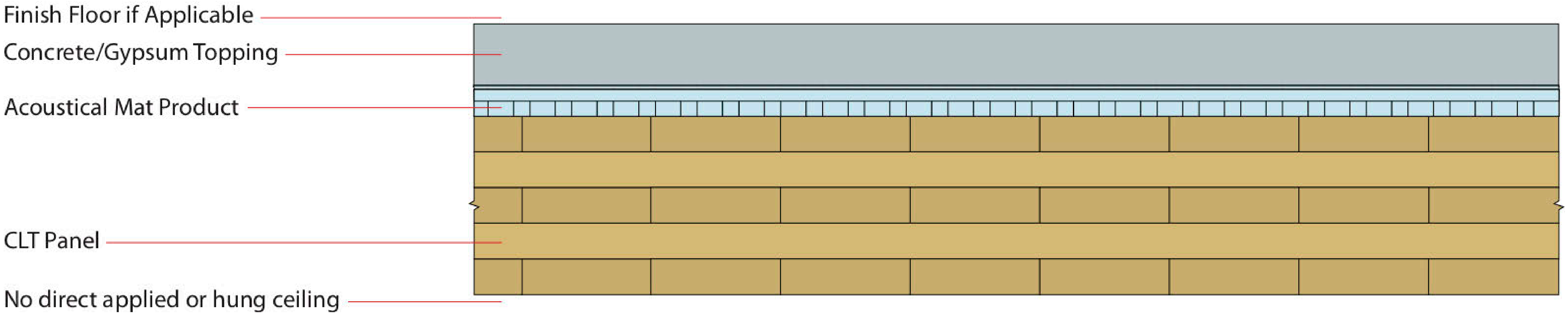
Regardless of the structural materials used in a wall or floor ceiling assembly, there are 3 effective methods of improving acoustical performance:

1. Add mass
2. Add noise barriers
3. Add decouplers

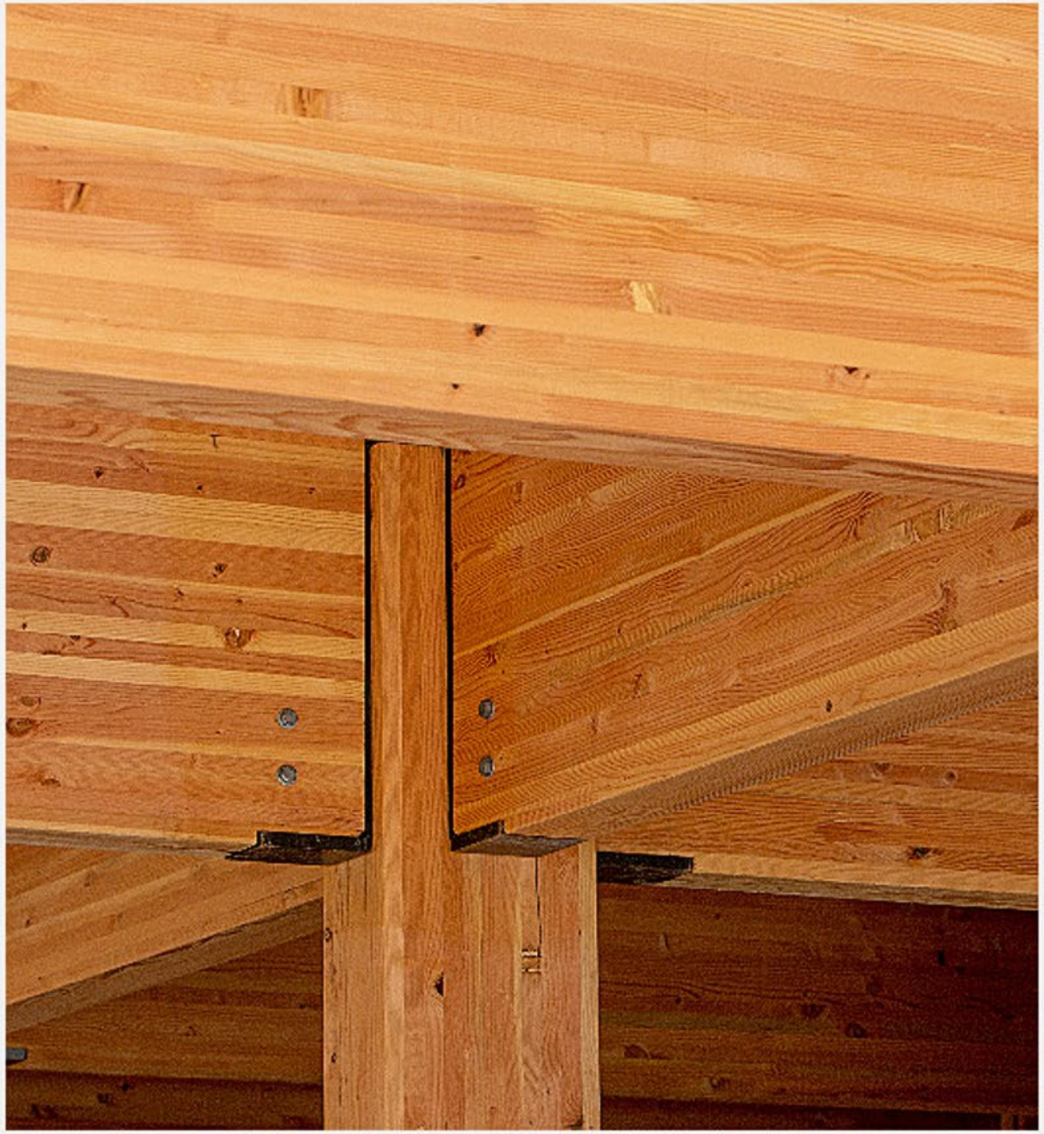
Image credit: Christian Columbres

Acoustics & Sound Control





VIDEO



Junction Lofts / Photo: Cutler Development

Elevating Fire Safety and Acoustics

Design Tips and Resources for Multi-Family Mass Timber Use

https://www.woodworks.org/resources/elevating-fire-safety-and-acoustics/

NEW ONLINE TOOL

Mass Timber Fire & Acoustic Database

Search tested and approved assemblies

https://www.woodworks.org/mass-timber-fire-acoustic-database/

< Back to Mass Timber Fire & Acoustic Database

Assembly Type

- ☐ Floor/Roof 532
- ☐ Wall 147

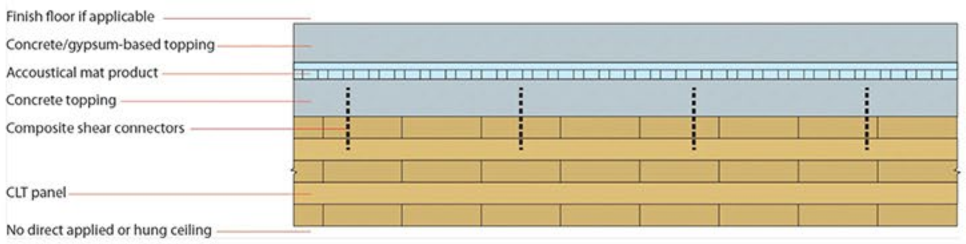
Application Type

- ☐ CLT/Concrete Composite 7
- ☐ Concealed Ceiling 201
- ☐ Concrete/Gypsum Topping 138
- ☐ Other 108
- ☐ Raised Access Floor or Wood Sleepers 78

Mass Timber Panel

- ☐ CLT 507
- ☐ CLT (SCL) 56
- ☐ NLT 72
- ☐ DLT 22

CLT-Concrete Composite Floor Assemblies, Ceiling Side Exposed



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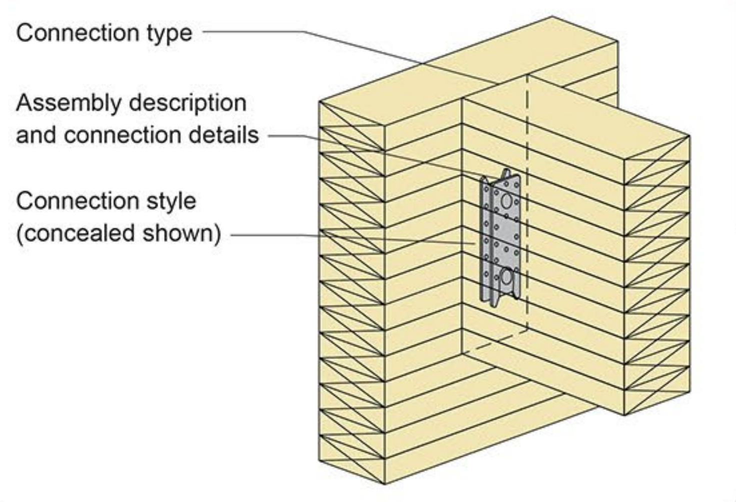
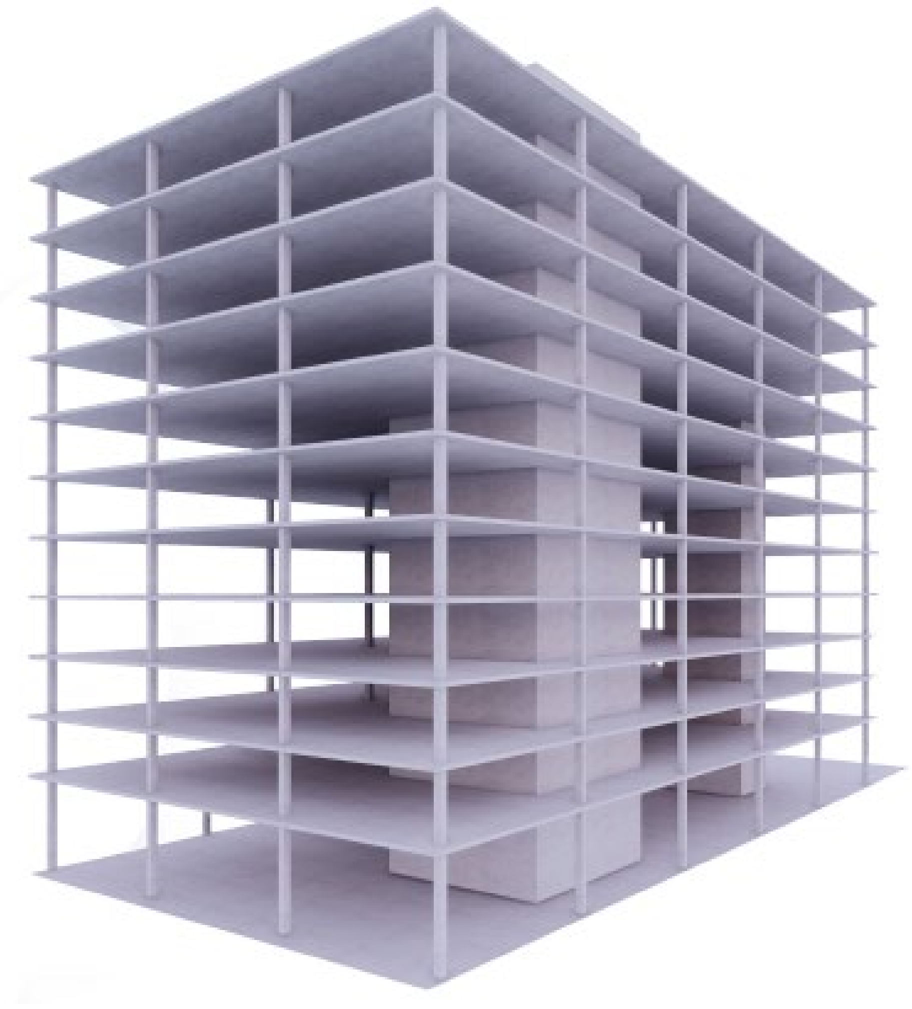


Mass Timber Panel	Topping	Acoustical Mat Products Between Concrete Composite and Upper Topping	Upper Topping	Finish Floor	Sound Rating	Impact Rating	Method of Compliance
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® 3/8	1" Gyp-Crete®	52	STC	50 IIC	Maxxon / Intertek Report # K3094.97-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® 3/8	1" Gyp-Crete®	53	STC	52 IIC	Maxxon / Intertek Report # K3094.69-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® SBR over Maxxon Acousti-Mat® 3/4 Premium	1.5" Gyp-Crete®	56	STC	57 IIC	Maxxon / Intertek Report # K3094.98-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® SBR over Maxxon Acousti-Mat® 3/4 Premium	1.5" Gyp-Crete®	57	STC	61 IIC	Maxxon / Intertek Report # K4507.06-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® SBR over Maxxon Acousti-Mat® 3/4 Premium	2" Gyp-Crete®	60	STC	61 IIC	Maxxon / Intertek Report # K3094.86-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® SBR over Maxxon Acousti-Mat® 3/4 Premium	2" Gyp-Crete®	58	STC	63 IIC	Maxxon / Intertek Report # K3094.86-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	5/8" OSB on 5/8" Georgia Pacific Dens Deck® on Kinetics® Ultra Quiet SR	None	60	STC	62 IIC	Veneklasen Associates / Intertek Report # K3094.19-113-11-R0 Contact Product Manufacturer for More Information

Need to Consider Holistic Costs, Not Structure Only



$/SF

$/SF

Image: GBD Architects

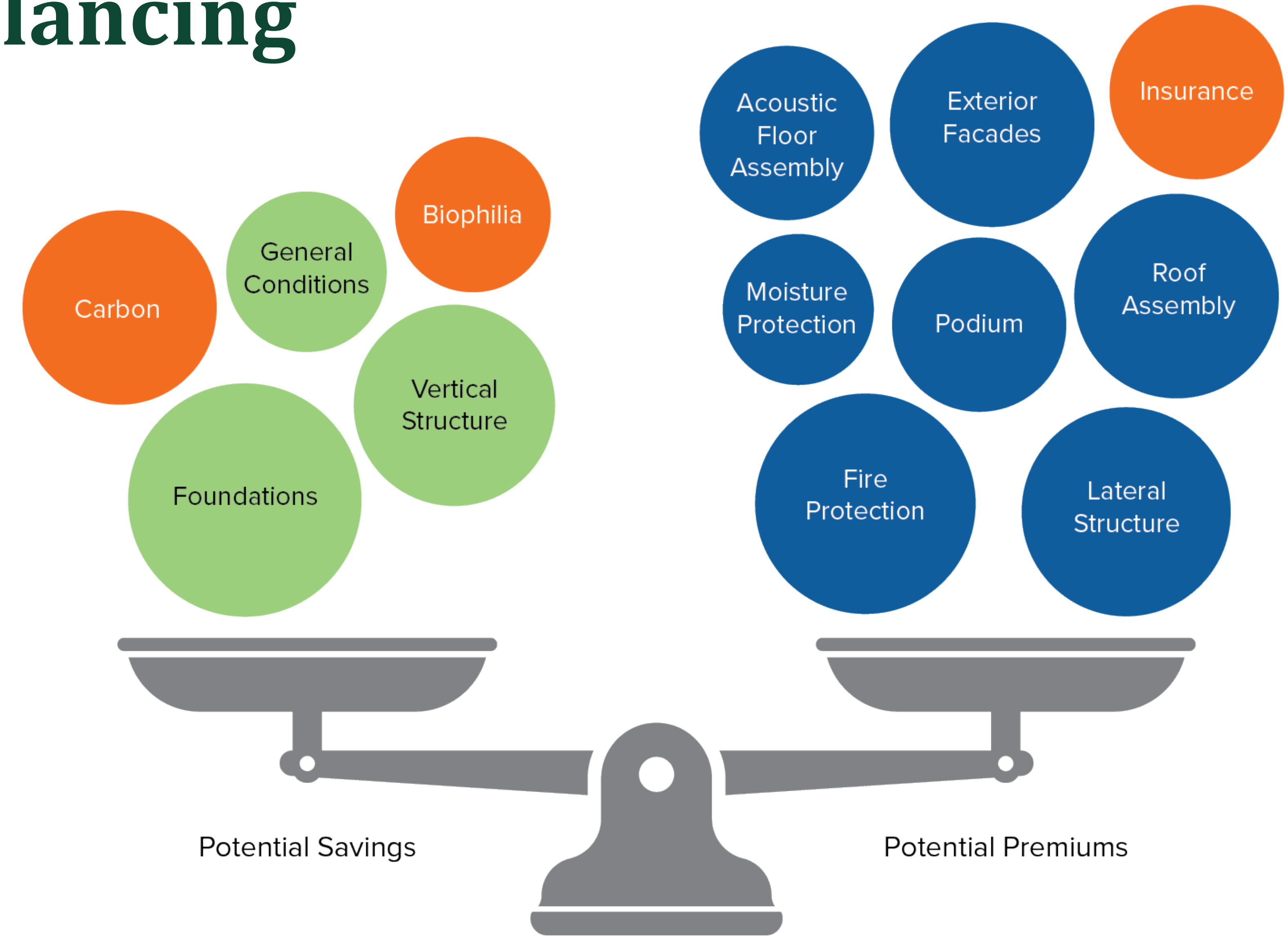
Risk Mitigation: Total Project Cost Analysis

CONSIDERATIONS:

- Ceiling Treatment
- Floor Topping
- HVAC System & Route
- Foundation Size
- Soil Improvements
- Exterior Skin Coordination
- Value of Time

Credit: Hacker Architects

Mass Timber Construction Cost Balancing



Do Your Homework

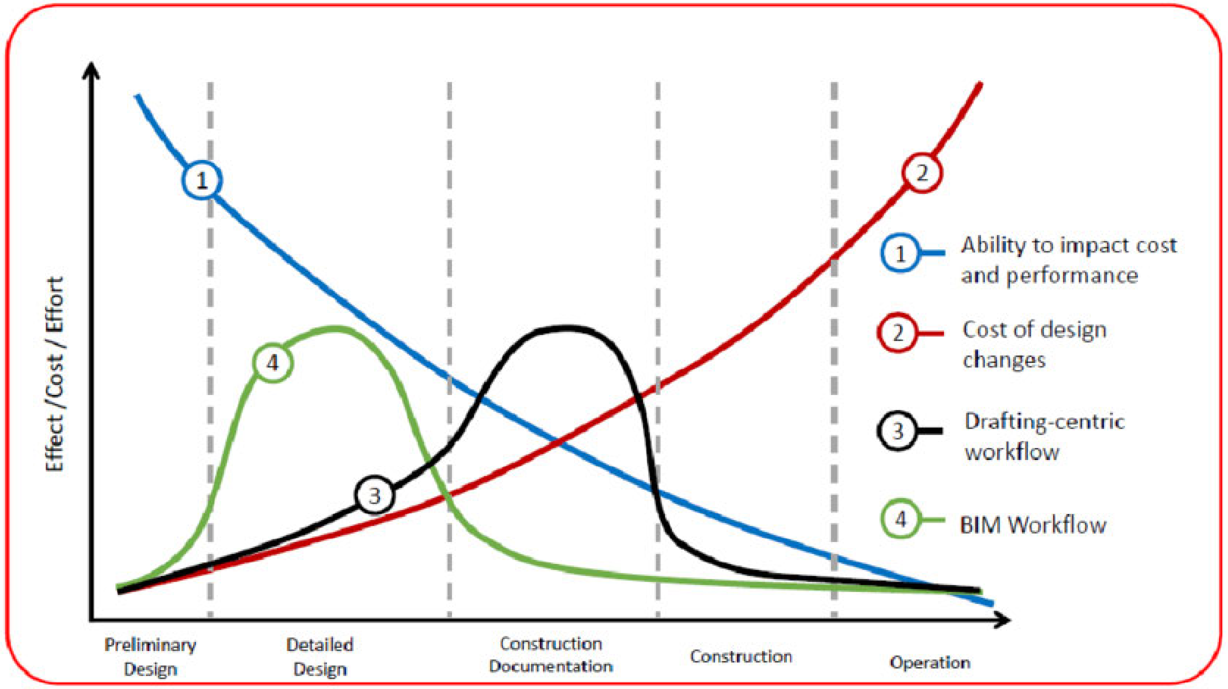
Factors Influencing Cost Estimation

Design Complexity: High impact on material and labor costs

Material Availability:

- Regional differences in availability and pricing
- Understand which suppliers and subcontractors are appropriate for your project and how best to use them

Procurement Model: Can impact the timber package price by as much as 30%—or more than 5% of total project hard costs



Manage Project Costs

Other Non-Timber Design Cost Levers

- Cost saving opportunities can be offset by increases in other areas of the construction budget.
- Compensating for these incremental increases and achieving real savings requires a focused effort to both actively leverage opportunities and minimize (in order of effect);

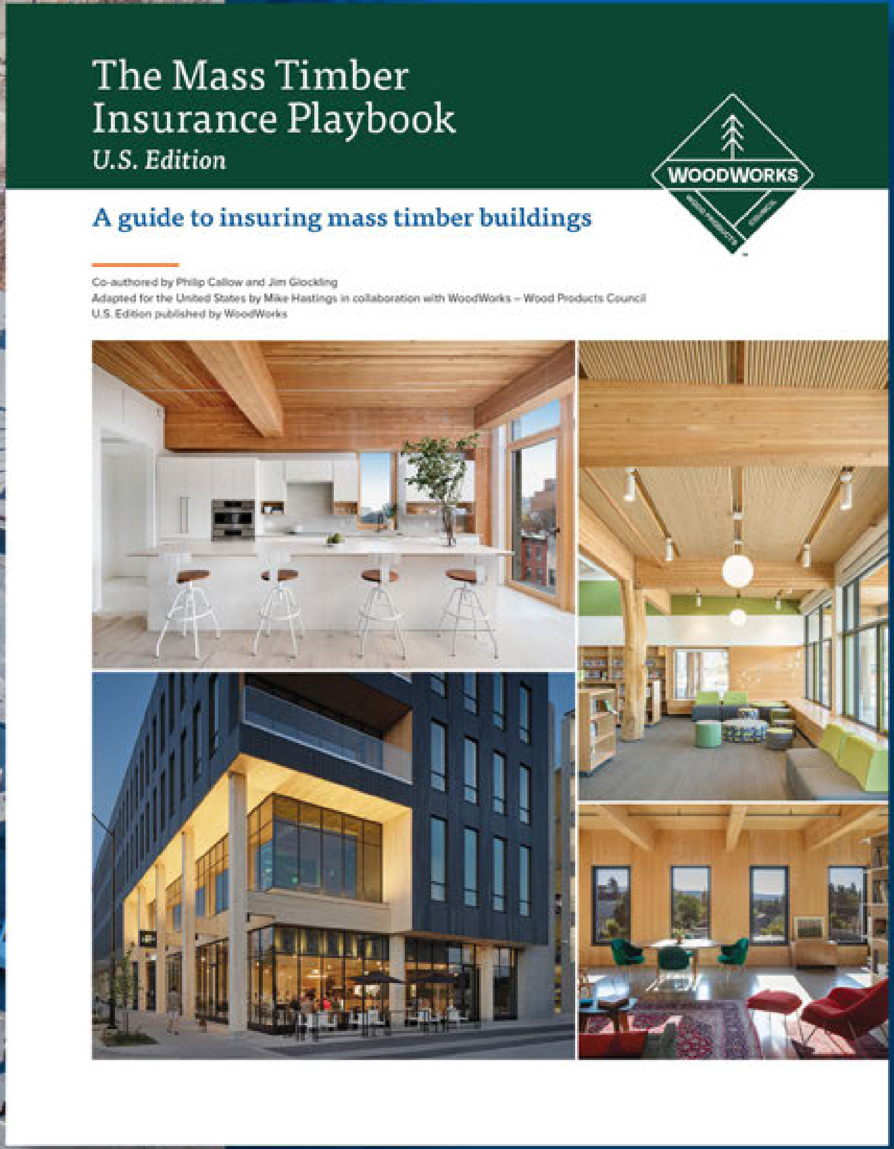
  Lateral systems
  Fire protection
  Acoustic floor assemblies
  Exterior facades

Wellesley College Science Complex / Skidmore, Owings & Merrill / Le Messurier / Photo Dave Burk © SOM

Healthy Buildings & Biophilia


George Fox University – Canyon Commons | Hacker | Photo: Jeremy Bittermann

11 E Lenox / Monte French Design Studio / H+O Structural Engineering
Photo H+O Structural Engineering



The Mass Timber Insurance Playbook

U.S. Edition

A guide to insuring mass timber buildings

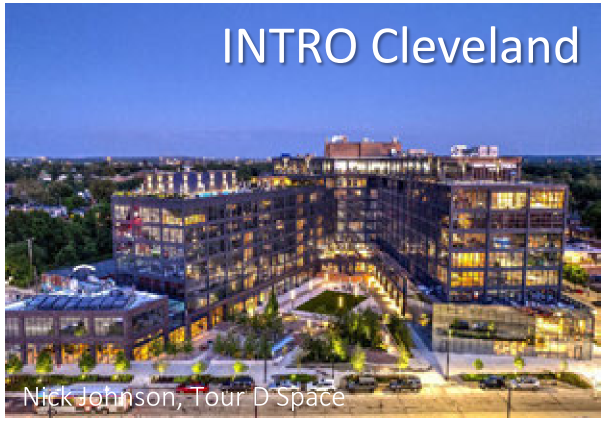
Co-authored by Philip Callow and Jim Glockling
Adapted for the United States by Mike Hastings in collaboration with WoodWorks – Wood Products Council
U.S. Edition published by WoodWorks

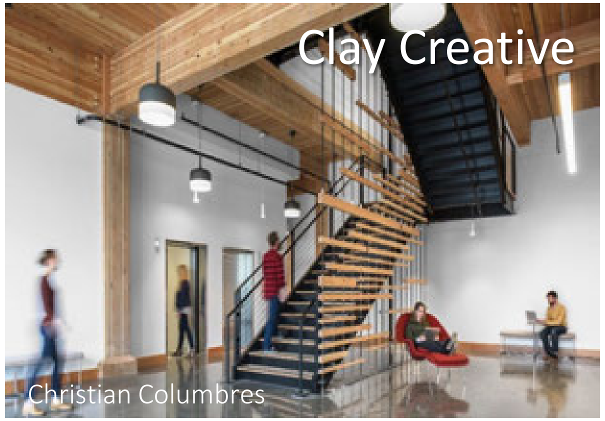
Labor Benefits

- Labor Shortage Solution
- Small crews for timber frame installation
- Utilize more entry-level laborers when MEPF systems fully designed, coordinated & pre-planned
- Safer construction sites

T3 Atlanta
Hartshorne Plunkard Architecture / DLR Group / StructureCraft / New South Construction /
Photo StructureCraft

Mass Timber Business Case Studies: Value Creation Analysis





Scan to download

WOODWORKS WOOD PRODUCTS COUNCIL

CONRAD INVESTMENT MANAGEMENT

INTRO, Cleveland

CLEVELAND, OH

Nick Johnson, Tour D Space

WOODWORKS™ WOOD PRODUCTS COUNCIL

Mass Timber Business Case Study

INTRO, Cleveland: Project Team

Developer
Harbor Bay Ventures

HARBOR BAY VENTURES

Investor Profile
Private Family Office

Lender Profile
First National Bank of Omaha
Busey Bank
First National Bank of Pennsylvania

Architect
Hartshorne Plunkard Architecture

HPA

Structural Engineer
Forefront Structural Engineers
Fast + Epp

FOREFRONT STRUCTURAL ENGINEERS, INC.

