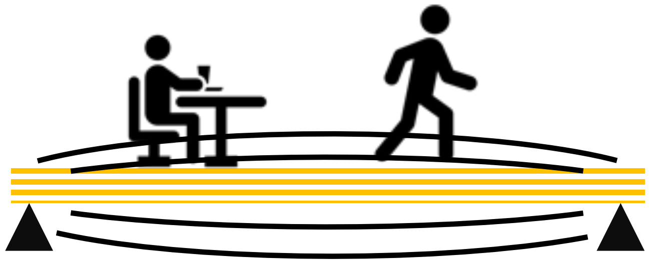
Mass Timber Design: Acoustic, Vibration, MEPF Integration, Embodied Carbon and LCA

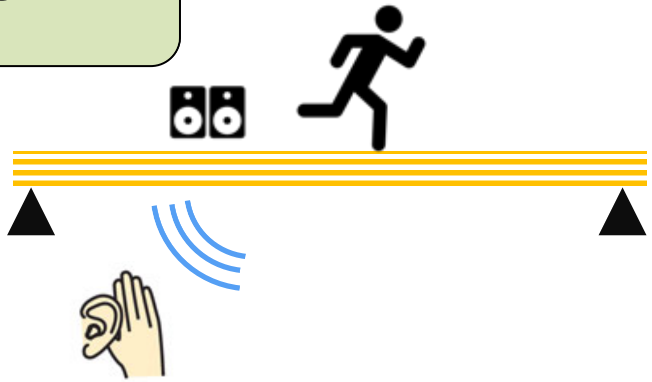
March 26, 2024

Presented by Eric Gu, John O’Donald II and Chelsea Drenick

Vibrations vs Acoustics

Structural Vibrations	Acoustic Vibrations
1 Hz – 100 Hz	20 Hz – 15,000 Hz
Transmitted through structure or through ground	Transmitted through air, walls, floors, windows
Physical effects	Audible effects





Acoustics & Sound Control

Code requirements only address residential occupancies:

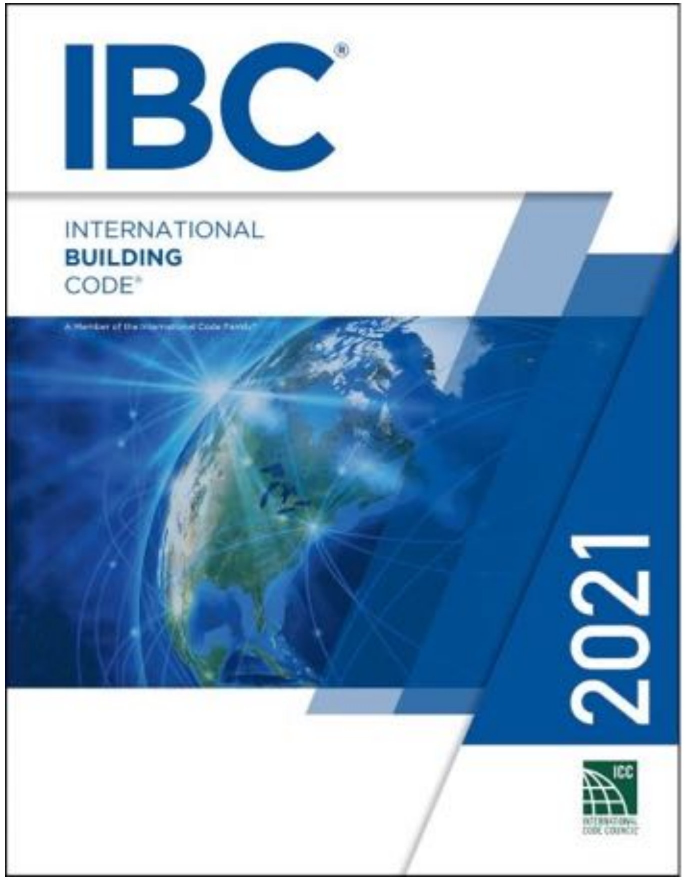
For unit to unit or unit to public or service areas:

Min. STC of 50 (45 if field tested):

- Walls, Partitions, and Floor/Ceiling Assemblies

Min. IIC of 50 (45 if field tested) for:

- Floor/Ceiling Assemblies



Acoustics & Sound Control

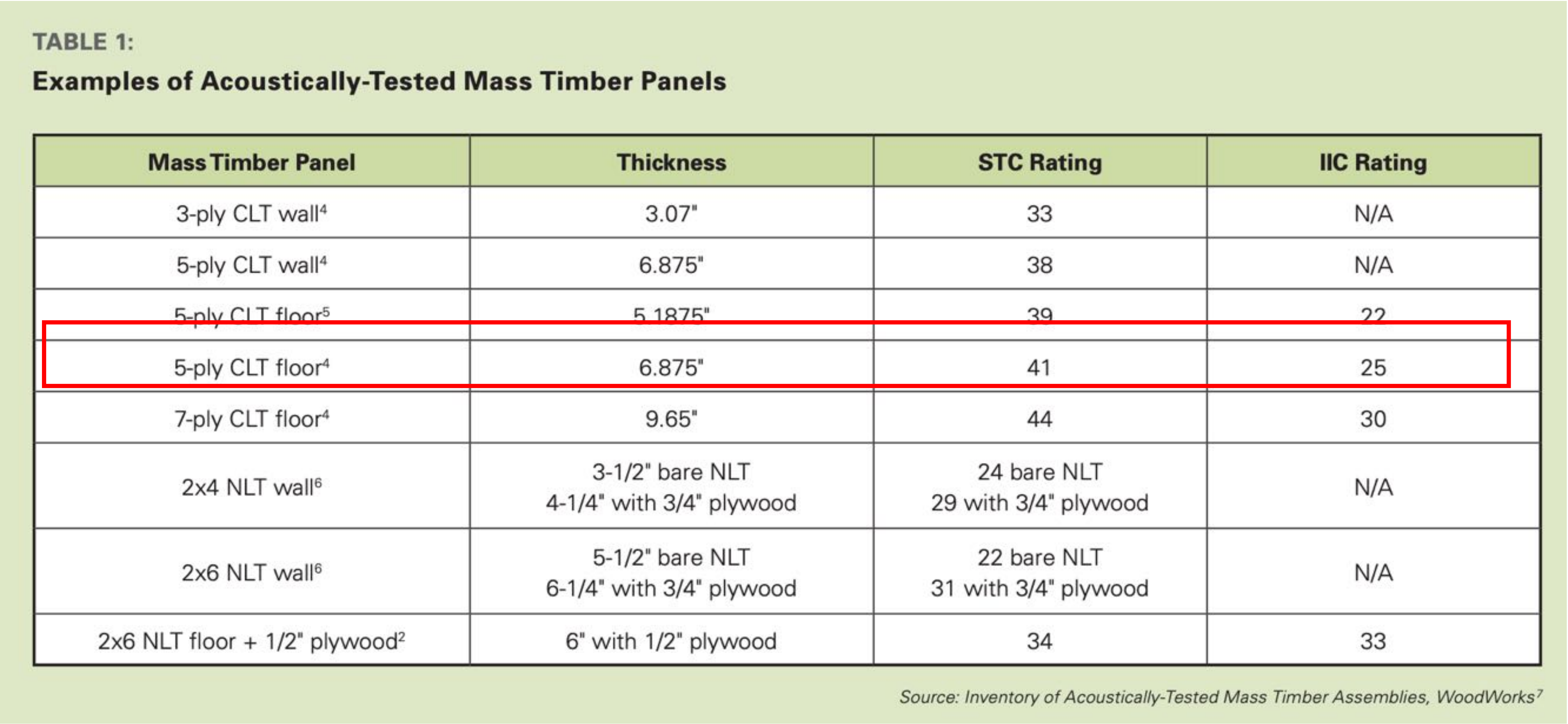


TABLE 1:

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

Concrete Slab:
6” Thick
80 PSF ⟷ 18 PSF
STC 53 ⟷ STC 41

CLT Slab:
6-7/8” Thick

Acoustics & Sound Control

Common mass timber floor assembly:

- Finish floor (if applicable)
- Underlayment (if finish floor)
- 1.5” to 4” thick concrete/gypcrete topping
- Acoustical mat
- WSP (if applicable)
- Mass timber floor panels