Fast+Epp

Contractor
Panzica Construction

PANZICA Construction

Nick Johnson, Tour D Space

Development Overview

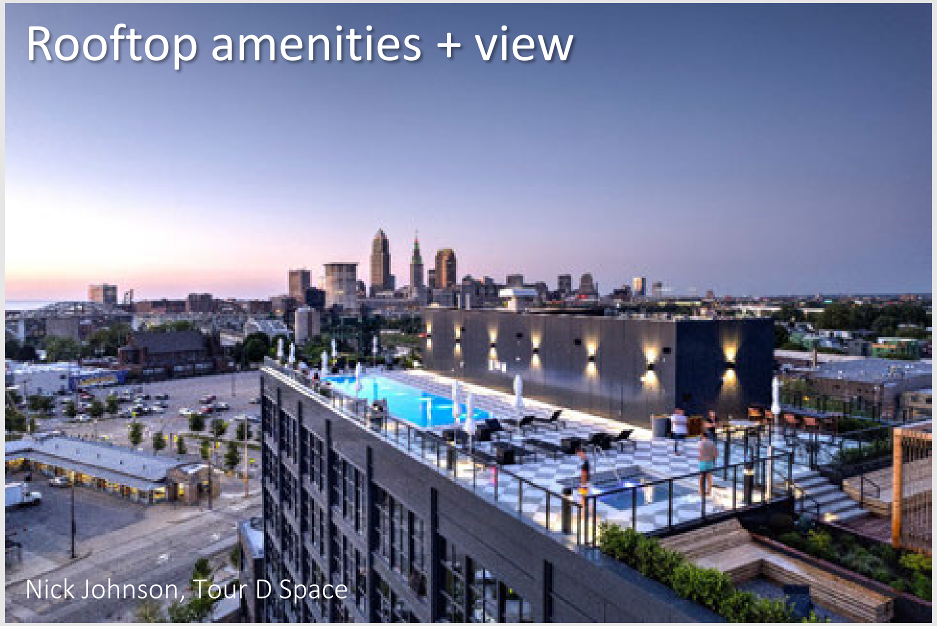
- 9-story, 115’ tall building
- 8 stories of CLT & glulam construction over a podium
- Strategy:
    - Create Cleveland's best, most distinctive urban living experience; a new level and bespoke brand
    - Combine best-in-city amenity package and contemporary interiors to appeal to health/ wellness & entertainment-focused young professionals

Property Information	
Property timing	Completed Feb 2022
Submarket	Cleveland’s Ohio City neighborhood
Construction Type	4-B over 1-A retail & parking
Site size	2.1 acres (FAR 5.5)
Gross building area	512,000 SF
Net rentable area (total)	279,000 SF

Nick Johnson, Tour D Space

Cleveland's Ohio City Market

- **Cleveland Economy:** driven by healthcare, manufacturing, food industry, & financial services
- **Neighborhood:** Ohio City is a destination neighborhood overlooking downtown with a trendy dining and entertainment scene along West 25th Street
- **Connectivity:** walk score of 83, connected to the Lakefront Bikeway, and is a 20-minute train ride to the airport



Quantitative Overview

Costs			
Total project cost	$147,000,000		
	$494,950/ unit		
Land Cost	$10,450,000	@ appraised value	
	Market Standard*	**Pro Forma**	**Realized****
Construction costs	$212 / GSF	$200 / GSF	$215 / GSF

NOI				
Apartment		**Market**	**Realized**	
Rental rates				
	Studio	$1,279	$1,500 -$1,750 (P.H. $2,000)	~26% higher
	1-BR	$1,631	$1,675 -$2,500 (P.H. $5,700)	~28% higher
	2-BR	$2,301	$2,500 -$5,200 (P.H. $7,800)	~67% higher
	3-BR	$3,334	$8,800 -$19,500 P.H.	~324% higher
Occupancy at stabilization		91%	98%	~7% higher
Parking Revenue		**Market**	**Pro Forma**	**Realized****
Included or in addition to lease?		Additional	Additional	Additional
Rate		$175 / lot / month	$185 -$200 / lot / month	$225 -$375 / lot / month
Retail		**Market**	**Pro Forma**	**Realized****
Retail rental rates		$30 -$40 / RSF/YR	$45 / RSF/YR	$45 / RSF/YR
Rent type (e.g., NNN)		NNN & Gross	NNN	NNN
Expenses		$7 -$10 / RSF/YR	$8 / RSF/YR	$8 / RSF/YR
Tenant improvement allowance		$40 -$50 / RSF	$150 / RSF	$150 / RSF
Occupancy after 12 months		60% -70%	90%	75%

**Market standard costs refer to normal cost to build for subject's use, irrespective of structural approach.*
***Realized metrics at stabilization*
****Conversations with local building officials were held concurrent to land use entitlement approvals processes such that the overall building code review process was only slightly longer. This concurrent approach was essential given that Ohio was not adopting the 2021 IBC, so the Type 4 code path was performance-based, albeit a mirror of what other states have adopted.*

Return Performance	Market	Pro Forma	Realized**	
Yield on cost – untrended	6.25%	7.00%	7.35%	Higher
Cap rate	4.75%	4.50%	TBD	
Value/rentable SF	$550 / RSF	$717 / RSF	TBD ($800+ / RSF)	Higher
Leverage	65%	65%	N/A	

Timeline	Date	Context/Comment
Date of conception (first dollar spent)	Mid 2018	Mid-cycle
Date underwriting finalized (go/no-go decision)	Mid 2019	Mid-cycle
Date equity capital secured	N/A	Developer is equity
Permitting duration***	3 + 6 mo.	Demolition permit first, then building permit
GMP in place	Feb/March 2020	COVID
Construction start	April 2020	
Duration of construction	24 months	Faster by about 2 months
Construction completed	April 2022	Early-cycle
Date stabilized (80% occupancy, NOI, or at pro forma or refinanced)	June 2022	Faster

Project Context

Unparalleled leasing velocities at significant premiums

- The project was 90% leased 4 months after completion
- The premium product drives both velocity and rates with rents significantly higher than market counterparts
- Leasing velocity allowed refinancing activities to start 3 months after completion

Unparalleled leasing velocities at significant premiums

Disclaimer: Information herein was provided by the developer and verified for reasonableness by a third-party expert. Market data and figures have been reviewed by an independent third party utilizing industry standard resources. For additional sources and disclaimers, see the *Basis of Information* page for this case study and the *Disclosures, Disclaimers and Confidentiality* page at the end of this case study package.

Exceptional Leasing Velocity and Premiums

Lessons Learned

- **Schedule Savings:** Anticipated schedule savings not fully achieved - subcontractors had not shifted approaches
- **Critical paths:** Exterior cladding system required multiple subcontractors & erection did not keep up w/ speed of timber structure; faster (unitized) skin would be better

Challenges

- **International shipping**: Issues during COVID delayed delivery; assurances compromised by lowest cost bid
- **Moisture Protection:** Laborious repairs required due to insufficient water management

Successes

- **Fast lease-up**: 60% pre-leased & stabilized after 4 months
- **Premiums**: Achieved rent premiums in market

Nick Johnson, Tour D Space

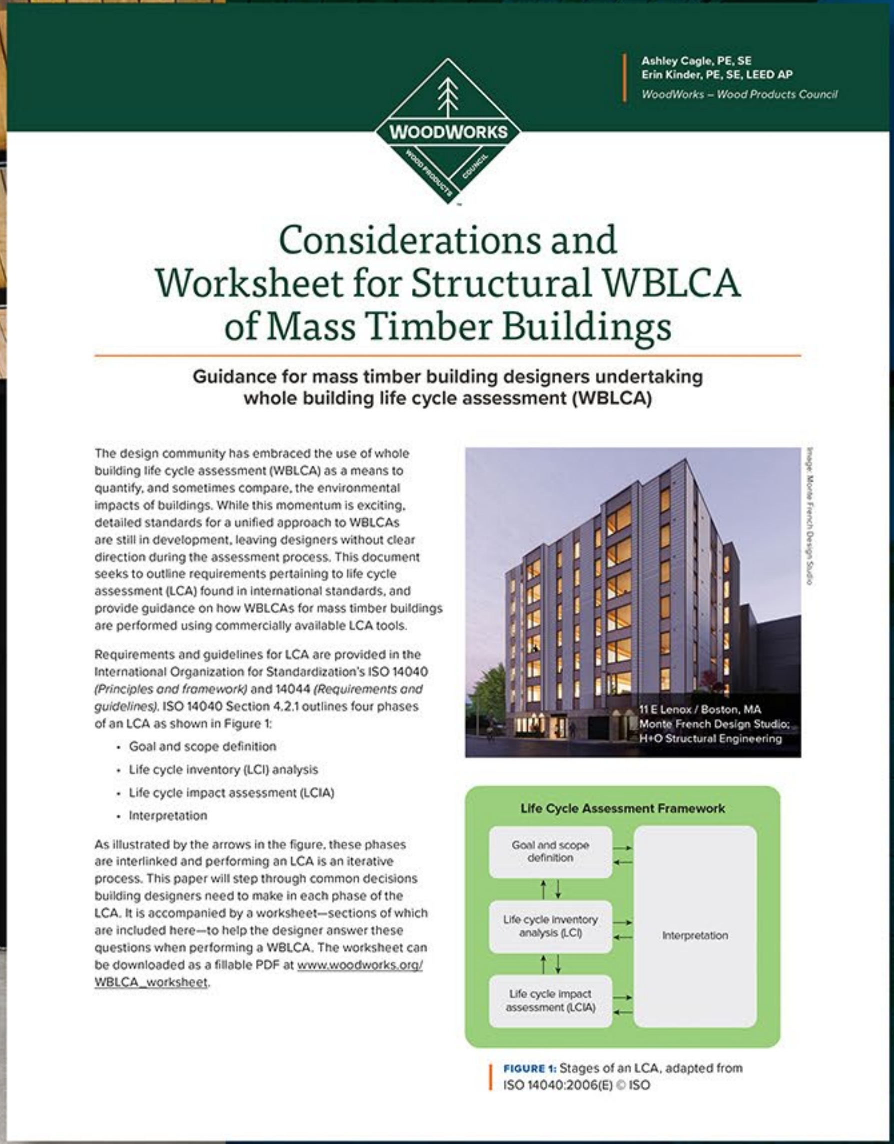
EXPERT TIP

Mass Timber Moisture Management for Construction

Photo RDH Building Science

Strategies for managing the unique moisture risks of mass timber building projects

https://www.woodworks.org/resources/mass-timber-moisture-management-for-construction/



Ashley Cagle, PE, SE
Erin Kinder, PE, SE, LEED AP
WoodWorks – Wood Products Council

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.

Image: Monte French Design Studio

11 E Lenox / Boston, MA
Monte French Design Studio;
H+O Structural Engineering

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

Nez Perce-Clearwater National Forests Supervisor's Office / Kamiah, IDMosiac Architecture; Morrison-Maierle

https://www.woodworks.org/resources/considerations-and-worksheet-for-structural-wblca-of-mass-timber-buildings/

WoodWorks Resources

Whole Building Life Cycle Assessment (WBLCA)

- Introduction to Whole Building Life Cycle Assessment: The Basics
- Worksheet for Structural WBLCA of Mass Timber Buildings
- WBLCAs of Built Projects

Expert articles on topics such as:

- Biogenic Carbon in LCA Tools
- Long-Term Biogenic Carbon Storage
- What Net Zero Means in Building Construction
- Environmental Product Declarations (EPDs)

Scan for a complete list of sustainability resources at woodworks.org

Photo: DPR Office, SmithGroup, photo Chad Davies

Credits for Sustainable/ Well Certifications

LEED v4.1 BD+C

Indoor Environmental Air Quality

- Low-Emitting Materials
  Thermal Comfort

Materials & Resources

- Environmental Product Declarations
- Responsible Sourcing of Raw Materials
- Building Life-Cycle Impact Reduction
- Construction & Demolition Waste Management

Passive House 3rd Edition

Core Principles

- Thermal Insulation
- Thermal Bridge Reduced Design
- Airtightness

WELL v2

Materials

- Materials Transparency

Mind

- Nature & Place
- Restorative Spaces

Thermal Comfort

- Thermal Performance
- Verified Thermal Comfort

Living Building Challenge 4.0

Energy Petal

- Energy + Carbon Reduction
- Net Positive Carbon

Materials Petal

- Responsible Materials
- Responsible Sourcing
- Living Economy Sourcing
- Red List
- Net Positive Waste

Beauty Petal

- Beauty + Biophilia

Source: Mercer Mass Timber and The Environment

Life Cycle Assessment (LCA)

"Evaluation of the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle"

- Systematic, scientific **quantification**

Used for:

- Single products or processes: e.g., a wood product
- Complex, integrated systems: e.g., an entire building (**WBLCA**)

https://www.woodworks.org/resources/introduction-to-whole-building-life-cycle-assessment-the-basics/

Source: ISO 21930:2017(E), 3.3.2

Life Cycle Assessment (LCA)

"Evaluation of the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle"

Environmental Impacts:

- Global Warming Potential (GWP)
- Ozone depletion
- Smog formation
- Acidification
- Eutrophication
- Depletion of nonrenewable resources
- Etc.

Source: ISO 21930:2017(E), 3.3.2

Global Warming Potential (GWP)

- Allows comparisons of different **greenhouse gases (GHGs)**
- How much energy 1 ton of a gas will absorb over 100 years relative to 1 ton of carbon dioxide (CO_2)

	GWP
Carbon Dioxide (CO_2)	1
Methane (CH_4)	28-36
Nitrous Oxide (N_2O)	265-298
Fluorinated Gases	Thousands to Tens of Thousands

- Reported in **carbon dioxide equivalents (CO_{2eq})**

Life Cycle

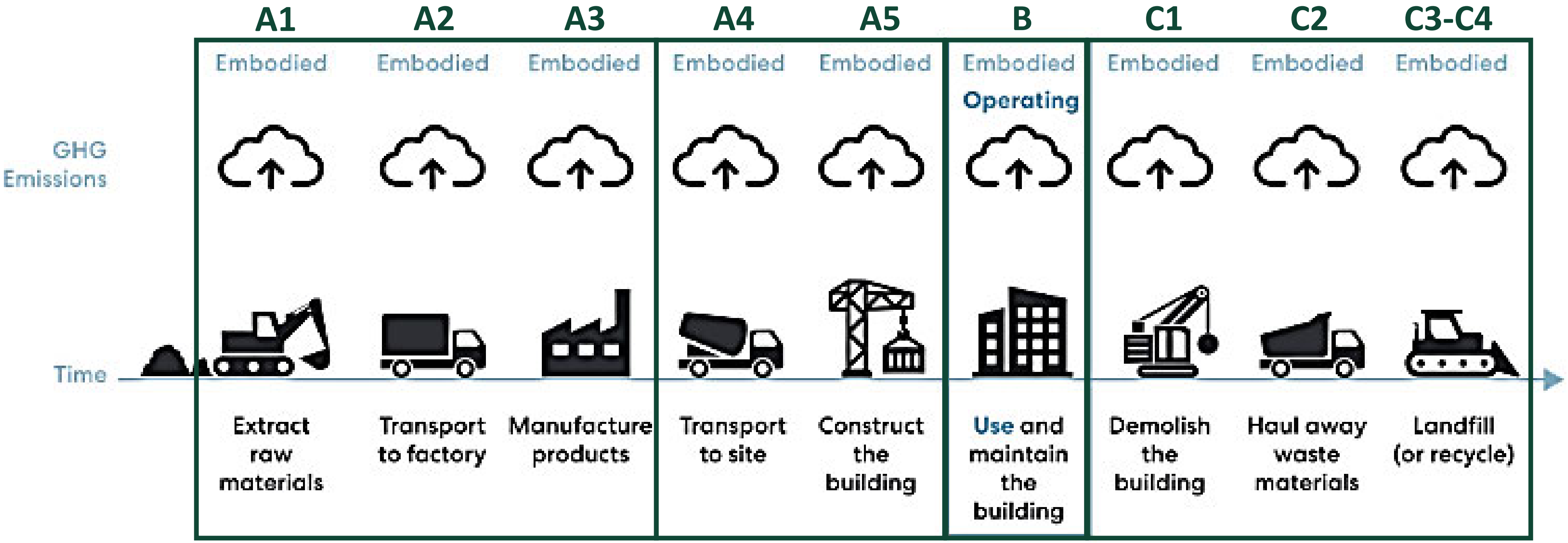
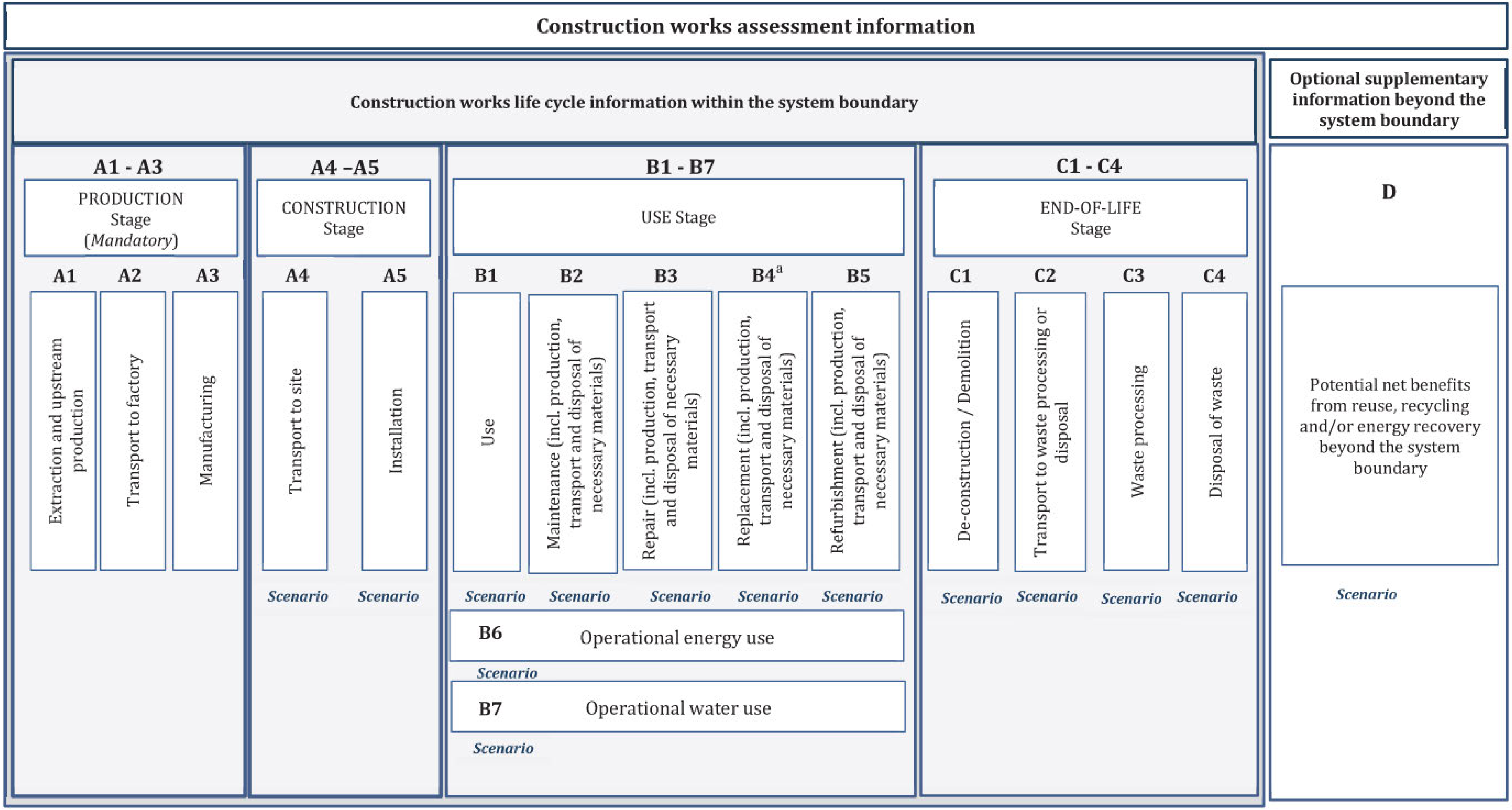


Image: Think Wood

What makes wood different?



[a] Replacement information module (B4) not applicable at the product level.

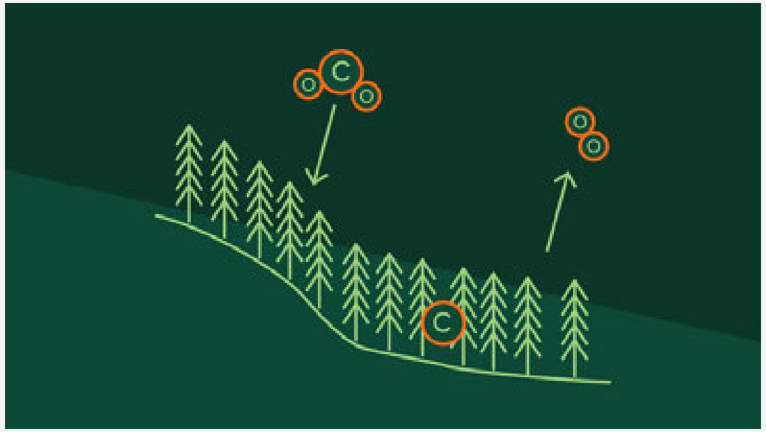
Source: ISO 21930:2017(E), Figure 2

Biogenic Carbon

"**<u>Carbon derived from... material of biological origin</u>** excluding material embedded in geological formations or transformed to fossilized material and excluding peat."

Photosynthesis:

$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6\ \text{(stored)} + 6\ O_2\ \text{(released)}$$



Source: ISO 21930:2017(E), 3.7

Carbon Storage

Wood ≈ **50% Carbon** (dry weight)

Image: Kaiser + Path

Image: Lever Architecture

Carbon Storage Calculation

Douglas-Fir-Larch:

1 ft^3 = 34.5 lb (15% MC)

= 30.0 lb (dry)

50% Carbon by dry weight:

1 ft^3 = 15 lb Carbon stored

Carbon vs CO_2

+ 2 *

= 44 CO_2

1 lb Carbon ≠ 1 lb CO_2

1 lb Carbon = (44/12=) **<u>3.67</u> lb CO_2**

Carbon Storage Calculation

Douglas-Fir-Larch:

1 ft^3 = 34.5 lb (15% MC)

= 30.0 lb (dry)

50% Carbon by (dry) weight:

1 ft^3 = 15 lb Carbon stored

1 lb Carbon converts to 3.67 lb CO_2:

1 ft^3 = 55 lb CO_2

https://www.woodworks.org/resources/calculating-the-carbon-stored-in-wood-products/

Should I include biogenic carbon?

Biogenic Carbon

"Bio-based materials originating from renewable resources (such as wood…) contain biogenic carbon."

- Biogenic carbon removals and emissions **shall be reported** as CO_2 in the LCI
- When entering the product system (**removal**), characterized with a factor of **-1**
- When converted to emissions (**emission**), characterized with a factor of **+1**
- When leaving the product system (**export**), characterized with a factor of **+1**

https://www.woodworks.org/resources/when-to-include-biogenic-carbon-in-an-lca/

Source: ISO 21930:2017(E), 7.2.7

Biogenic Carbon Accounting

Biogenic Carbon

"For wood, biogenic carbon may be characterized with a -1… when entering the product system **only when the wood originates from sustainably managed forests.**"

Source: ISO 21930:2017(E), 7.2.7

Biogenic Carbon

“For wood, biogenic carbon may be characterized with a -1… when entering the product system **only when the wood originates from sustainably managed forests.**”

So…

What is a sustainably managed forest?

Source: ISO 21930:2017(E), 7.2.7

Sustainably Managed Forests

"… zero emissions associated with land use change"

Option 1:

Includes wood products *responsibly sourced and certified* to:

- » **Standards** globally endorsed by PEFC and FSC
- » FSC, SFI, CSA, ATFS, etc.

This includes "responsible sourcing" standards and does not require that all wood come from certified forests.

Option 2: (NOTE 2)

- » "The concept of sustainably managed forests is linked but not limited to respective certification schemes"
- » Evidence such as national reporting under UNFCCC to identify forests with stable or increasing forest carbon stocks

Source: ISO 21930:2017(E), 7.2.11

Sustainably Managed Forests

"… zero emissions associated with land use change"

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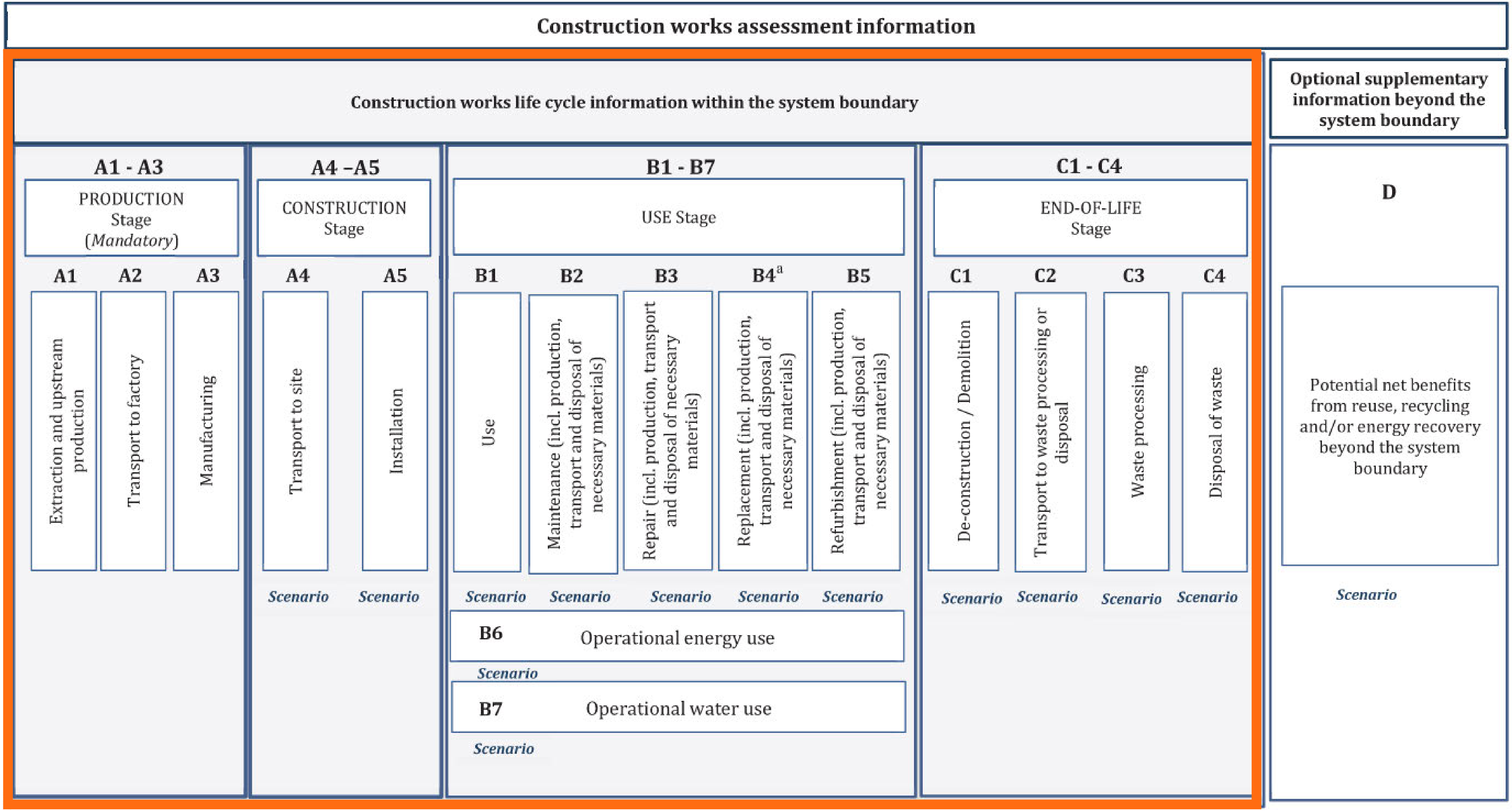
https://www.woodworks.org/resources/when-to-include-biogenic-carbon-in-an-lca/

Source: ISO 21930:2017(E), 7.2.11

Should I include biogenic carbon?

Should I include biogenic carbon?

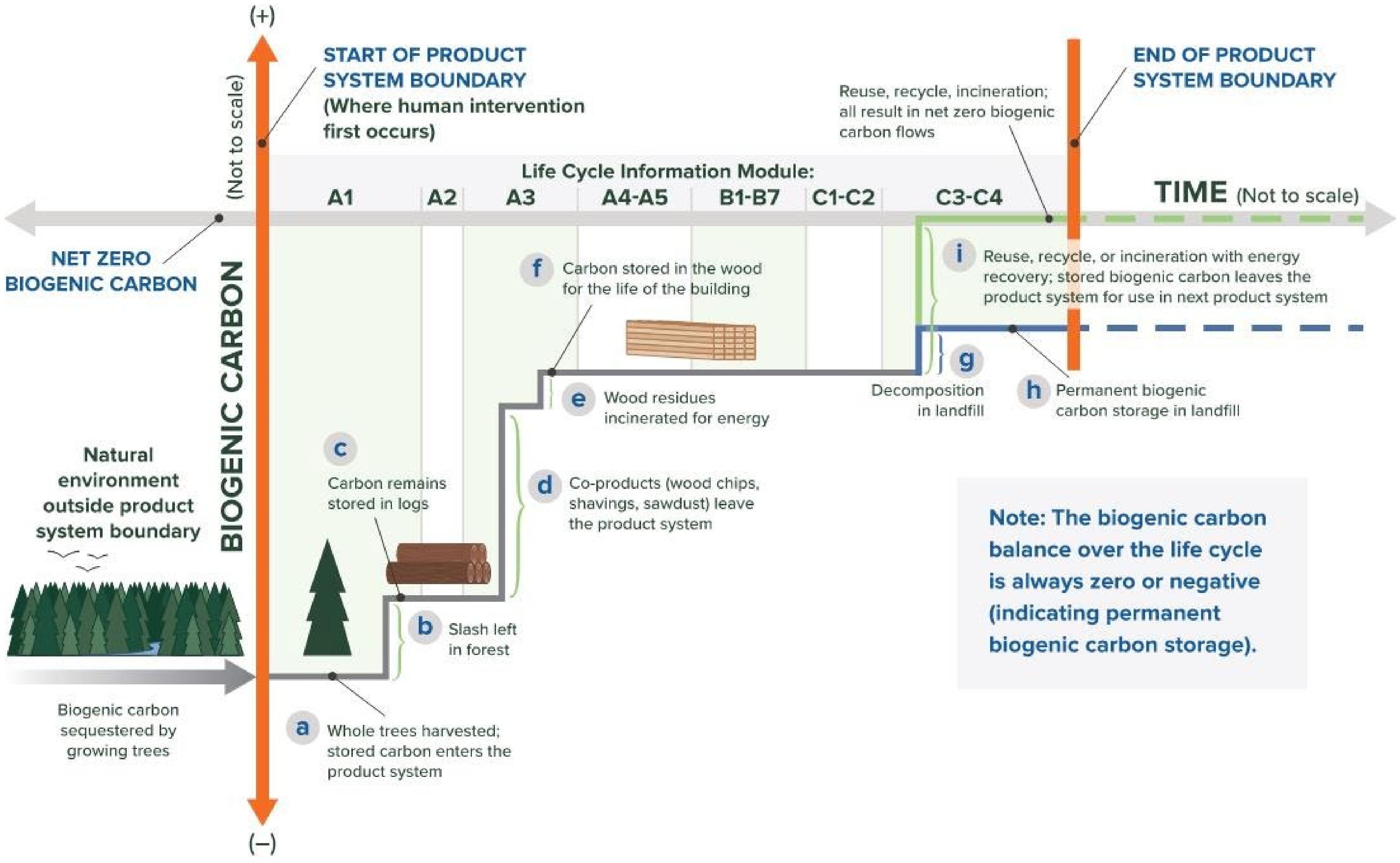
Yes! But how?



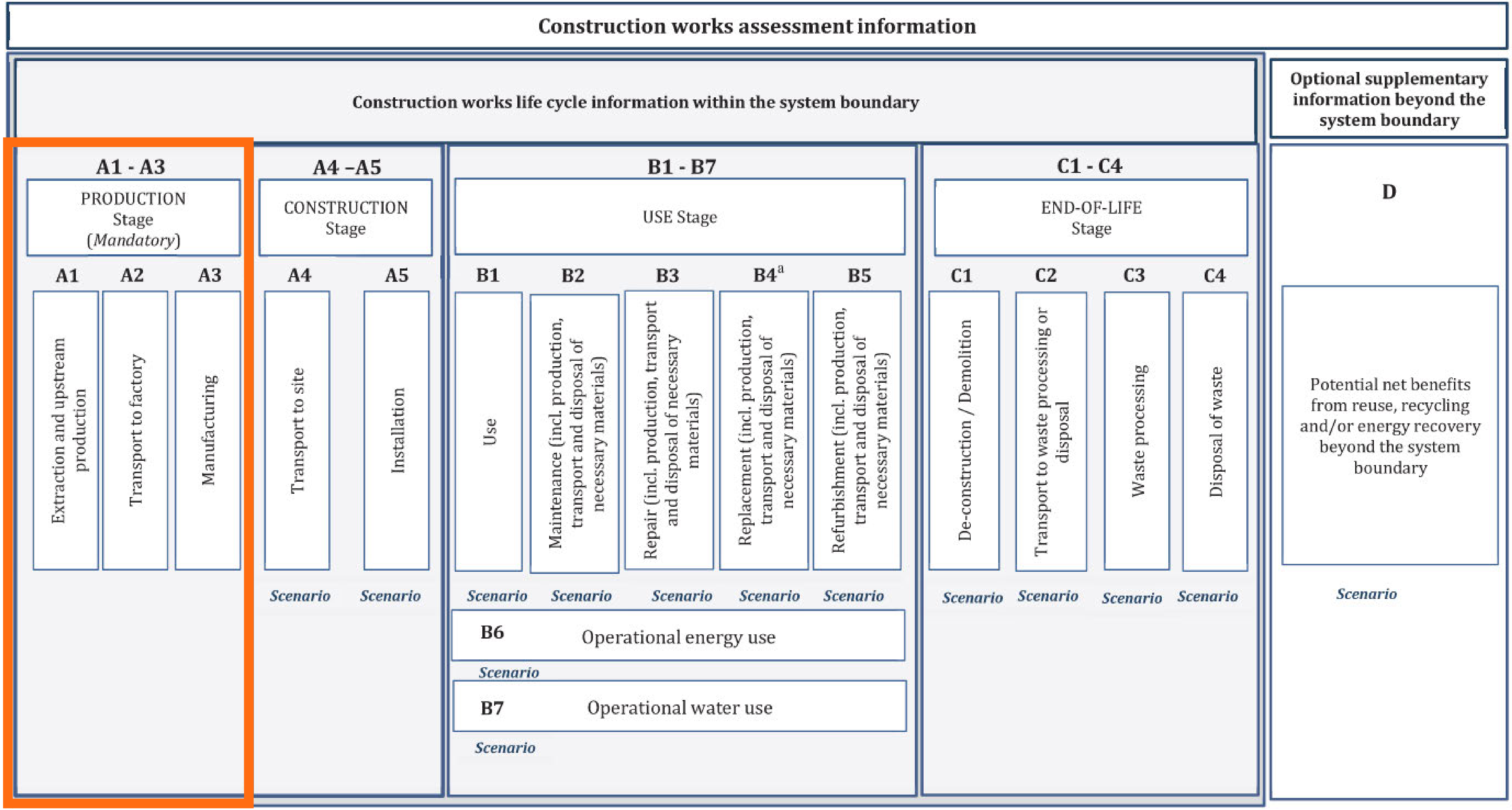
[a] Replacement information module (B4) not applicable at the product level.

Source: ISO 21930:2017(E), Figure 2

BIOGENIC CARBON FLOWS



https://www.woodworks.org/resources/how-to-include-biogenic-carbon-in-an-lca/



[a] Replacement information module (B4) not applicable at the product level.

Source: ISO 21930:2017(E), Figure 2

Production Stage: A1-A3

A1: Extraction and upstream production

- Raw material extraction or harvest

A2: Transport to factory

- Transportation of raw materials to the mill or factory

A3: Manufacturing

- Manufacturing of the product itself

A1-A3 is often called cradle-to-gate

A1 for Wood Products

Starts at **first point of human intervention**

A1: Extraction and upstream production

» Raw material extraction or harvest

A2: Transport to factory

» Transportation of raw materials to the factory or mill

A3: Manufacturing

» Manufacturing of the product itself

Includes:

- Forest road construction
- Fertilization
- Precommercial thinning
- Harvest (felling, skidding)
- Slash burning
- Growing seedlings (greenhouse operations)
- Planting seedlings

A1 for Wood Products

Starts at **first point of human intervention**

A1: Extraction and upstream production

» Raw material extraction or harvest

A2: Transport to factory

» Transportation of raw materials to the factory or mill

A3: Manufacturing

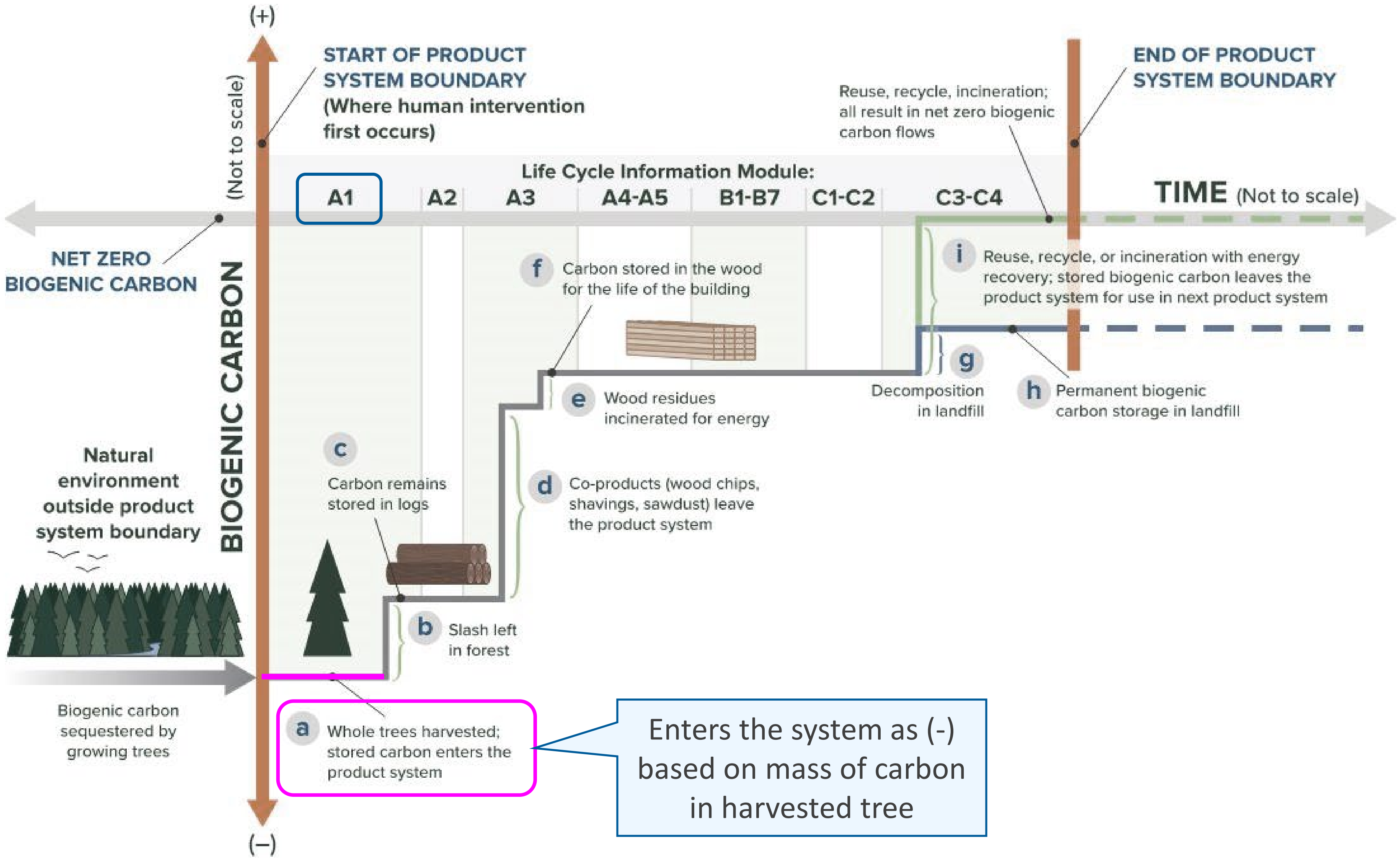
» Manufacturing of the product itself

Includes:

- Forest road construction
- Fertilization
- Precommercial thinning
- Harvest (felling, skidding)
- Slash burning
- Growing seedlings (greenhouse operations)
- Planting seedlings

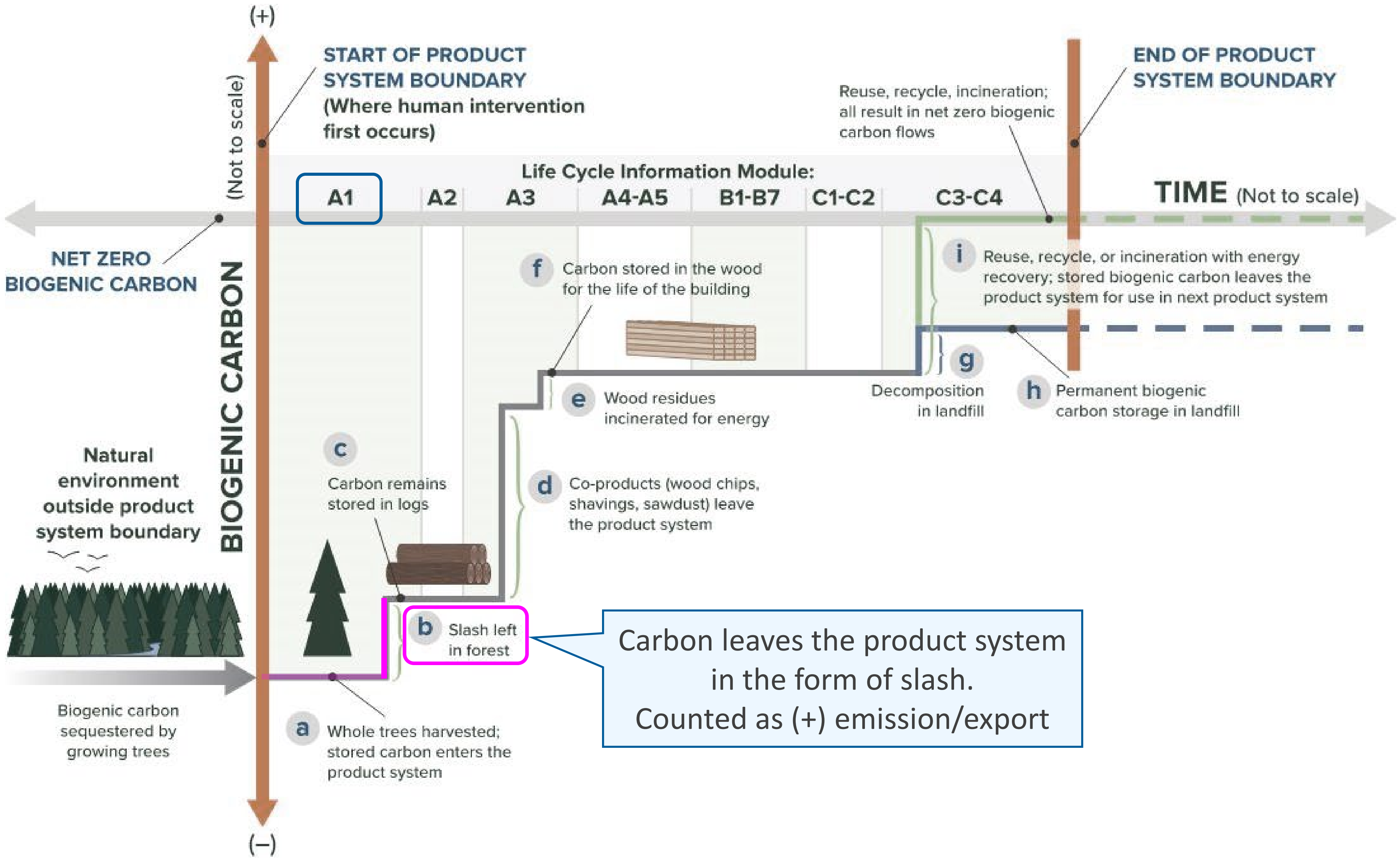
Biogenic carbon **enters** the product system as a carbon ***removal*** (-1).