Credit: AcoustiTECH

Acoustics & Sound Control

Inventory of Tested Assemblies

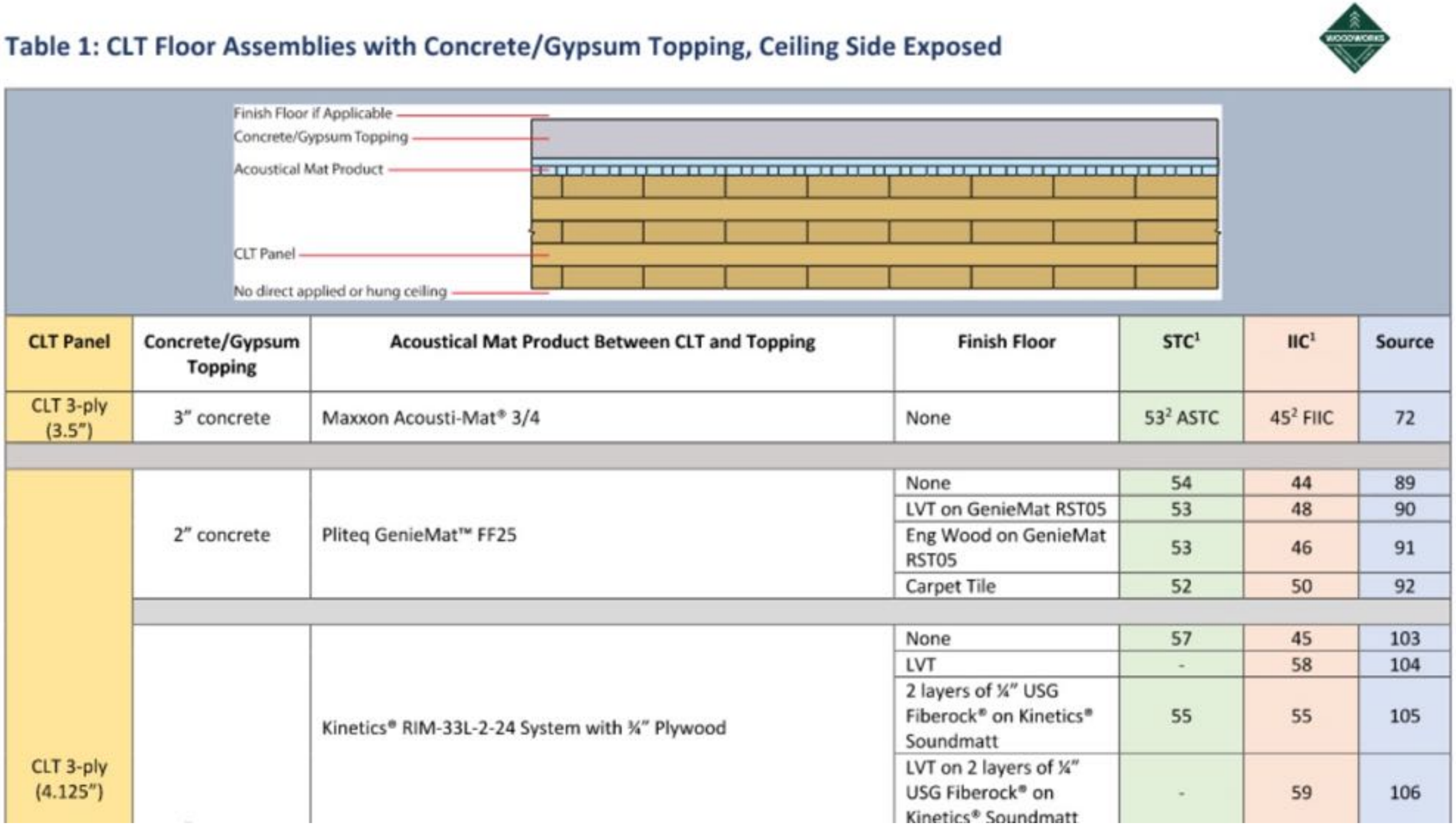


Table 1: CLT Floor Assemblies with Concrete/Gypsum Topping, Ceiling Side Exposed

CLT Panel	Concrete/Gypsum Topping	Acoustical Mat Product Between CLT and Topping	Finish Floor	STC[1]	IIC[1]	Source
CLT 3-ply (3.5")	3" concrete	Maxxon Acousti-Mat® 3/4	None	53[2] ASTC	45[2] FIIC	72
CLT 3-ply (4.125")	2" concrete	Pliteq GenieMat™ FF25	None	54	44	89
			LVT on GenieMat RST05	53	48	90
			Eng Wood on GenieMat RST05	53	46	91
			Carpet Tile	52	50	92
		Kinetics® RIM-33L-2-24 System with ¾" Plywood	None	57	45	103
			LVT	-	58	104
			2 layers of ¼" USG Fiberock® on Kinetics® Soundmatt	55	55	105
			LVT on 2 layers of ¼" USG Fiberock® on Kinetics® Soundmatt	-	59	106

Floor Vibration Design

“One might almost say that **strength is essential** and **otherwise unimportant**”

- Hardy Cross

US Building Code Requirements for Vibration

None

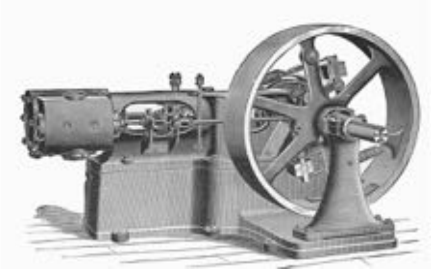
Barely discussed in IBC, NDS, etc.