BIOGENIC CARBON FLOWS



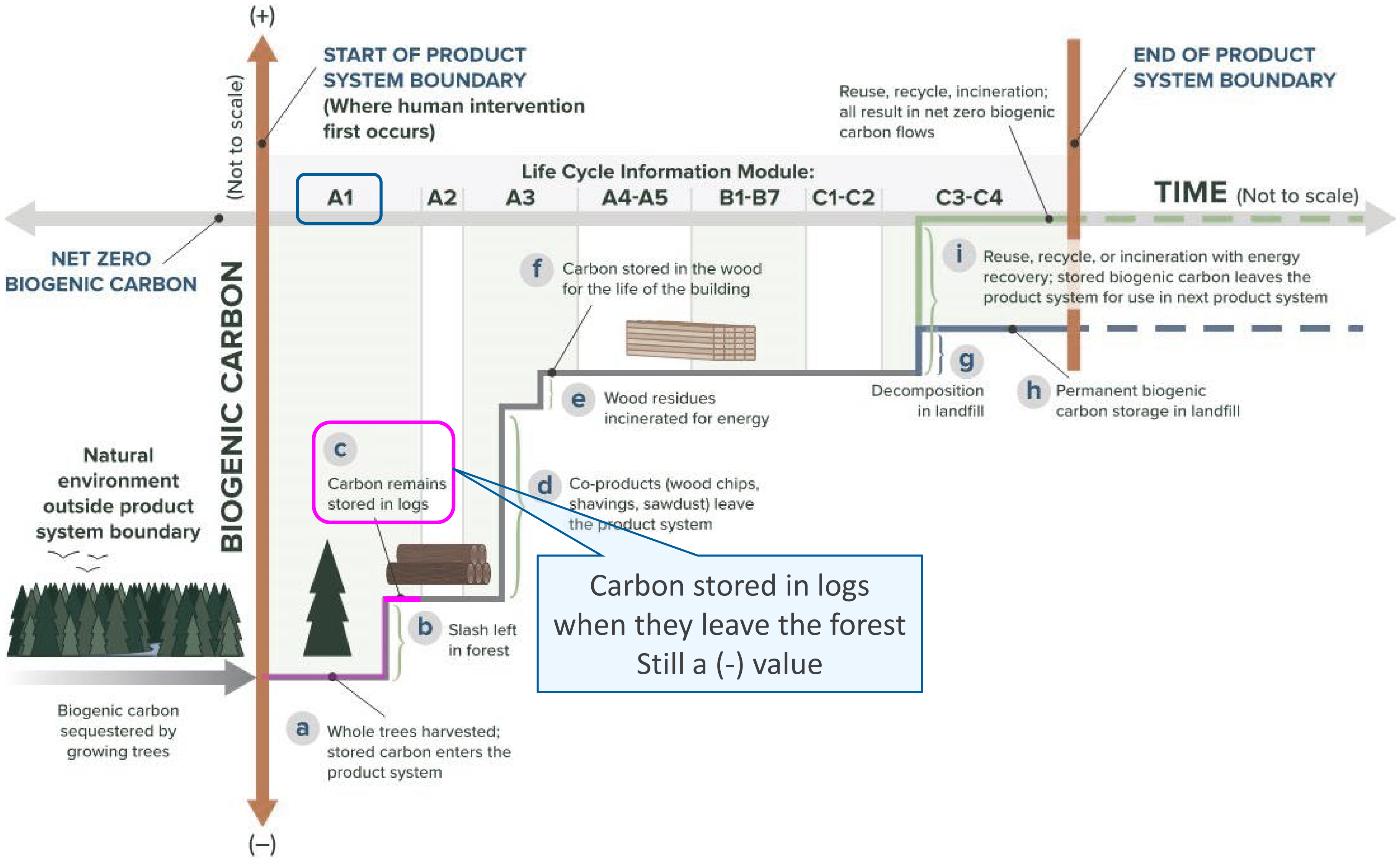
Enters the system as (-) based on mass of carbon in harvested tree

BIOGENIC CARBON FLOWS



Carbon leaves the product system in the form of slash.
Counted as (+) emission/export

BIOGENIC CARBON FLOWS



Carbon stored in logs when they leave the forest
Still a (-) value

A2 for Wood Products

A1: Extraction and upstream production

» Raw material extraction or harvest

A2: Transport to factory

» Transportation of raw materials to the mill or factory

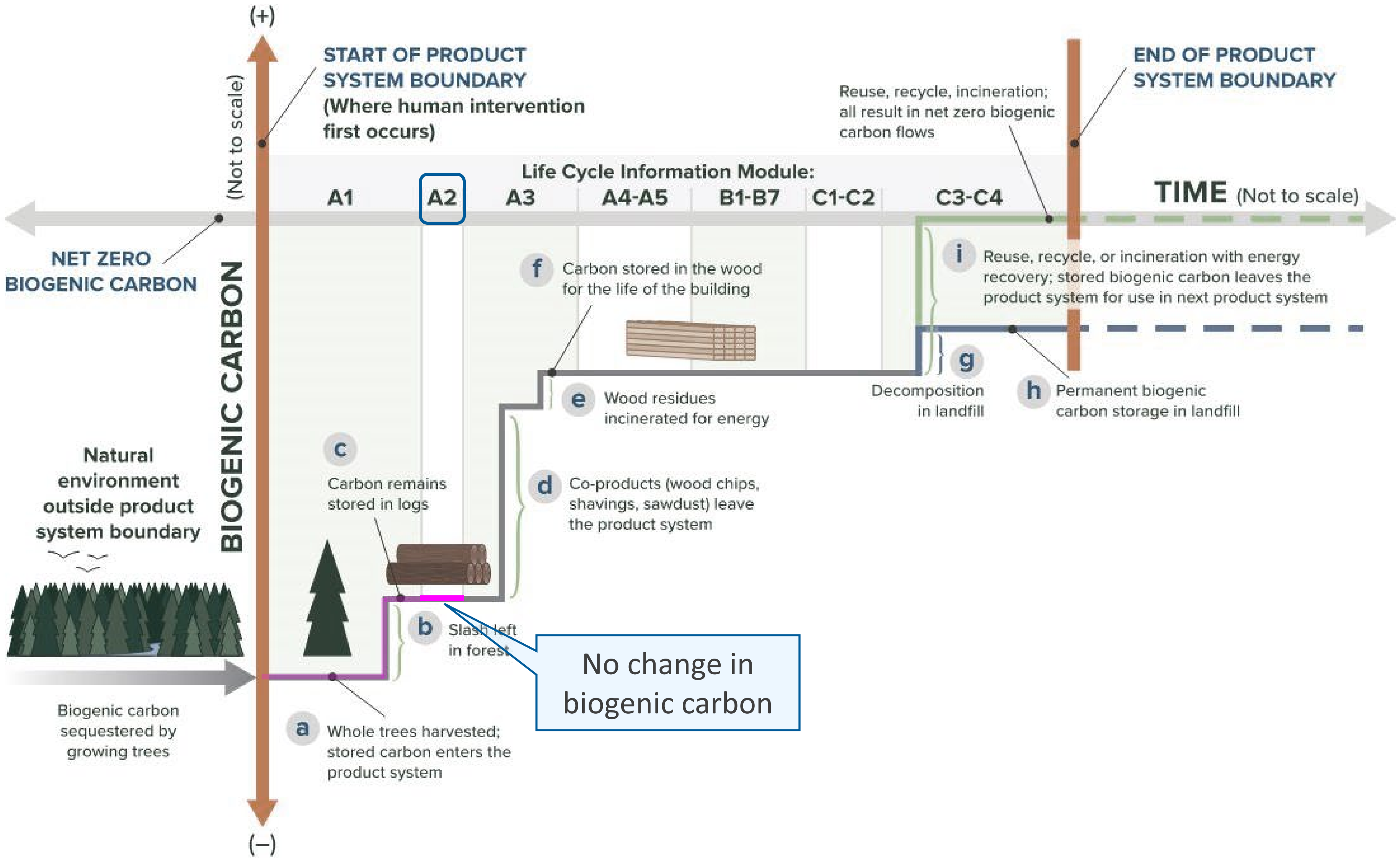
Diesel powered trucks

A3: Manufacturing

» Manufacturing of the product itself

No biogenic carbon flows

BIOGENIC CARBON FLOWS



A3 for Wood Products

A1: Extraction and upstream production

» Raw material extraction or harvest

A2: Transport to factory

» Transportation of raw materials to the mill or factory

A3: Manufacturing

» Manufacturing of the product itself

Includes:

- Debarking logs
- Sawing logs into rough sawn lumber
- Drying lumber
- Planing to final size
- Additional manufacturing and fabrication as required

A3 for Wood Products

A1: Extraction and upstream production

» Raw material extraction or harvest

A2: Transport to factory

» Transportation of raw materials to the mill or factory

A3: Manufacturing

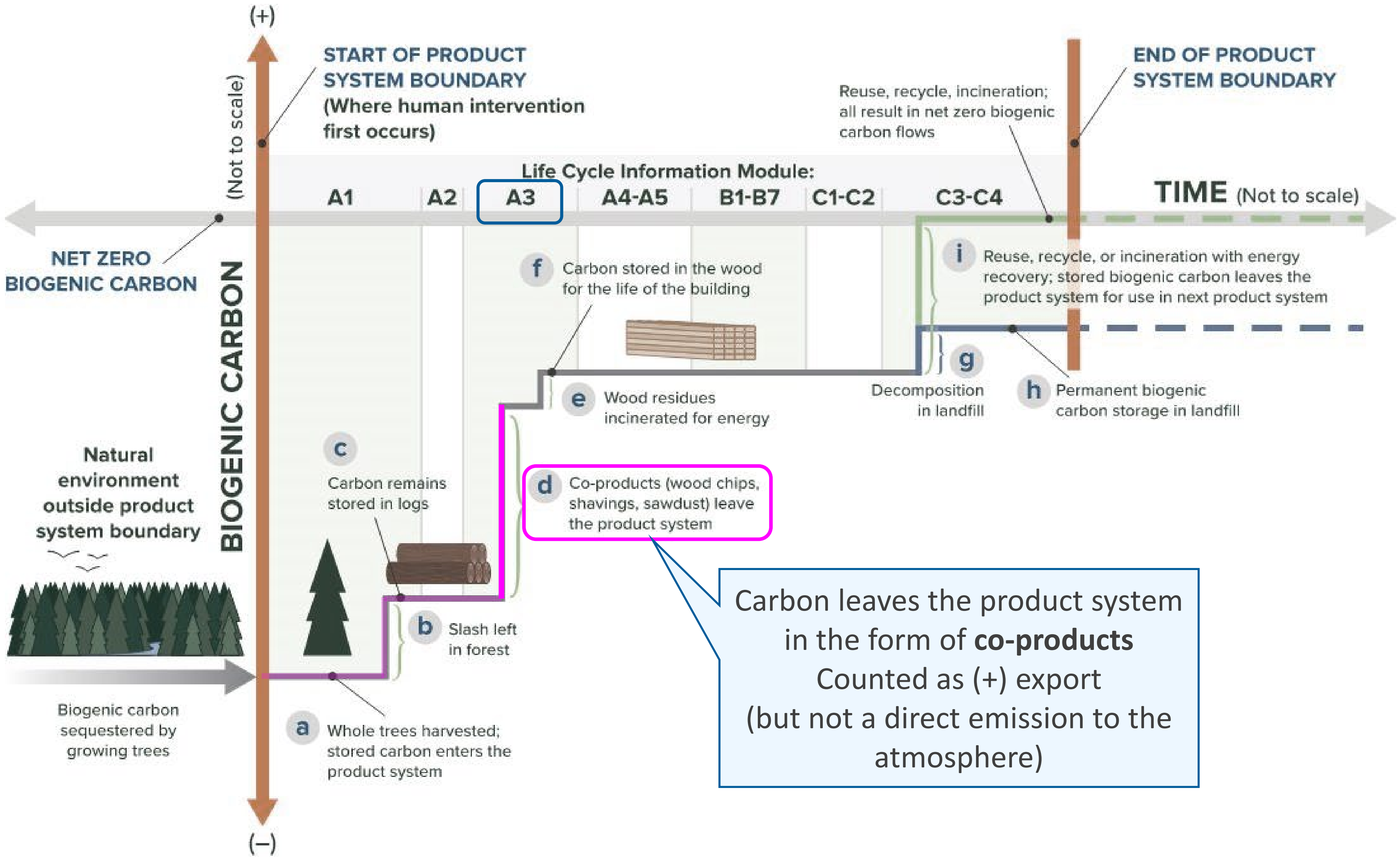
» Manufacturing of the product itself

Includes:

- Debarking logs
- Sawing logs into rough sawn lumber
- Drying lumber
- Planing to final size
- Additional manufacturing and fabrication as required

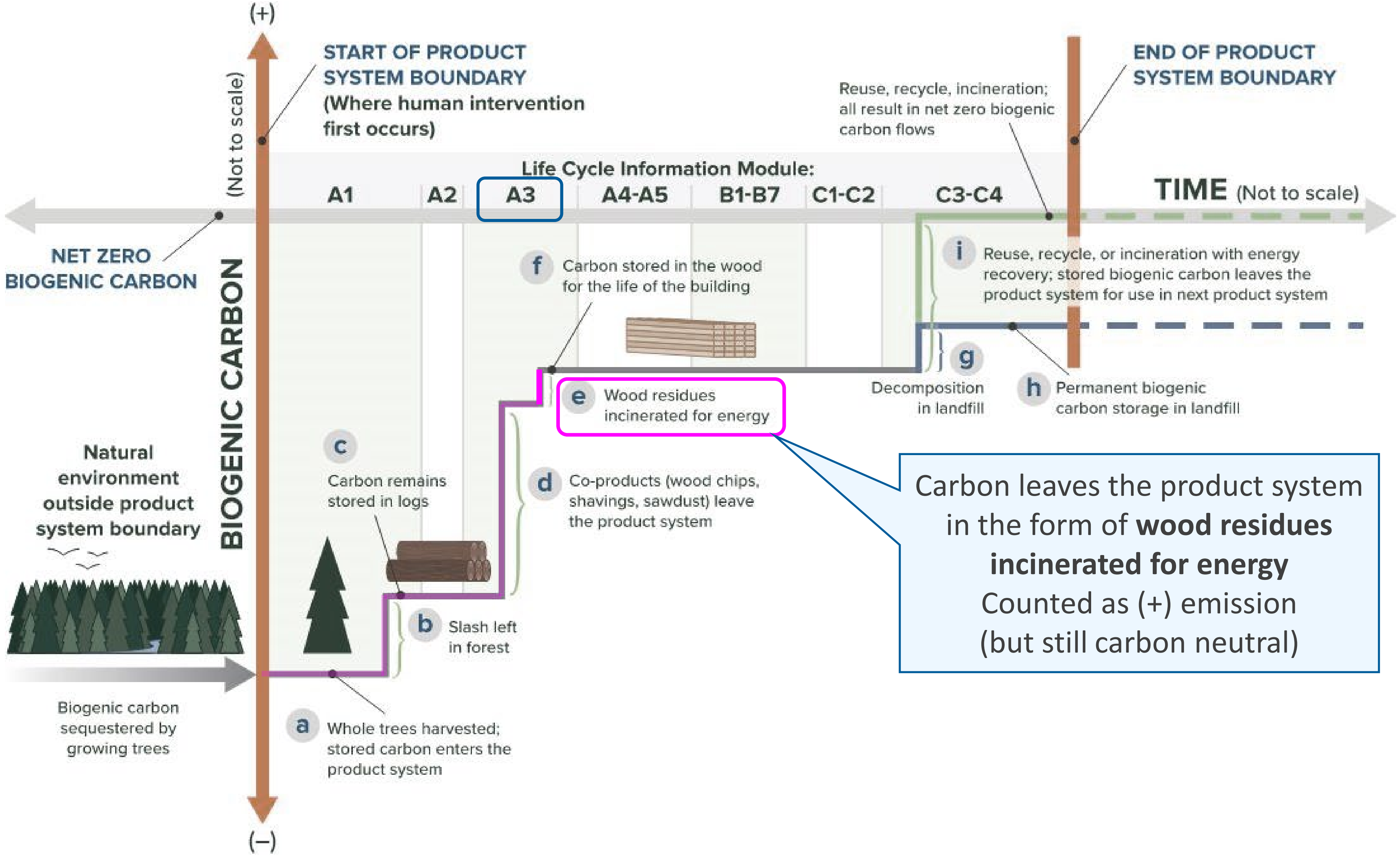
Biogenic carbon **leaves** the product system as co-products (***export***) and residues incinerated for energy (***emission***). Both are counted as +1.

BIOGENIC CARBON FLOWS



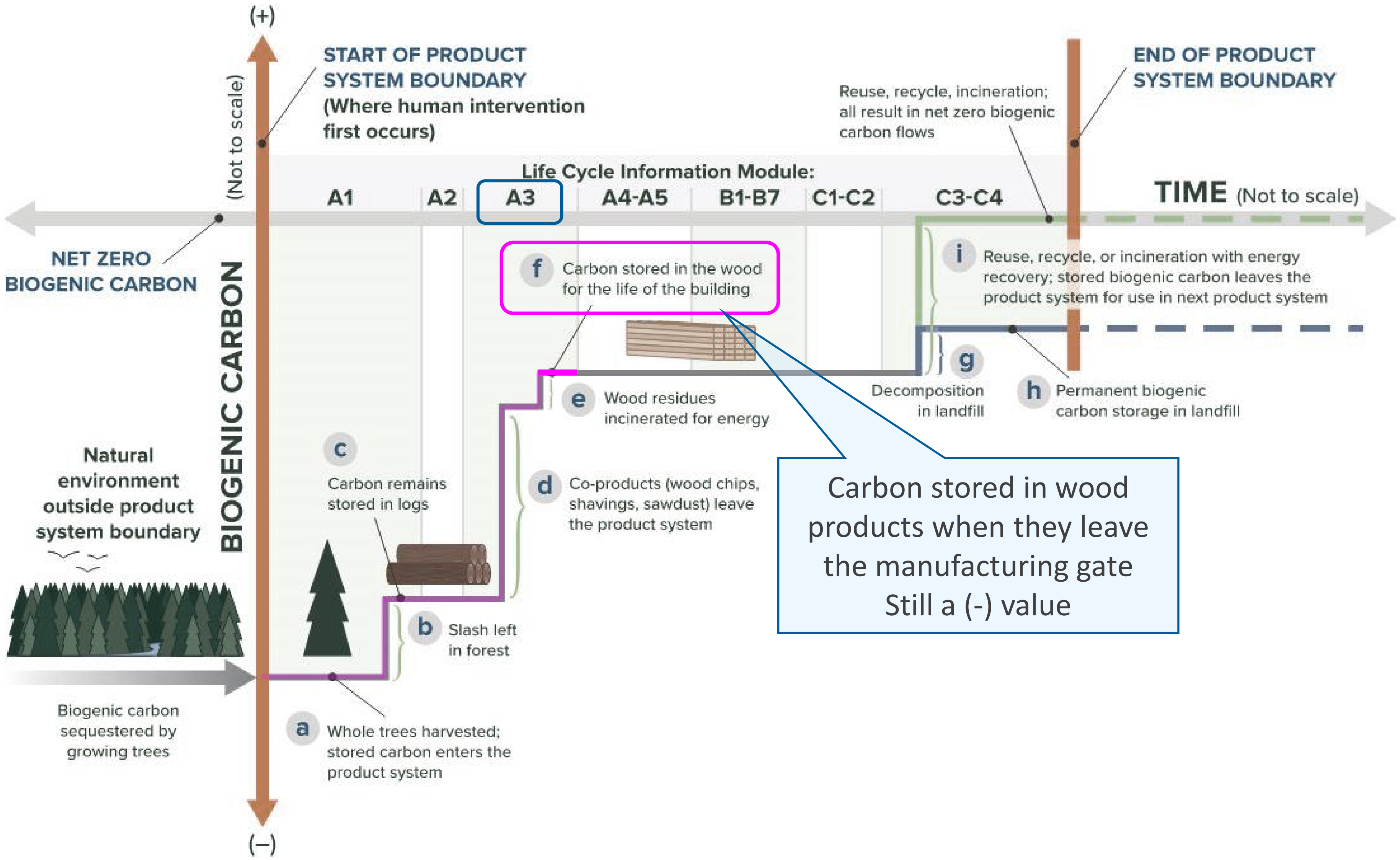
Carbon leaves the product system in the form of **co-products**
Counted as (+) export
(but not a direct emission to the atmosphere)

BIOGENIC CARBON FLOWS

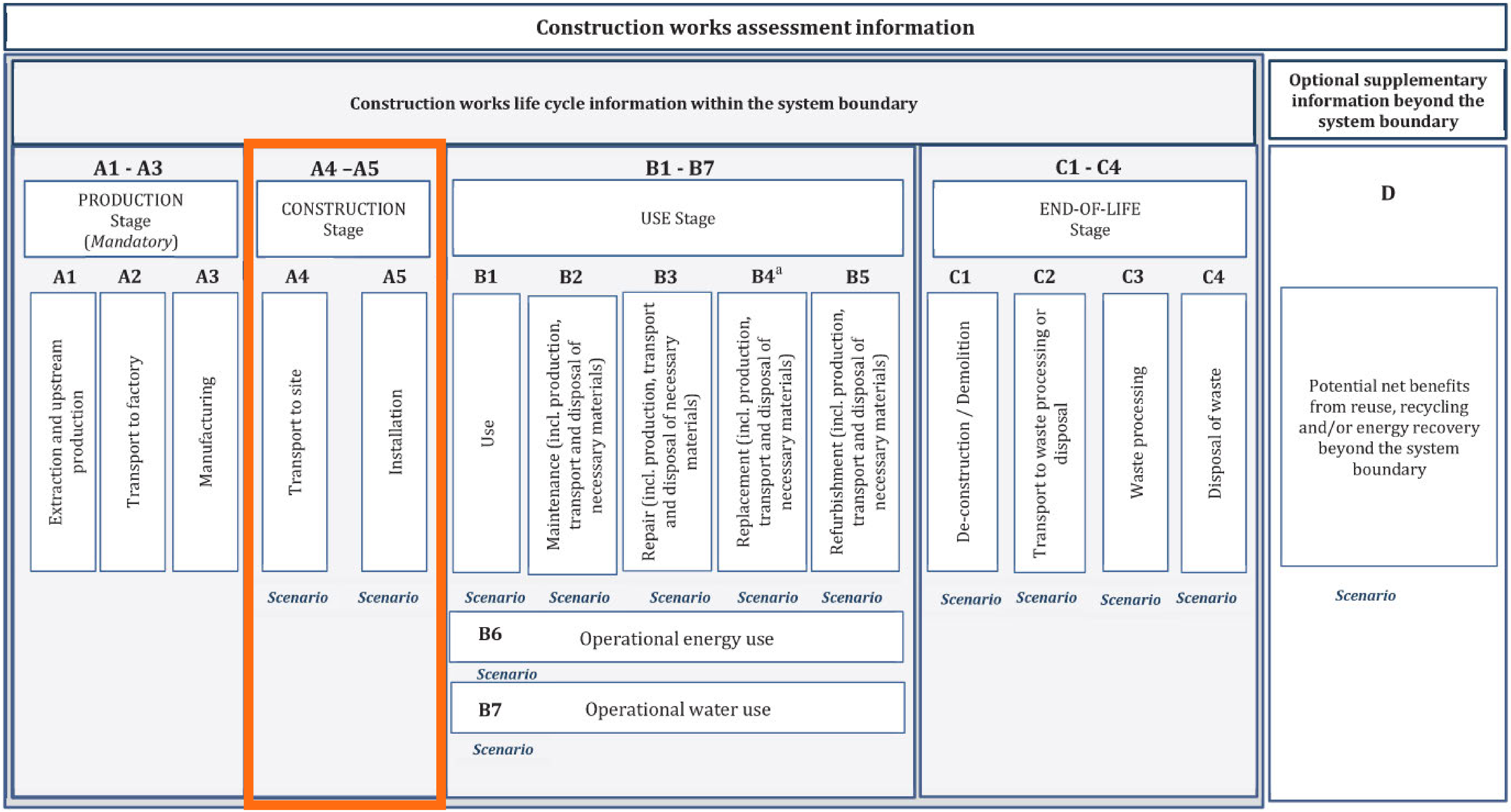


Carbon leaves the product system in the form of **wood residues incinerated for energy**
Counted as (+) emission
(but still carbon neutral)

BIOGENIC CARBON FLOWS



Carbon stored in wood products when they leave the manufacturing gate
Still a (-) value



[a] Replacement information module (B4) not applicable at the product level.

Source: ISO 21930:2017(E), Figure 2

Construction Stage: A4-A5

A4: Transport to site

» Transportation from the mill or factory “gate” to the job site

A5: Installation

» Installation/construction process

A4 for Wood Products

A4: Transport to site

» Transportation from the mill or factory “gate” to the job site

Could include:

- Truck
- Train
- Barge

A5: Installation

» Installation/construction process

No biogenic carbon flows

A5 for Wood Products

Consider light weight, speed of construction, benefits of prefabrication

A4: Transport to site

» Transportation from the mill or factory "gate" to the job site

A5: Installation

» Installation/construction process

Includes:
- Construction equipment
- Site power, water
- Waste generated on site

A5 for Wood Products

Consider light weight, speed of construction, benefits of prefabrication

A4: Transport to site

» Transportation from the mill or factory "gate" to the job site

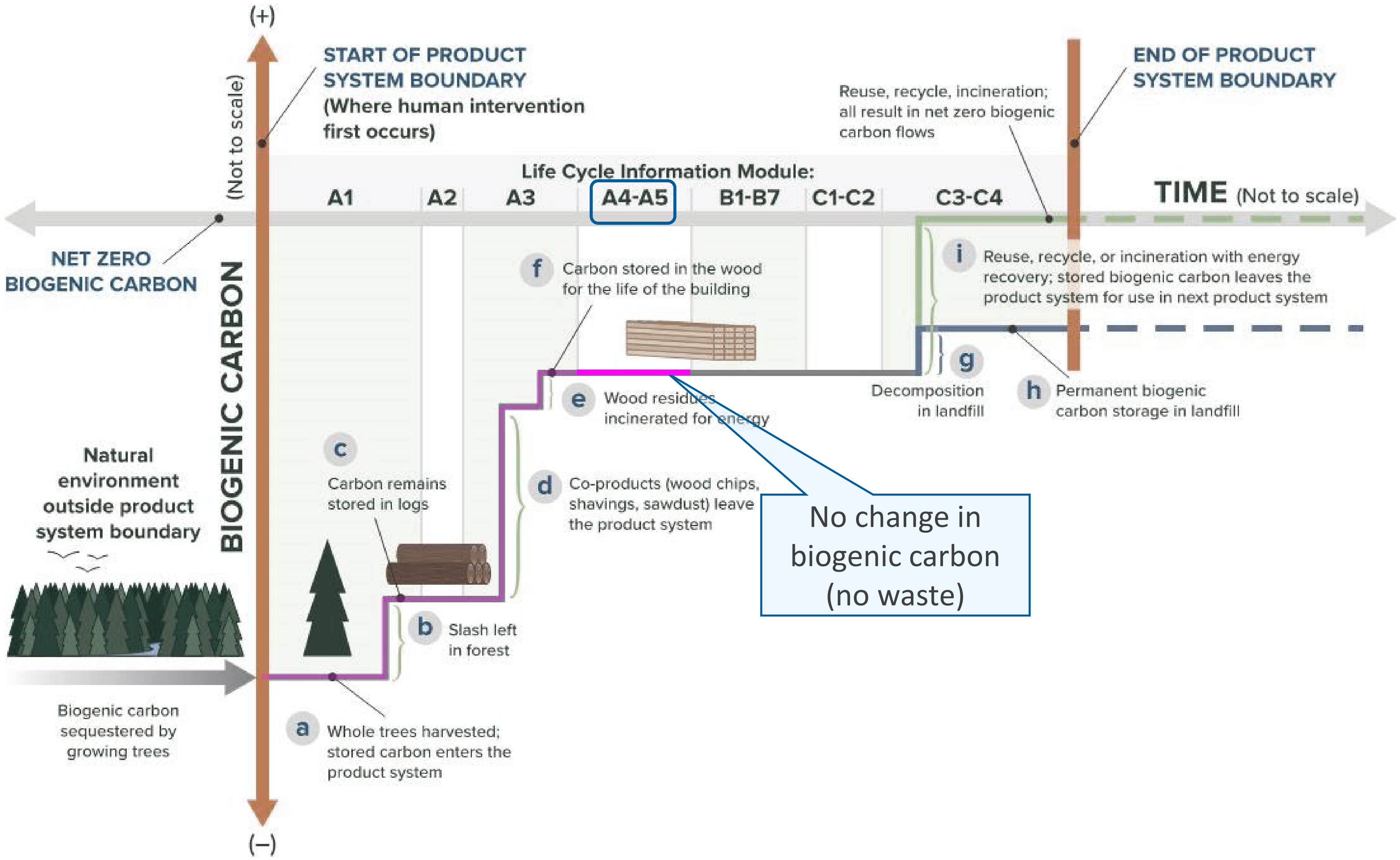
A5: Installation

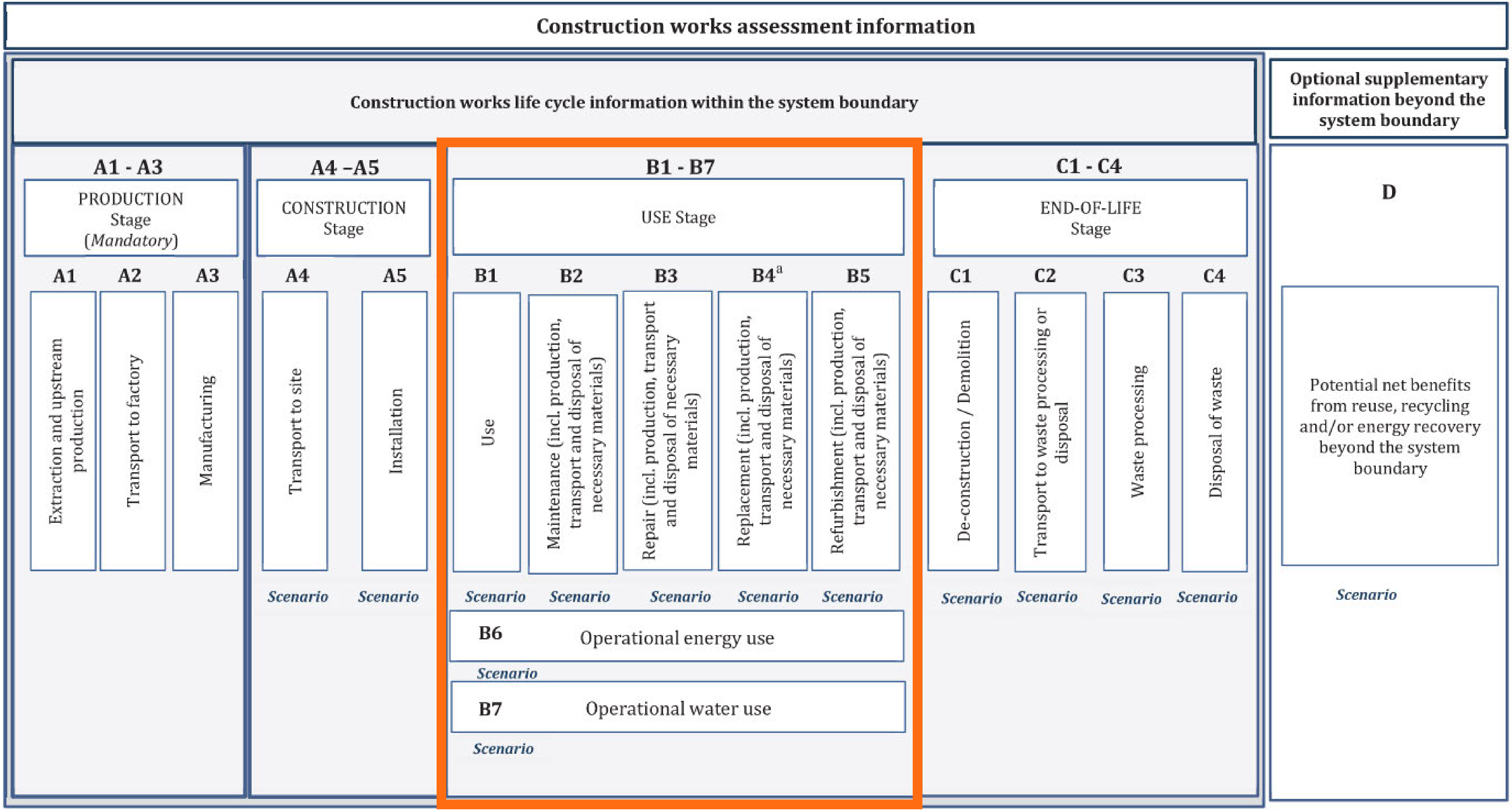
» Installation/construction process

Includes:
- Construction equipment
- Site power, water
- Waste generated on site

Possible biogenic carbon flows if wood products leave the system in the form of construction waste

BIOGENIC CARBON FLOWS





[a] Replacement information module (B4) not applicable at the product level.

Source: ISO 21930:2017(E), Figure 2

B1-B5 (Embodied) for Wood Products

B1: Use

» Normal use not covered in B2-B7

B2: Maintenance

» Preventative & regular maintenance throughout the service life

B3: Repair

» e.g. a window with a broken pane of glass

B4: Replacement

» e.g. replacing carpet at the end of its service life

B5: Refurbishment

» Maintenance, repair and/or replacement over a significant part of the building; includes restoration

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Be aware of default service life of wood products in the tools!
Structural wood products should have service life = building life

B1-B5 (Embodied) for Wood Products

Typically, no biogenic carbon flows

B1: Use

- Normal use not covered in B2-B7

B2: Maintenance

- Preventative & regular maintenance throughout the service life

B3: Repair

- e.g. a window with a broken pane of glass

B4: Replacement

- e.g. replacing carpet at the end of its service life

B5: Refurbishment

- Maintenance, repair and/or replacement over a significant part of the building; includes restoration

B6-B7 (Operational) for Wood Products

Typically excluded from structural WBLCA

No biogenic carbon flows

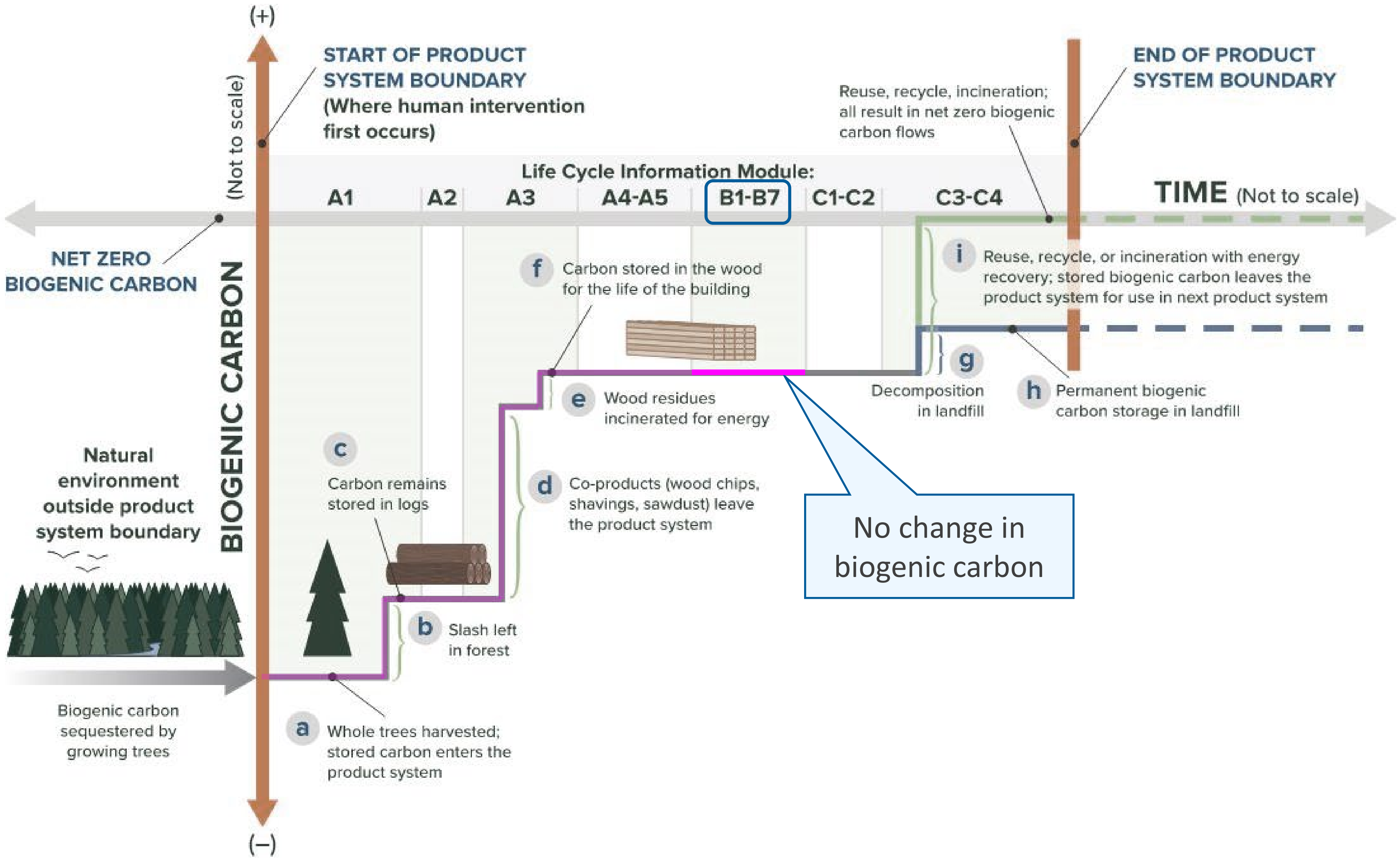
B6: Operational energy use

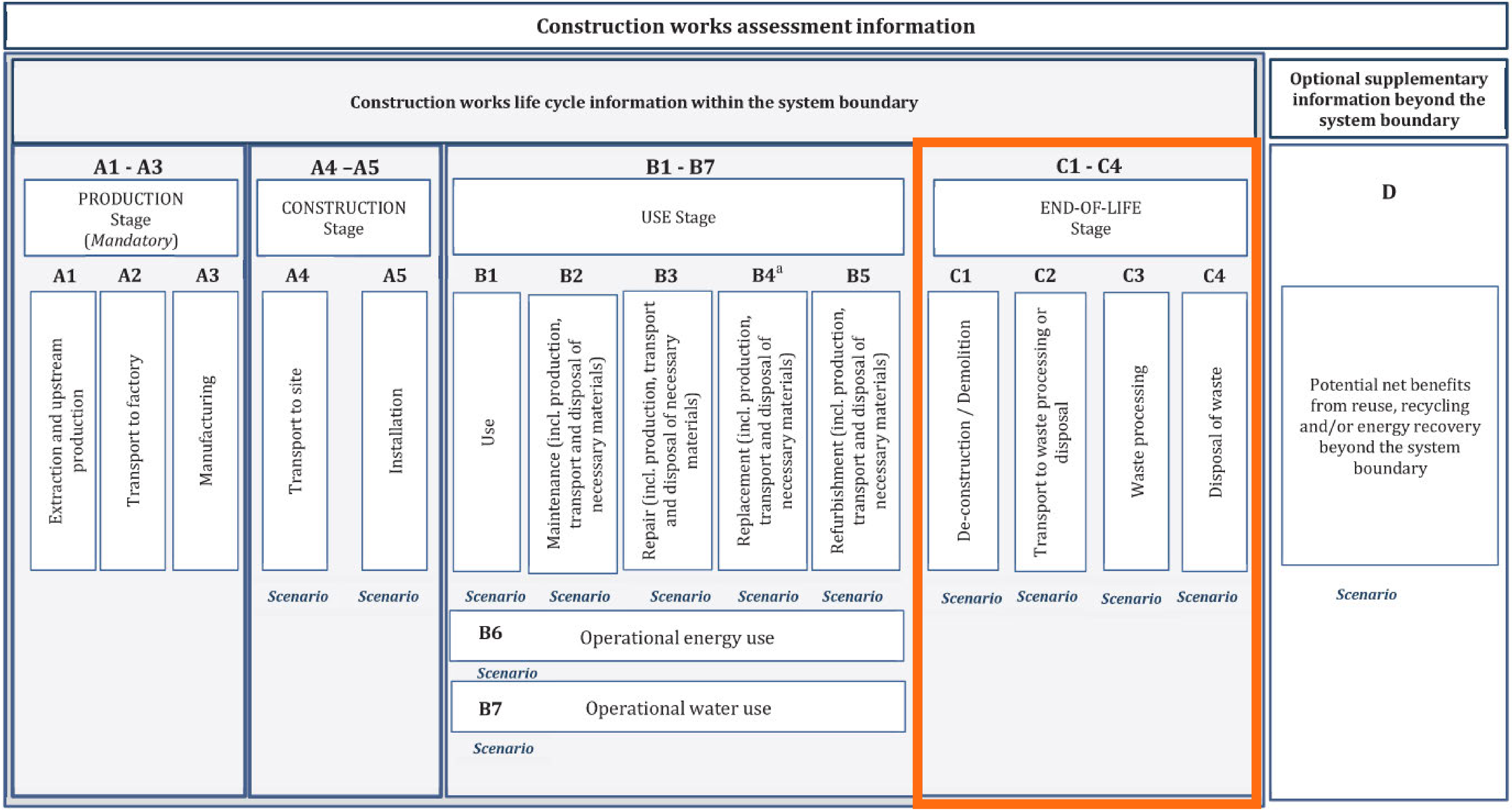
- Energy used during the operation of building systems (HVAC, lighting/electrical, DHW, fire safety, IT & communications, etc.)

B7: Operational water use

- Freshwater used during the operation of building systems
- Includes production, transportation and wastewater treatment

BIOGENIC CARBON FLOWS





[a] Replacement information module (B4) not applicable at the product level.

Source: ISO 21930:2017(E), Figure 2

End-of-Life: C1-C4

C1: Deconstruction / Demolition

» Dismantling the building

C2: Transport to waste processing or disposal

» Transportation to recycling site and/or solid waste disposal site

C3: Waste processing

» Including waste generated during the creation of secondary materials

C4: Disposal of waste

» Management of the disposal site including landfill gas energy recovery

A1-C4 is often called cradle-to-grave

C1-C2 for Wood Products

C1: Deconstruction / Demolition

» Dismantling the building

Similar to A5 installation:
- Construction equipment
- Site power, water

C2: Transport to waste processing or disposal

» Transportation to recycling site and/or solid waste disposal site

Similar to A4 transportation:
- Primarily diesel truck

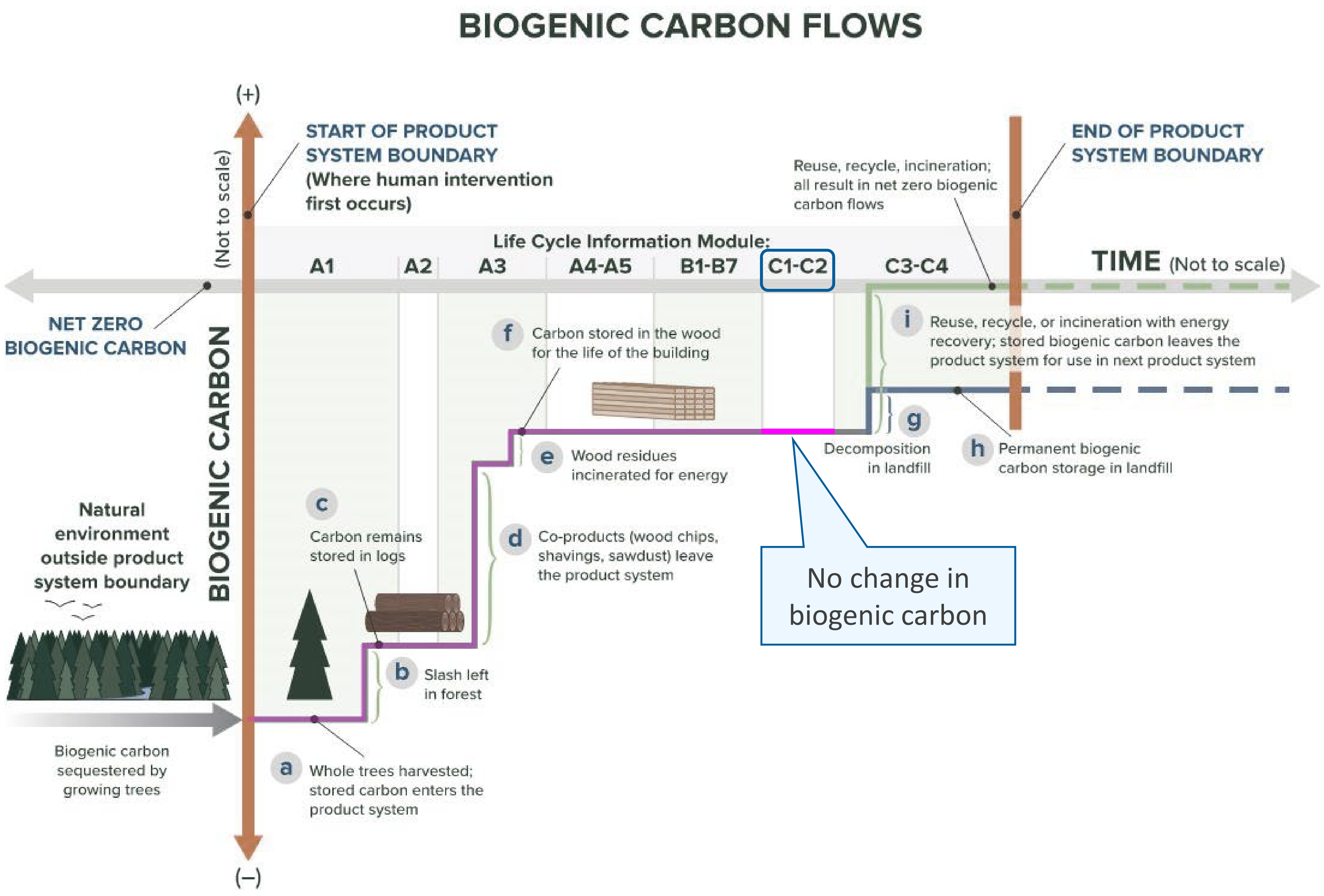
C3: Waste processing

» Including waste generated during the creation of secondary materials

C4: Disposal of waste

» Management of the disposal site including landfill gas energy recovery

No biogenic carbon flows


BIOGENIC CARBON FLOWS
(+)
(–)
(Not to scale)
BIOGENIC CARBON
START OF PRODUCT SYSTEM BOUNDARY (Where human intervention first occurs)
END OF PRODUCT SYSTEM BOUNDARY
Reuse, recycle, incineration; all result in net zero biogenic carbon flows
Life Cycle Information Module:
A1
A2
A3
A4-A5
B1-B7
C1-C2
C3-C4
TIME (Not to scale)
NET ZERO BIOGENIC CARBON
i Reuse, recycle, or incineration with energy recovery; stored biogenic carbon leaves the product system for use in next product system
f Carbon stored in the wood for the life of the building
g Decomposition in landfill
h Permanent biogenic carbon storage in landfill
e Wood residues incinerated for energy
c Carbon remains stored in logs
d Co-products (wood chips, shavings, sawdust) leave the product system
No change in biogenic carbon
Natural environment outside product system boundary
b Slash left in forest
Biogenic carbon sequestered by growing trees
a Whole trees harvested; stored carbon enters the product system

C3-C4 for Wood Products

End-of-Life Scenarios:
1. Landfill
2. Incineration (energy recovery)
3. Recycle (down-cycle)
4. Direct Reuse

C1: Deconstruction / Demolition

» Dismantling the building

C2: Transport to waste processing or disposal

» Transportation to recycling site and/or solid waste disposal site

C3: Waste processing

» Including waste generated during the creation of secondary materials

C4: Disposal of waste

» Management of the disposal site including landfill gas energy recovery

End-of-Life Fates for Wood Products

1. Landfill
2. Incineration (for energy recovery)
3. Recycle
4. Direct Reuse

End-of-Life Fates for Wood Products

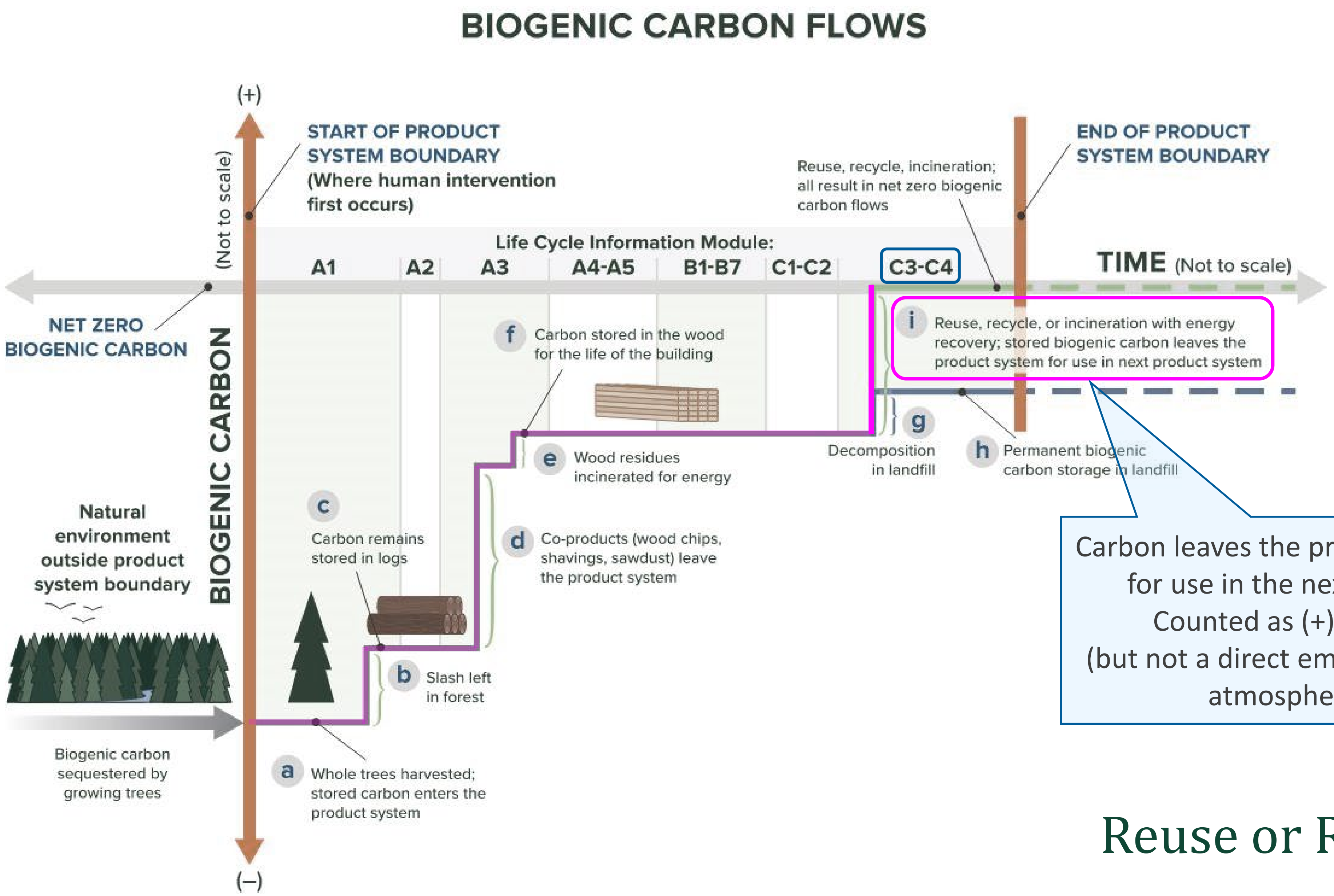
1. Landfill
2. Incineration (for energy recovery)
3. **Recycle**
4. **Direct Reuse**

Recycle: Processing required to turn existing product into new product for input into next system (i.e., chipping)

Direct Reuse: Minimal processing required

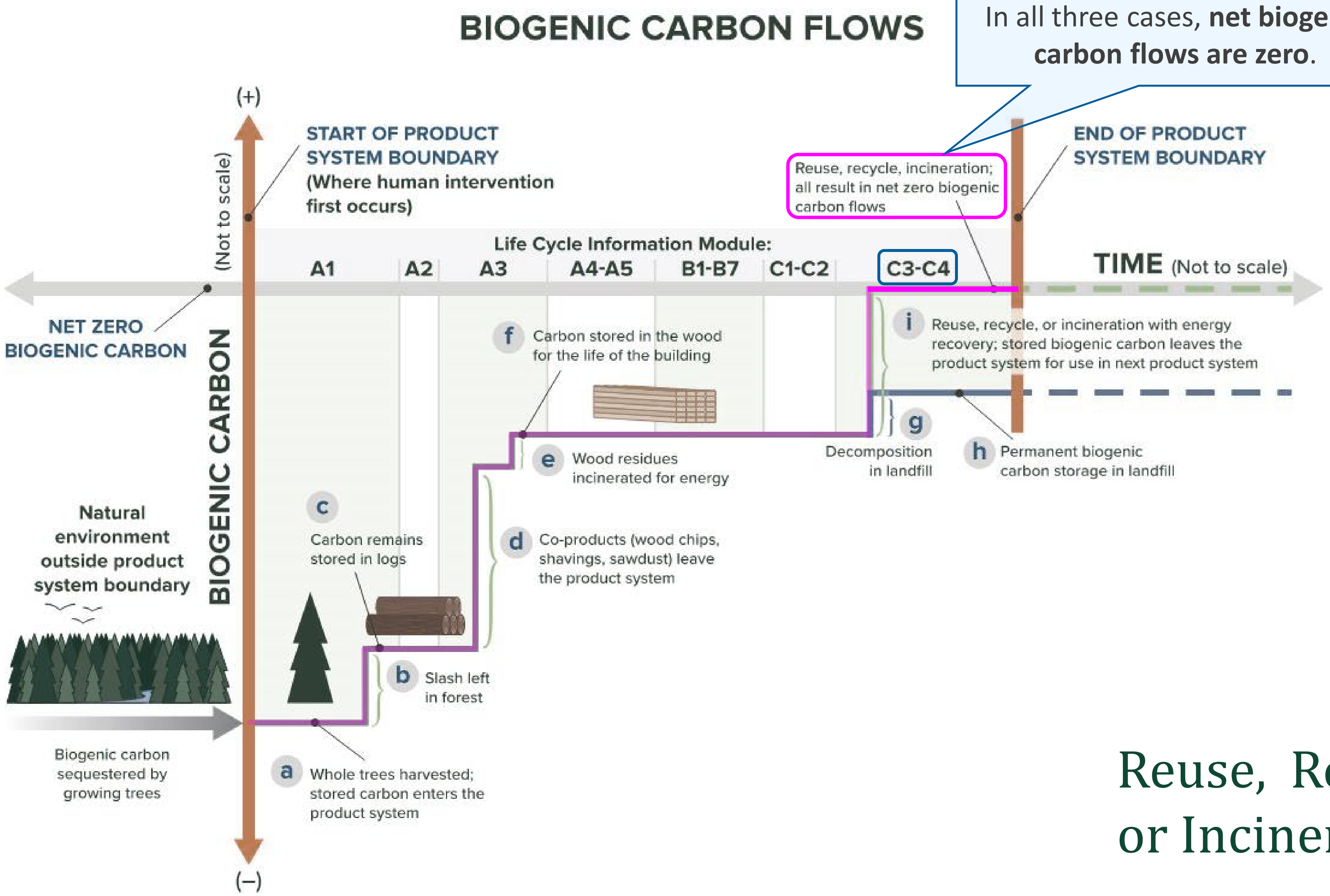
All biogenic carbon **leaves** the product system as an ***export*** (+1).

Reuse or Recycle



Carbon leaves the product system for use in the next system
Counted as (+) export
(but not a direct emission to the atmosphere)

In all three cases, **net biogenic carbon flows are zero**.



Reuse, Recycle or Incineration

End-of-Life Fates for Wood Products

1. **Landfill**
2. Incineration (for energy recovery)
3. Recycle
4. Direct Reuse

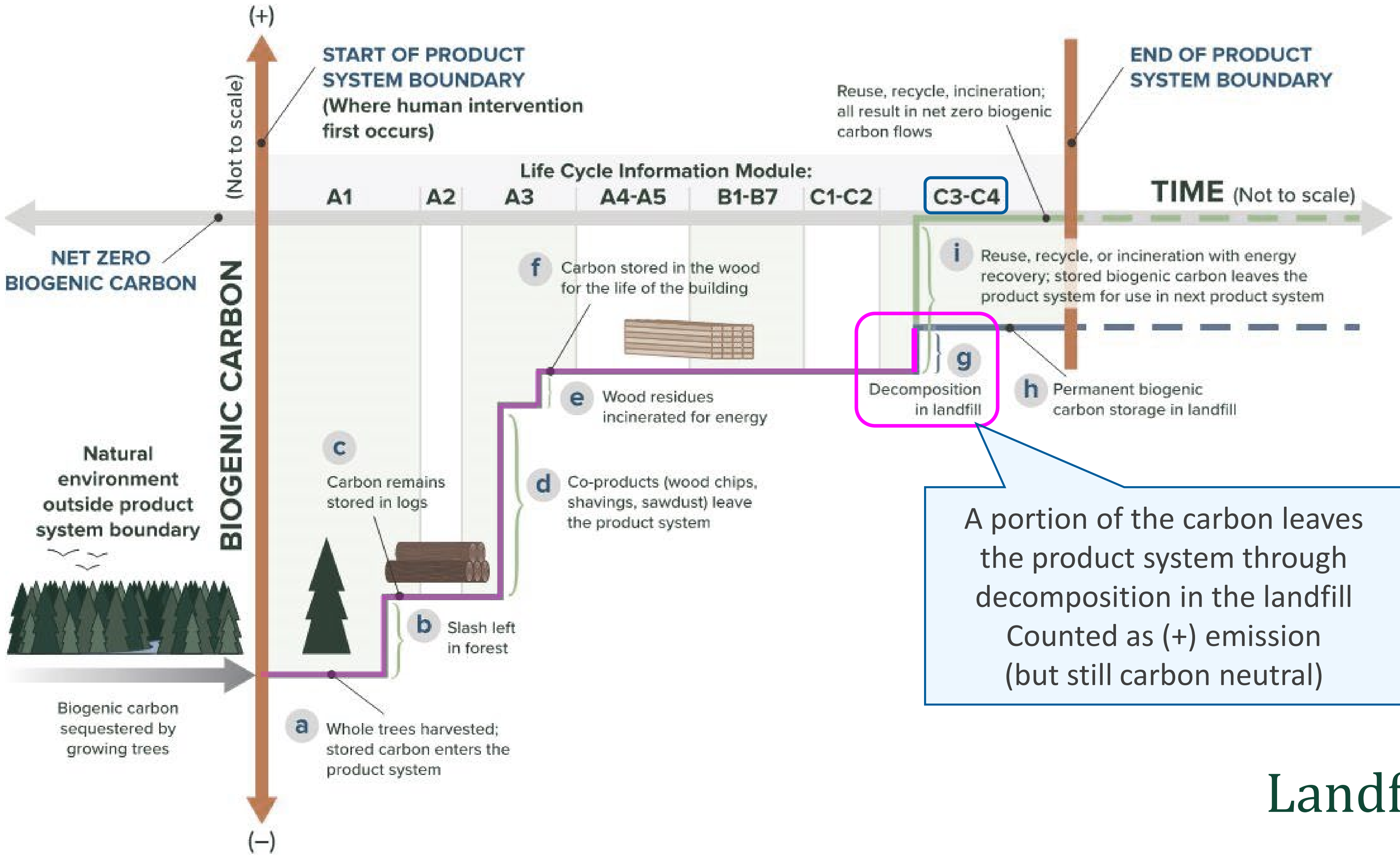
Landfill operations

- Most does <u>not</u> decay
- Decay releases landfill gases
  - Emitted directly to atmosphere, or
  - Landfill gas capture for energy recovery

Does <u>not</u> include benefits of using recovered energy

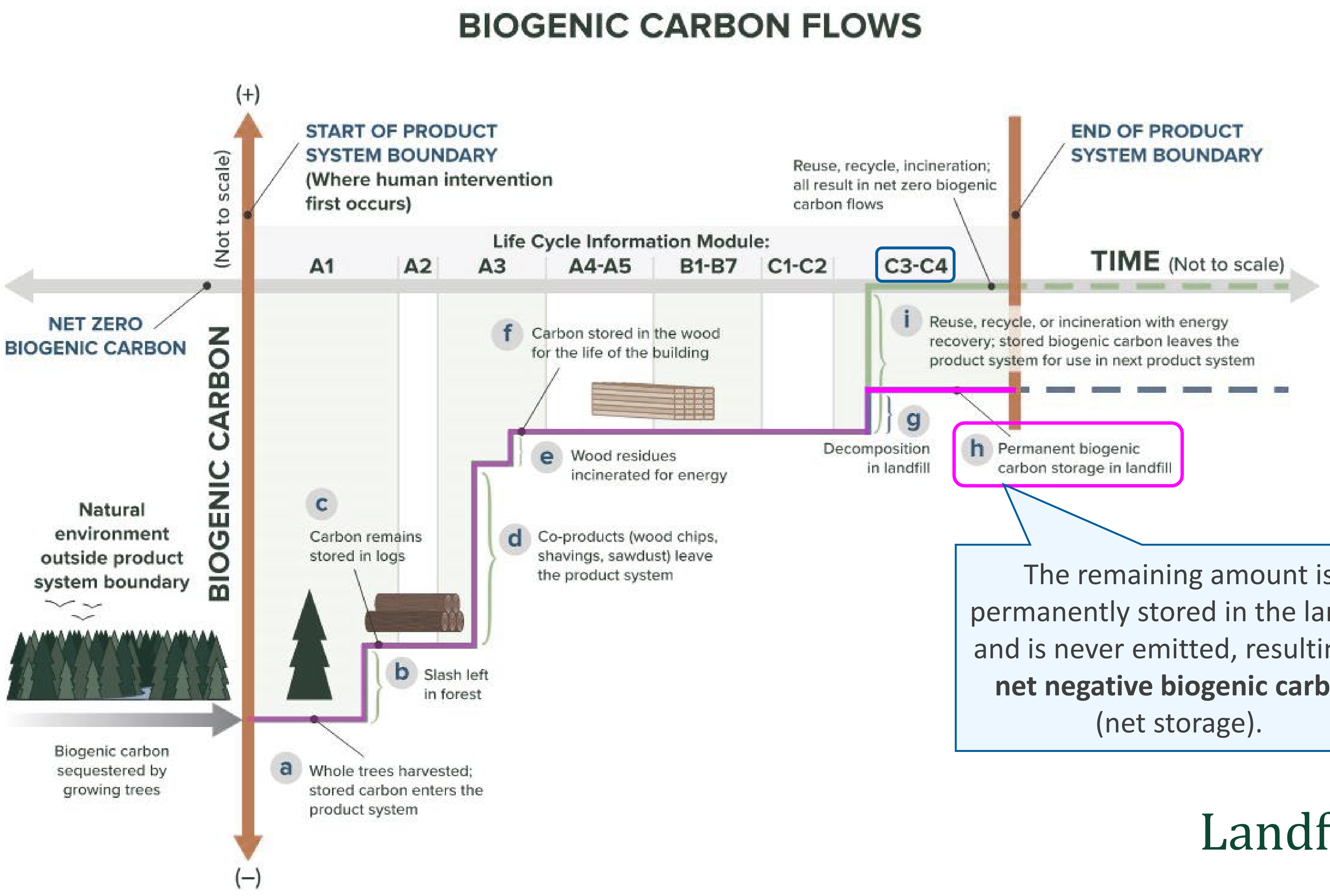
Most biogenic carbon is **<u>permanently stored</u>** in the landfill. The rest is released through decay as an ***emission*** (+1).

BIOGENIC CARBON FLOWS



A portion of the carbon leaves the product system through decomposition in the landfill
Counted as (+) emission
(but still carbon neutral)

Landfill

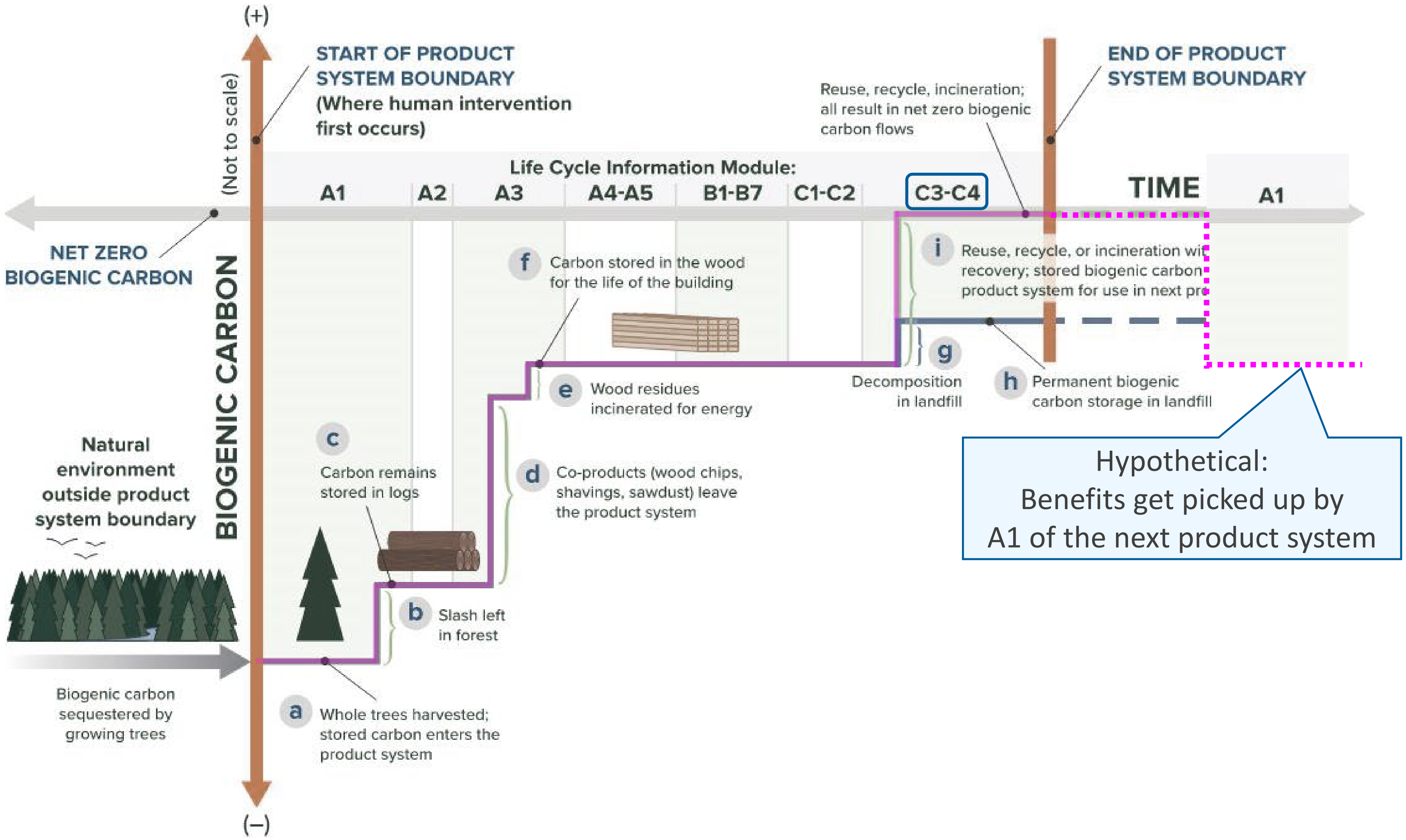


The remaining amount is permanently stored in the landfill and is never emitted, resulting in **net negative biogenic carbon** (net storage).

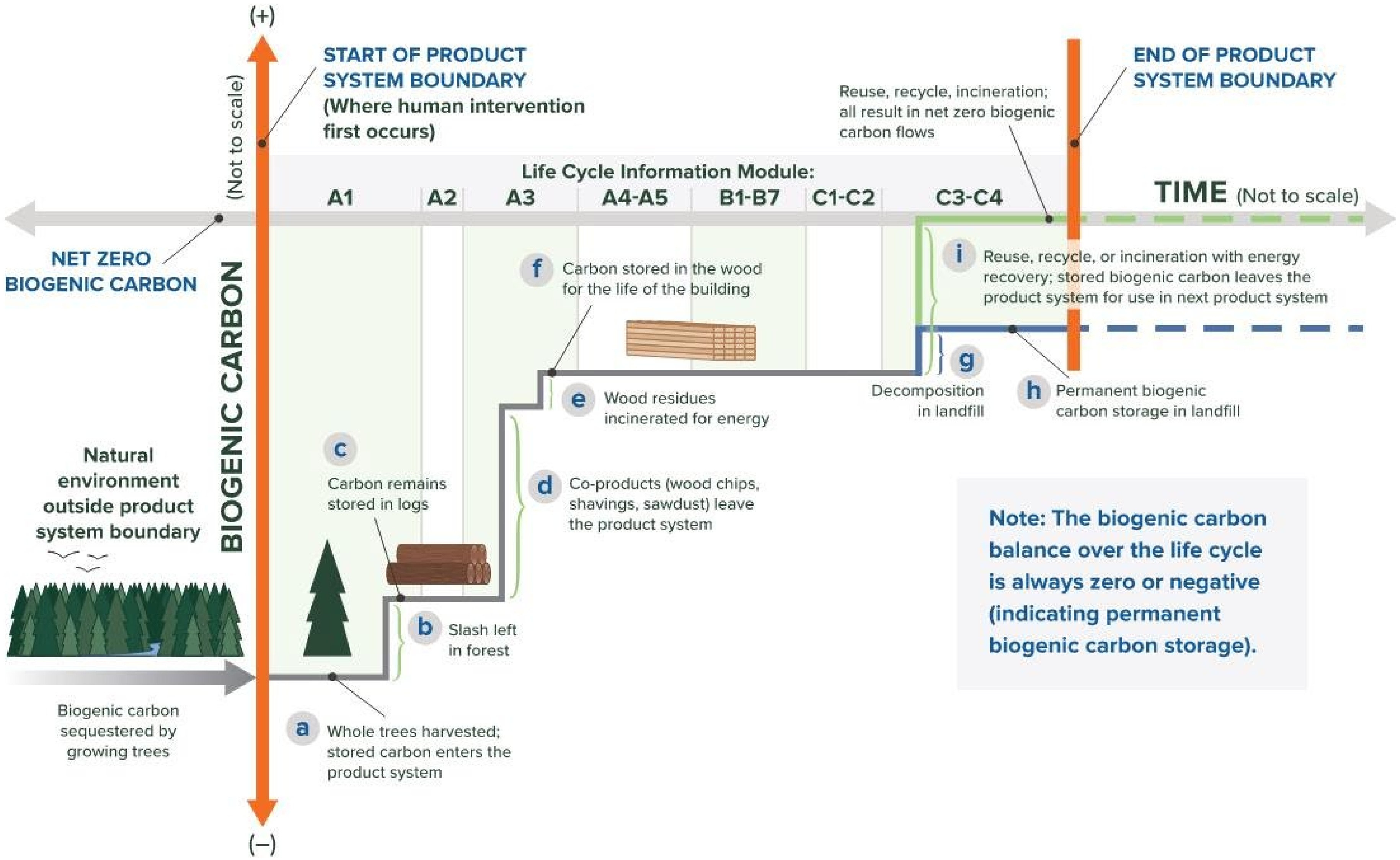
Landfill

But, isn’t reuse better?

BIOGENIC CARBON FLOWS



BIOGENIC CARBON FLOWS



https://www.woodworks.org/resources/how-to-include-biogenic-carbon-in-an-lca/

How to Compare Structures

Non-Wood vs Wood

Non-Wood:

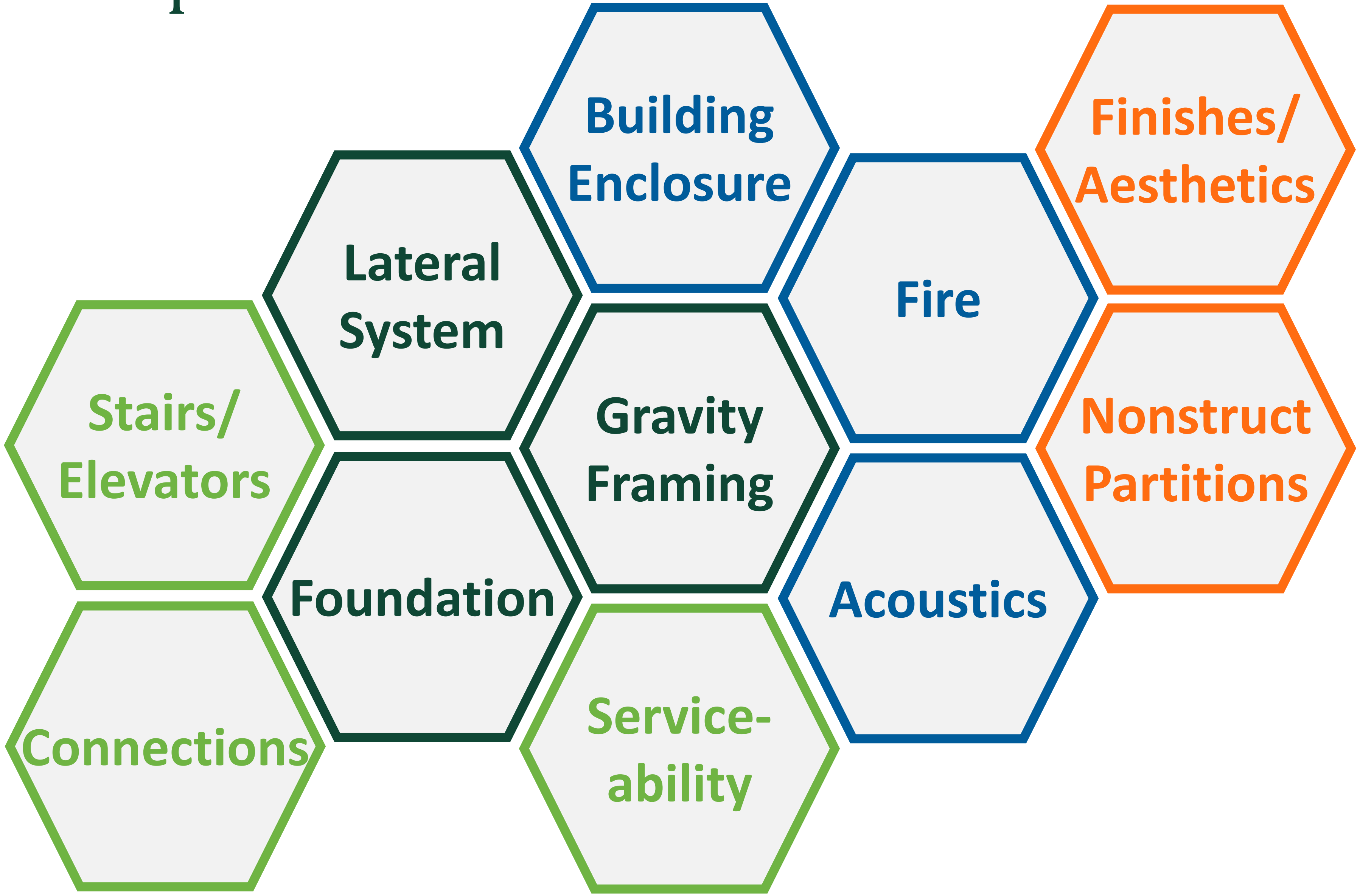
+ greenhouse gas emissions

Wood:

fewer
+ greenhouse gas emissions

and
- carbon storage

WBLCA Scope


Building Enclosure
Finishes/ Aesthetics
Lateral System
Fire
Stairs/ Elevators
Gravity Framing
Nonstruct Partitions
Foundation
Acoustics
Connections
Service-ability

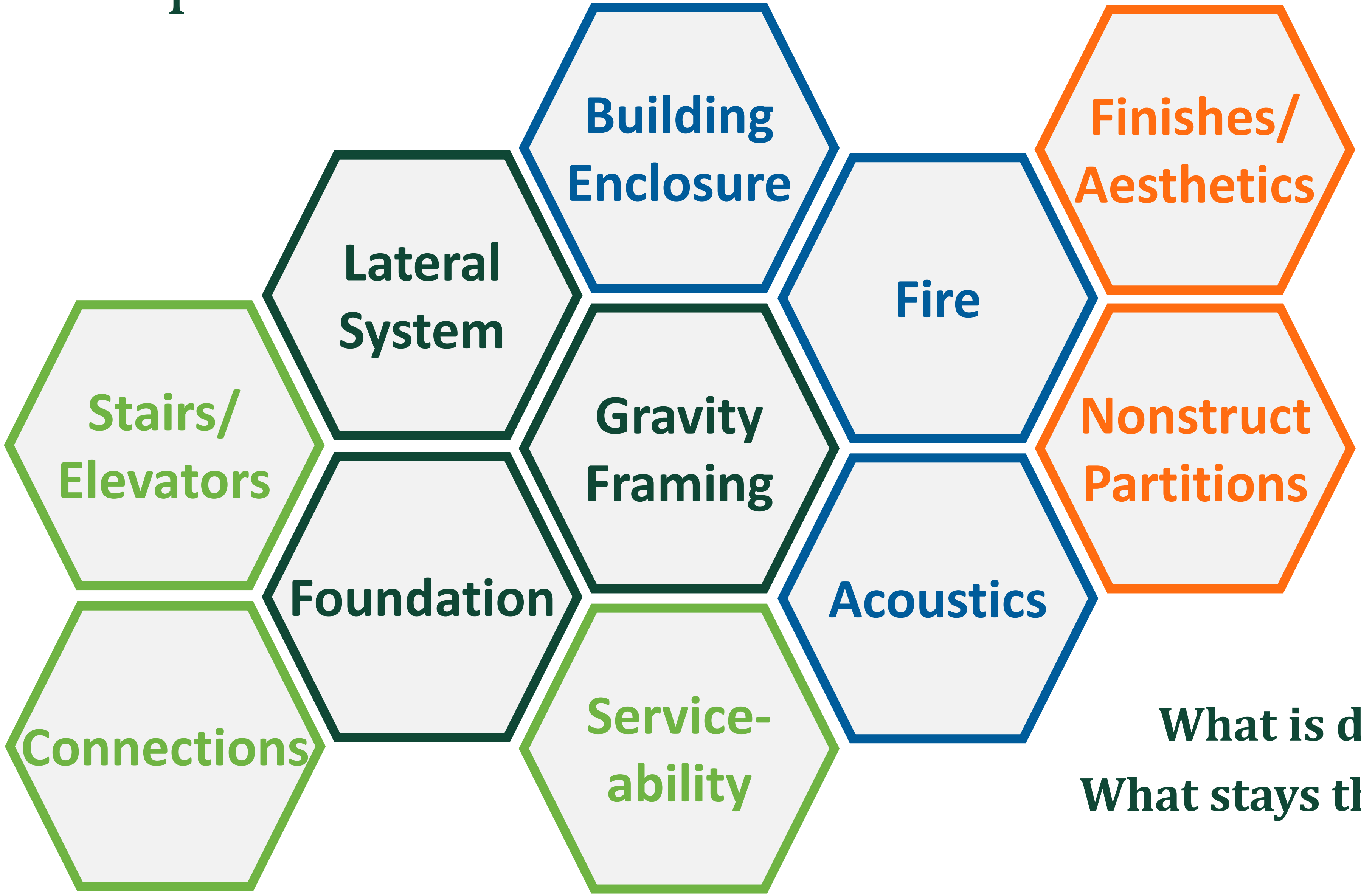
Comparative WBLCA

Mass Timber Building vs **Steel or Concrete Building**

requires

Functional Equivalency

WBLCA Scope

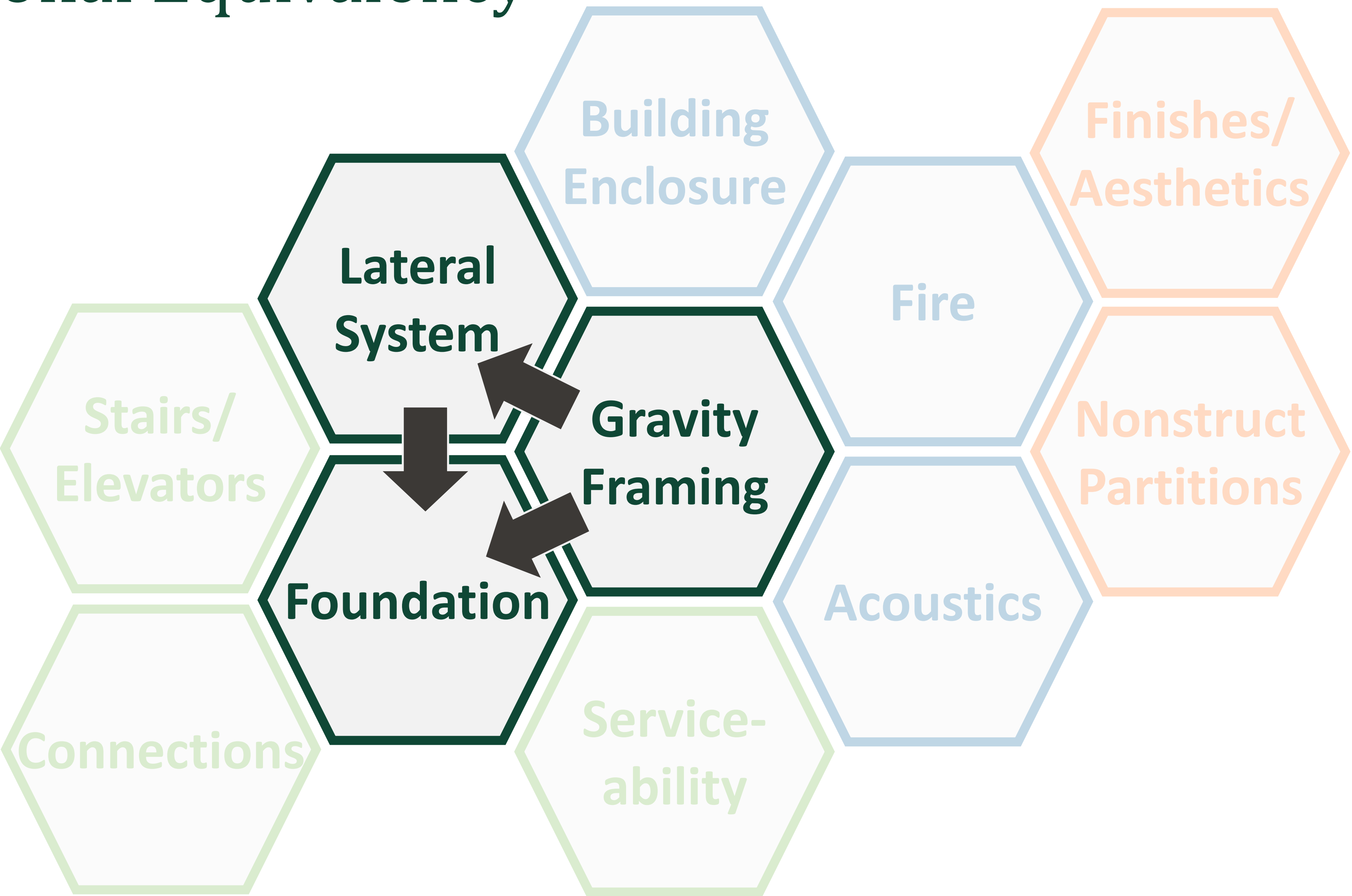


What is different?

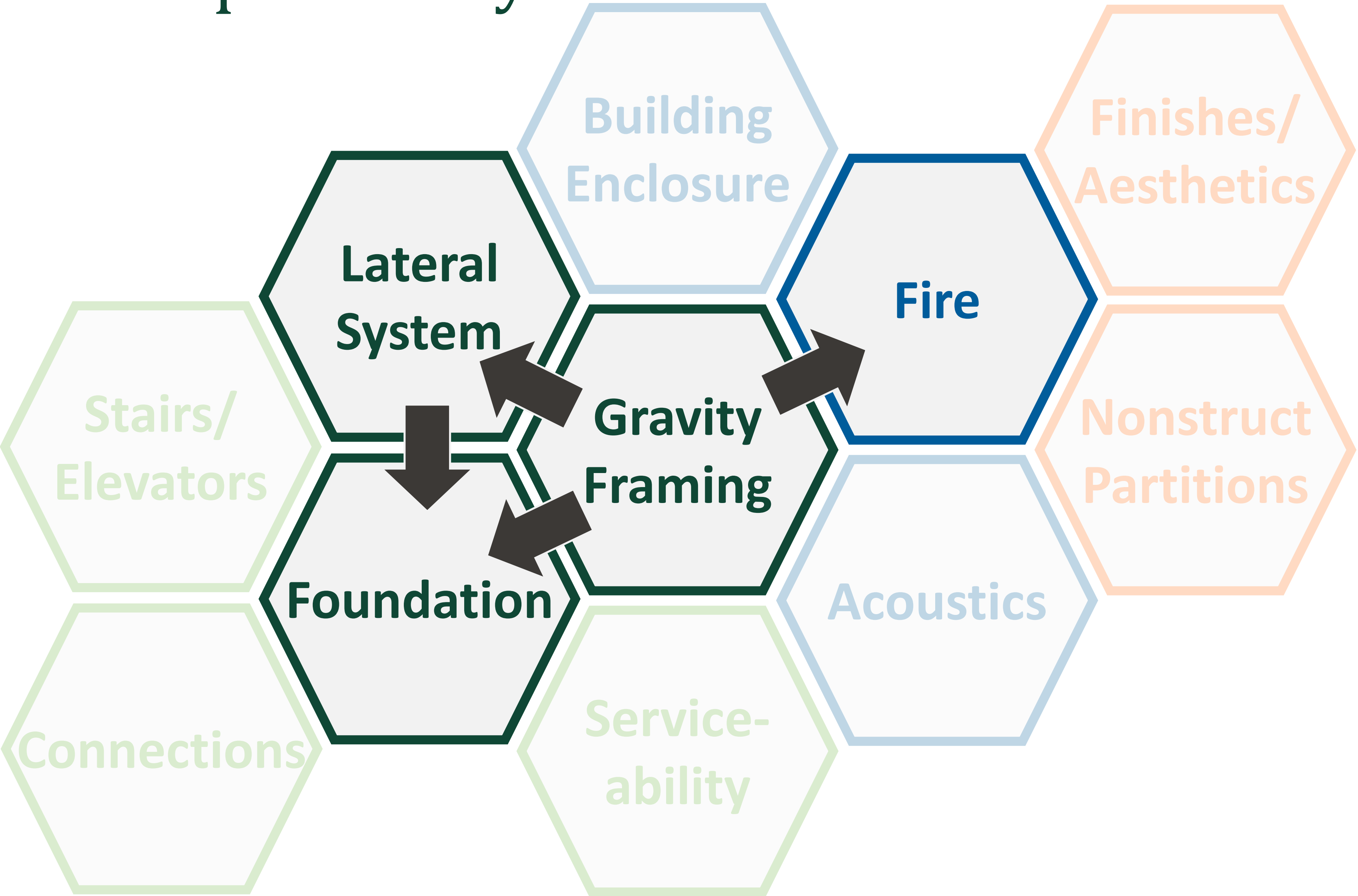
What stays the same?

Functional Equivalency

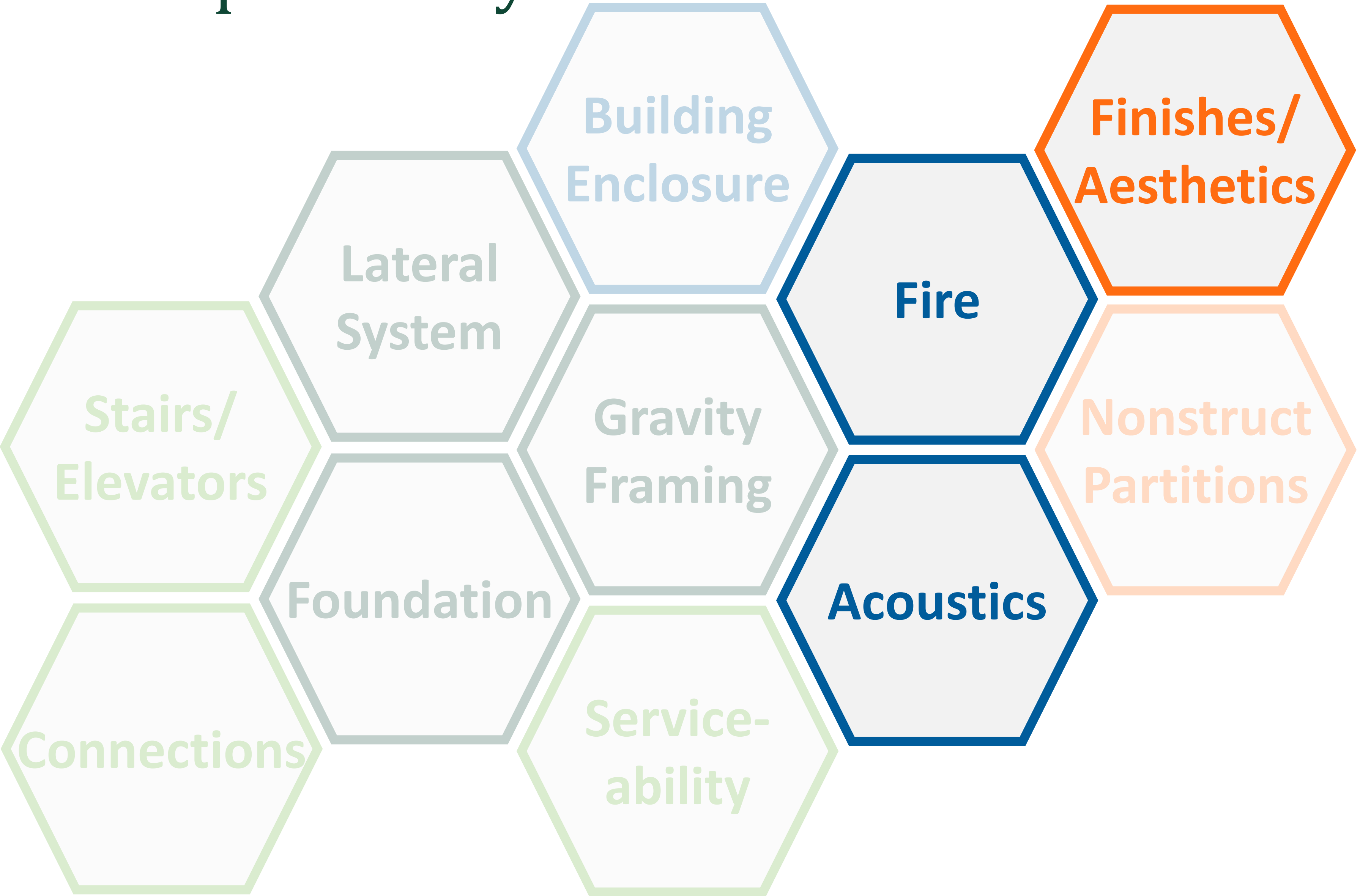
Functional Equivalency



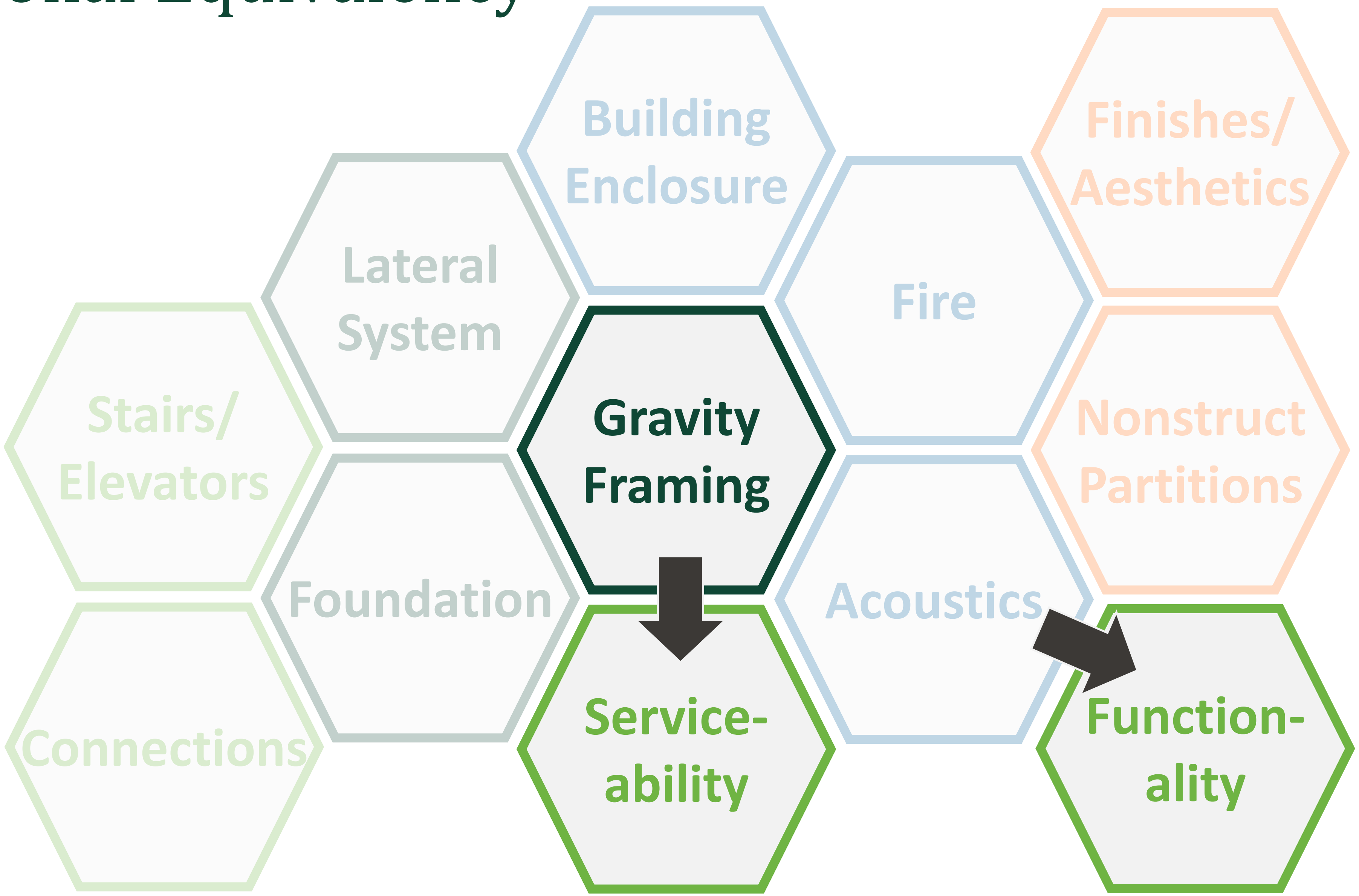
Functional Equivalency



Functional Equivalency



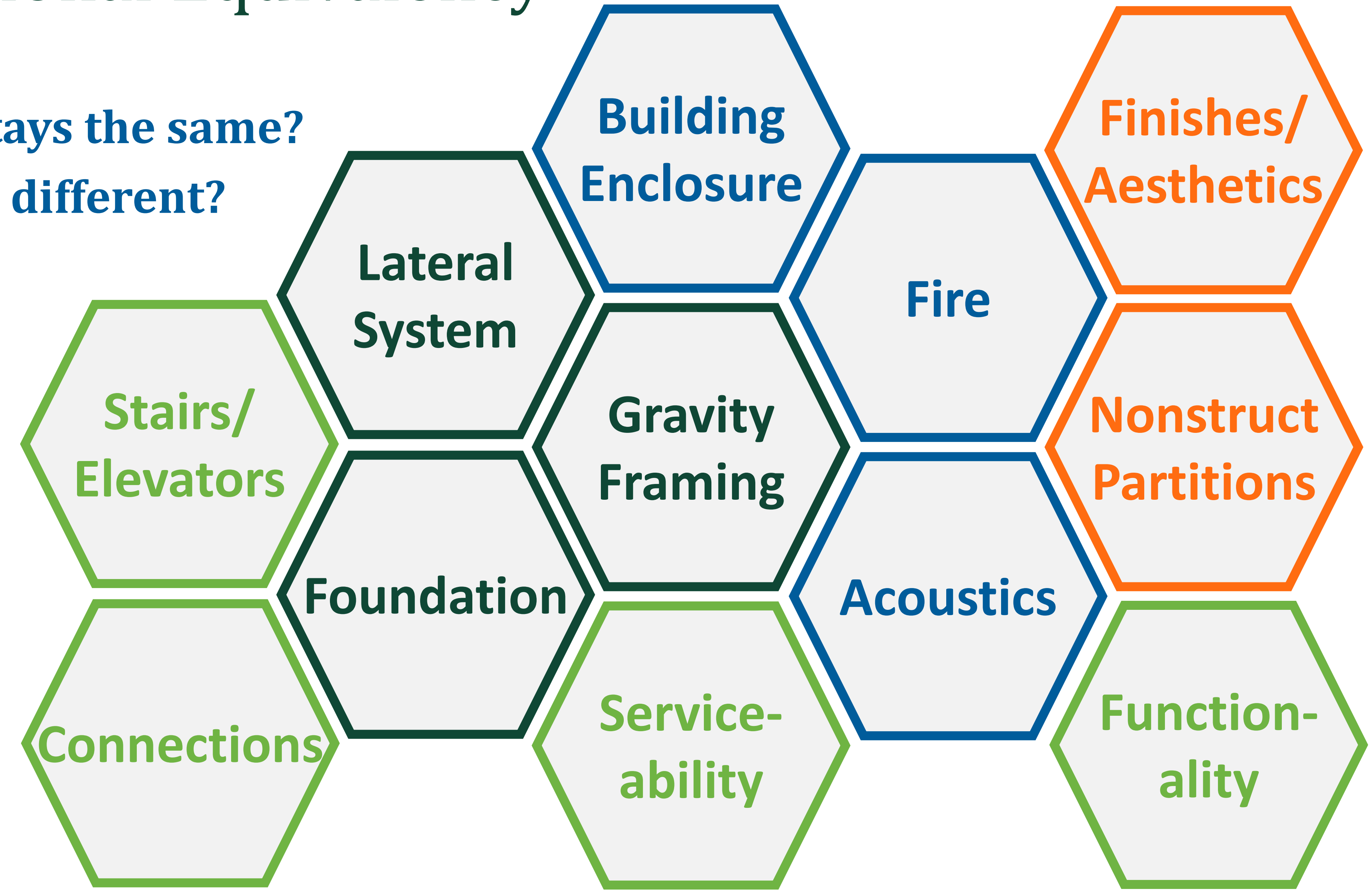
Functional Equivalency

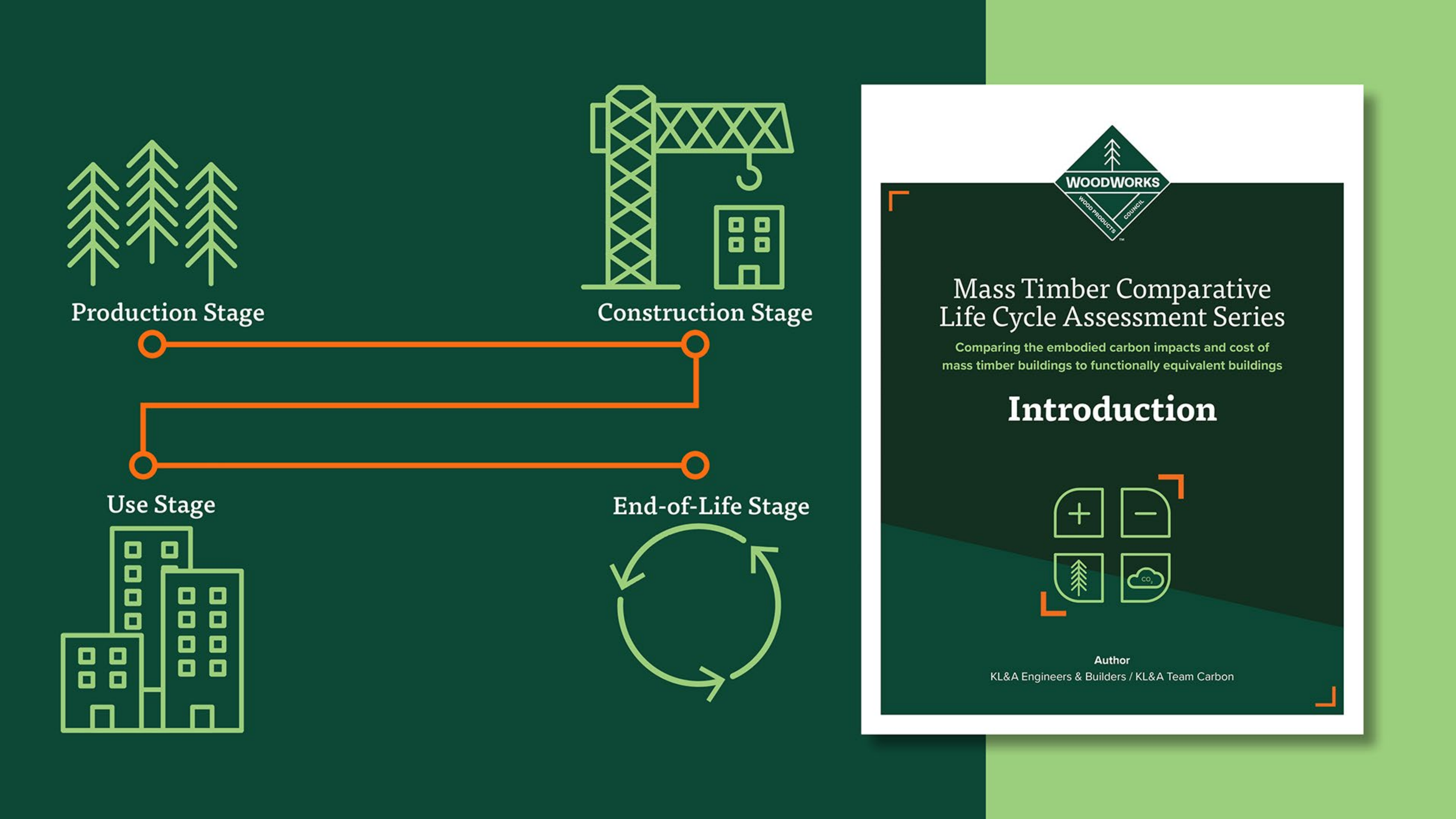


Functional Equivalency

What stays the same?

What is different?

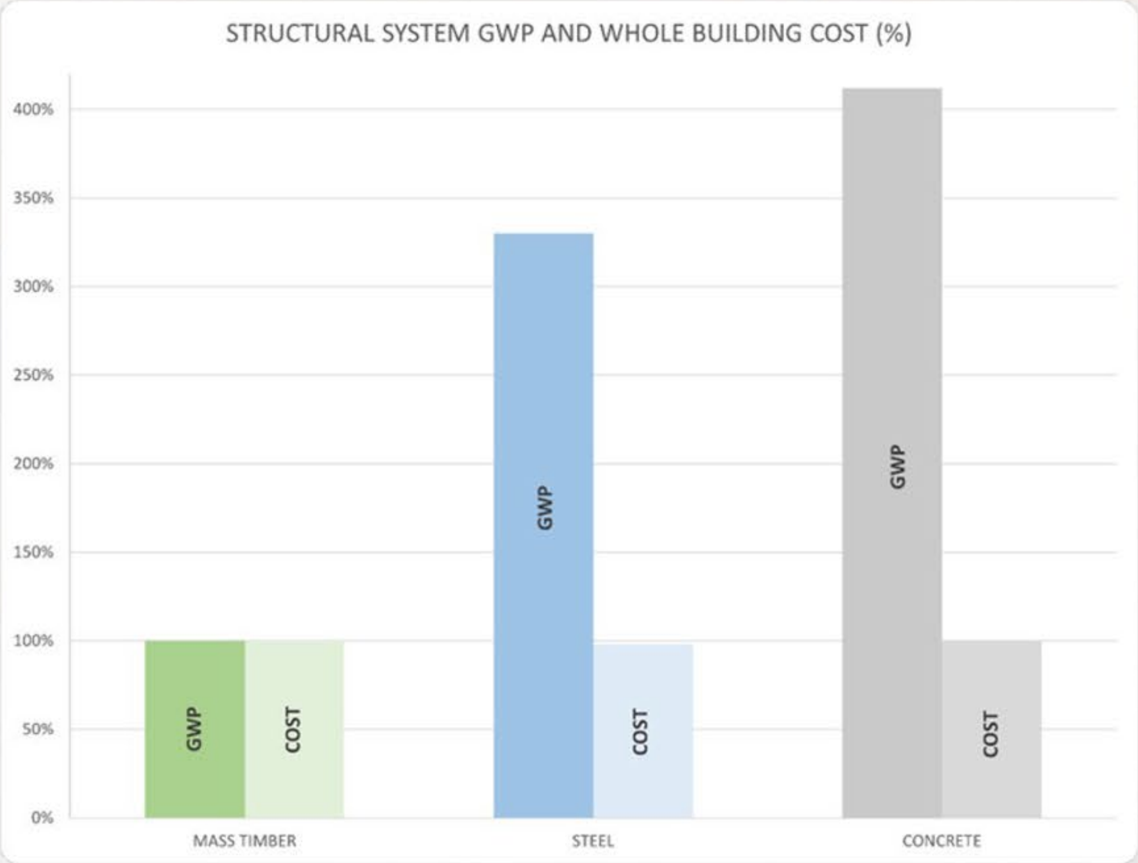



Production Stage
Construction Stage
Use Stage
End-of-Life Stage
WOODWORKS
WOOD PRODUCTS COUNCIL
Mass Timber Comparative
Life Cycle Assessment Series
Comparing the embodied carbon impacts and cost of
mass timber buildings to functionally equivalent buildings
Introduction
Author
KL&A Engineers & Builders / KL&A Team Carbon

PROJECT DETAILS

LOCATION:
Denver, Colorado

SIZE:
Five stories; 150,418 square feet



Source: Platte Fifteen Life Cycle Assessment
https://www.woodworks.org/resources/platte-fifteen-life-cycle-assessment/

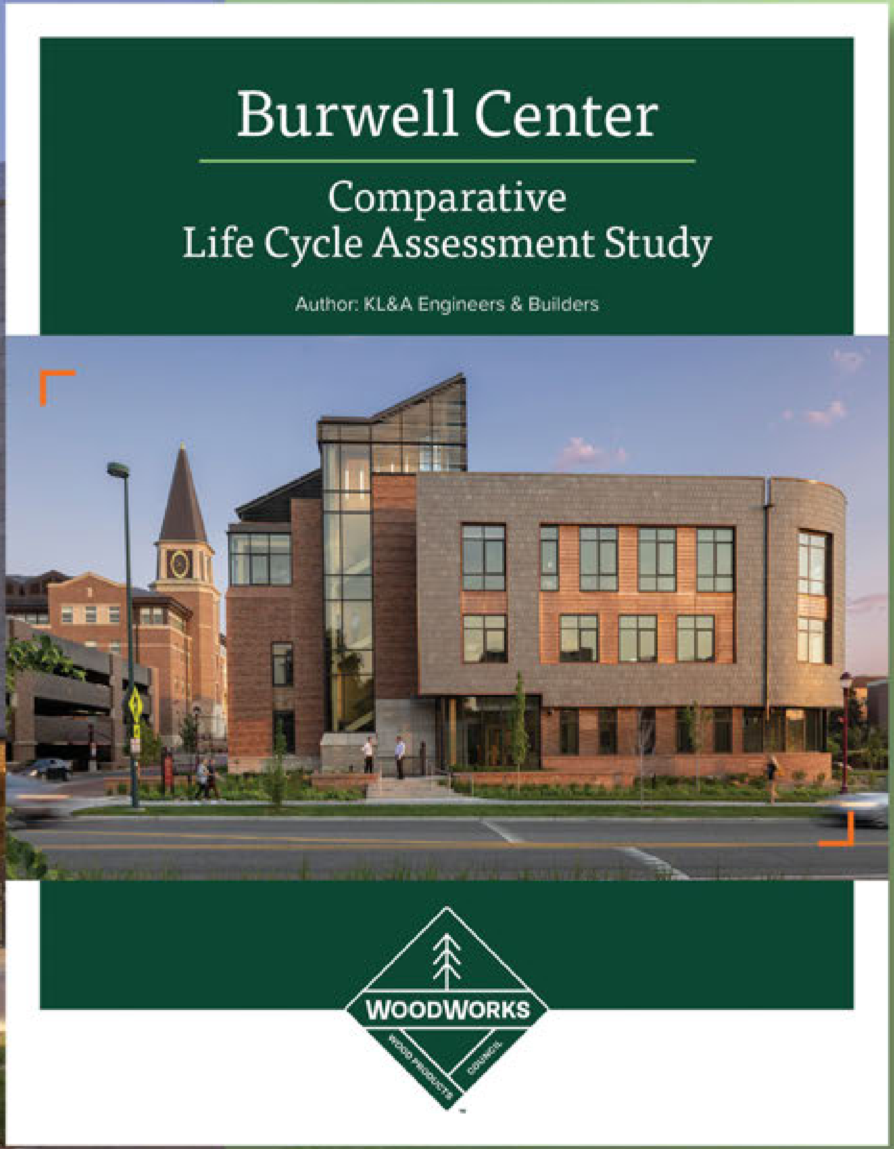
Rendering: Hickok Cole Architect


Denver Office
Comparative
Life Cycle Assessment Study
Author: KL&A Engineers & Builders
WOODWORKS
WOOD PRODUCTS COUNCIL
Rendering Shears Adkins Rockmore

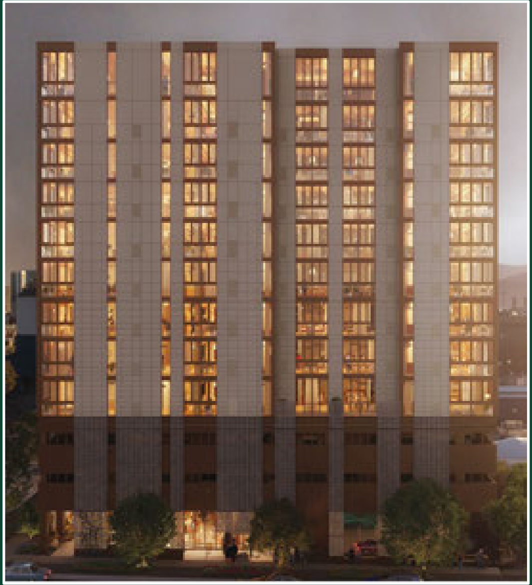

Nez Perce-Clearwater Office
Comparative
Life Cycle Assessment Study
Author: KL&A Engineers & Builders
WOODWORKS
WOOD PRODUCTS COUNCIL
Region 1
Caring for the Land and Serving People
Photo Heidi Long,
Longview Studios

Return to Form / Katz Development
/ tres birds / KL&A Engineers & Builders


Photo © Frank Ooms



Mass Timber Comparative Life Cycle Assessment Series

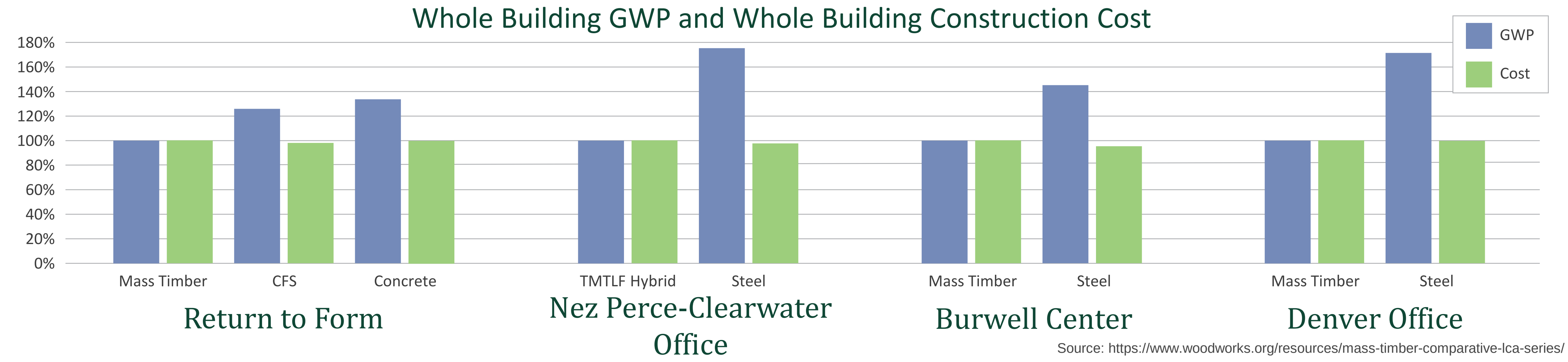


Rendering tres birds

Mosaic Architecture / Morrison-Maierle / Photo Heidi Long, Longview Studios

University of Denver Burwell Center for Career Achievement / Lake|Flato Architects / Shears Adkins Rockmore / KL&A Engineers and Builders / Photo © Frank Ooms

Rendering Shears Adkins Rockmore



Source: https://www.woodworks.org/resources/mass-timber-comparative-lca-series/

Reduce Risk

Optimize Costs

» For the entire project team, not just builders

» Lots of reference documents

Download Checklists at

www.woodworks.org

www.woodworks.org/wp-content/uploads/wood_solution_paper-Mass-Timber-Design-Cost-Optimization-Checklists.pdf

WOODWORKS WOOD PRODUCTS COUNCIL

Mass Timber Cost and Design Optimization Checklists

WoodWorks has developed the following checklists to assist in the design and cost optimization of mass timber projects. The *design optimization* checklists are intended for building designers (architects and engineers), but many of the topics should also be discussed with the fabricators and builders. The *cost optimization* checklists will help guide coordination between designers and builders (general contractors, construction managers, estimators, fabricators, installers, etc.) as they are estimating and making cost-related decisions on a mass timber project. The *pre-design* checklist should be reviewed by the developer/owner, designers and builders.

1 De Haro
San Francisco, CA
ARCHITECT:
Perkins&Will
ENGINEERS:
DCI Engineers
CONTRACTOR:
Hathaway Dinwiddie

WoodWorks offers a wide range of resources at woodworks.org, many of which are referenced in this document. We also recommend that designers and builders download the following:

Mass Timber Design Manual[1] – Includes technical papers, continuing education articles, expert Q&As and more. Published in partnership with Think Wood.

U.S. Mass Timber Construction Manual[2] – Provides a framework for the planning, procurement and management of mass timber projects.

Photo: David Wakely

Potential Benefits	Project Goal ✓	Value Add ✓
Fast construction		
Aesthetic Value (Potential leasing velocity/ premiums) Healthy Building / Biophilia		
Lightweight structure (multi-story, poor soils, tilt-walls, vertical additions)		
Labor shortage solution • small crews • entry level workers		
Just-in-time delivery (ideal for dense urban sites)		
Environmentally friendly (low carbon footprint)		
Healthy forests/ wildfire resiliency & support rural economies		

Keys to Mass Timber Success:

Know Your WHY

Design it as Mass Timber From the Start

Leverage Manufacturer Capabilities

Understand Supply Chain

Optimize Grid

Take Advantage of Prefabrication & Coordination

Expose the Timber

Discuss Early with AHJ

Work with Experienced People

Let WoodWorks Help for Free

Create Your Market Distinction

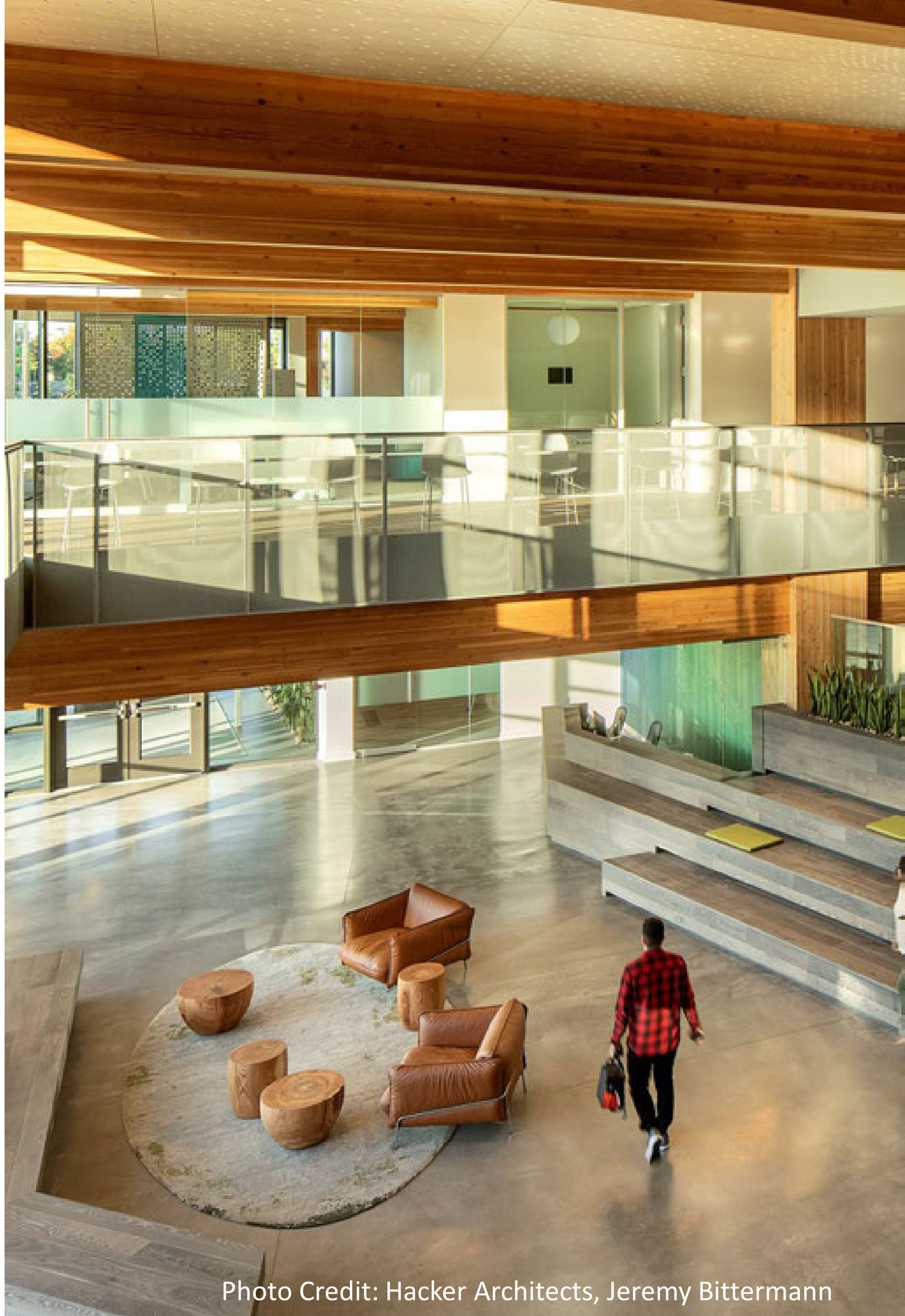


Photo Credit: Hacker Architects, Jeremy Bittermann

Questions? Ask us anything.

John O’Donald II, PE
Regional Director – DC, DE, MD, VA, WV
(814) 880-5636
john.odonald@woodworks.org

901 East Sixth, Thoughtbarn-Delineate Studio, Leap!Structures, photo Casey Dunn