ASCE 7 Commentary Appendix C has some discussion, no requirements

Common Vibration Sources for Buildings

Vibration sources are complex:

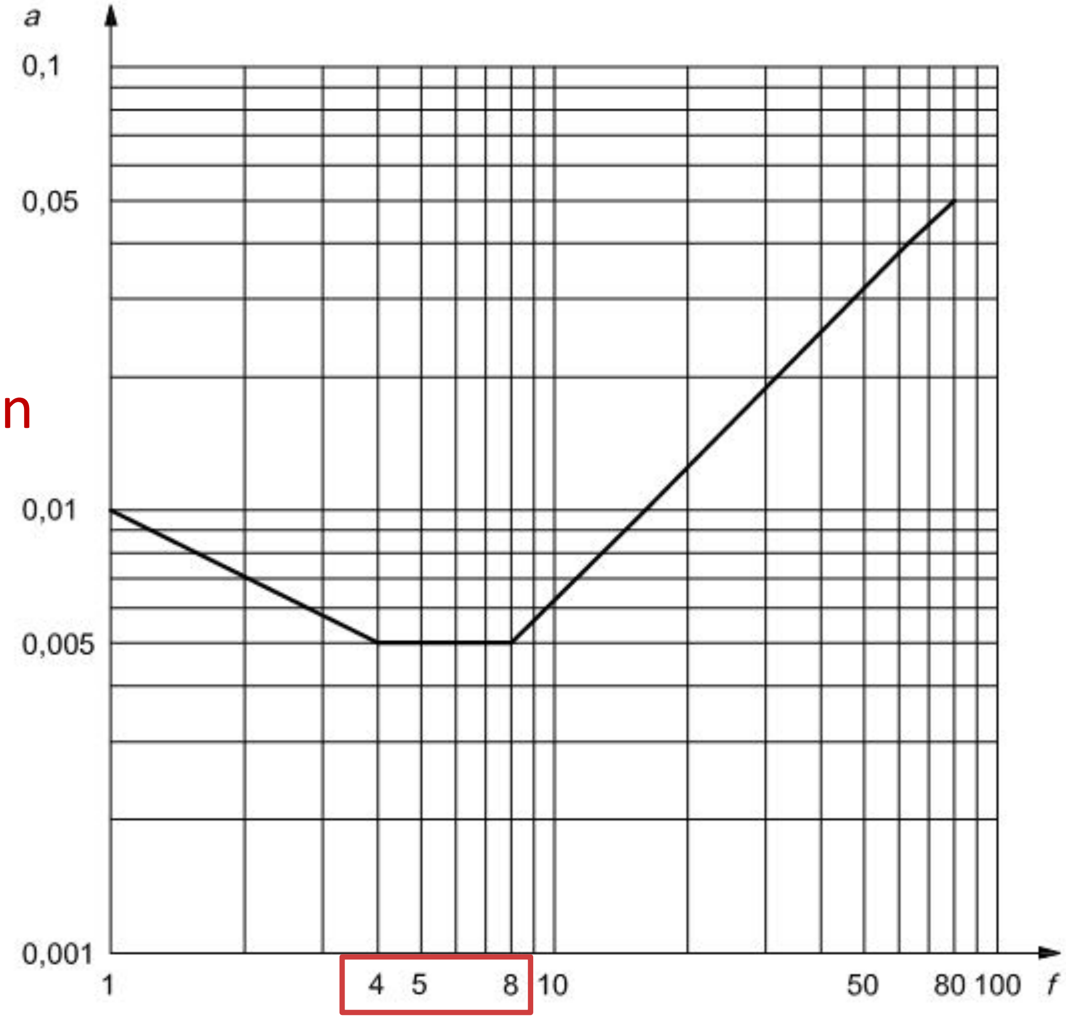
- Footfall, running, aerobics, etc.
- Machinery and equipment
- Vehicular traffic, rail traffic, forklifts
- Ground-borne, structure-borne, air-borne
- Steady-state, episodic, periodic
- Harmonic, pulse, random
- Moving, stationary



Floor Vibration Criteria – Human

Acceleration

0.05% g



Key

a acceleration (r.m.s.), m/s^2

f frequency, Hz

ISO 10137:2007

Limits of Human Perception of Acceleration

~.05% g (vertical) in 4-8 Hz

Framing Materials Properties for Vibration

Material	Floor Weight (psf)	Damping	Material Stiffness (10^6 psi)	Material Mass (pcf)	Example Floor System
Concrete	100-150	1-5%	3.2-5.8	120-150	2-way slab on columns
Steel	50-100	0.5-5%	30	490	Concrete on metal deck on purlins and girders
Mass Timber	15-65	1-5%	1.2-1.8	30-40	Beam *or* wall supported
Wood Frame	10-40	2-12%	1.2-2.0	30-40	Wall supported

Vibration Design Methods

Rules of Thumb

Empirical Methods

Simplified Analytical

FEM/Modal

FEM/Time History

$\Delta < L/480$

$f_n > 14$ Hz

Woeste & Dolan *Wood Frame*

FPI/CLT Handbook *Mass Timber*

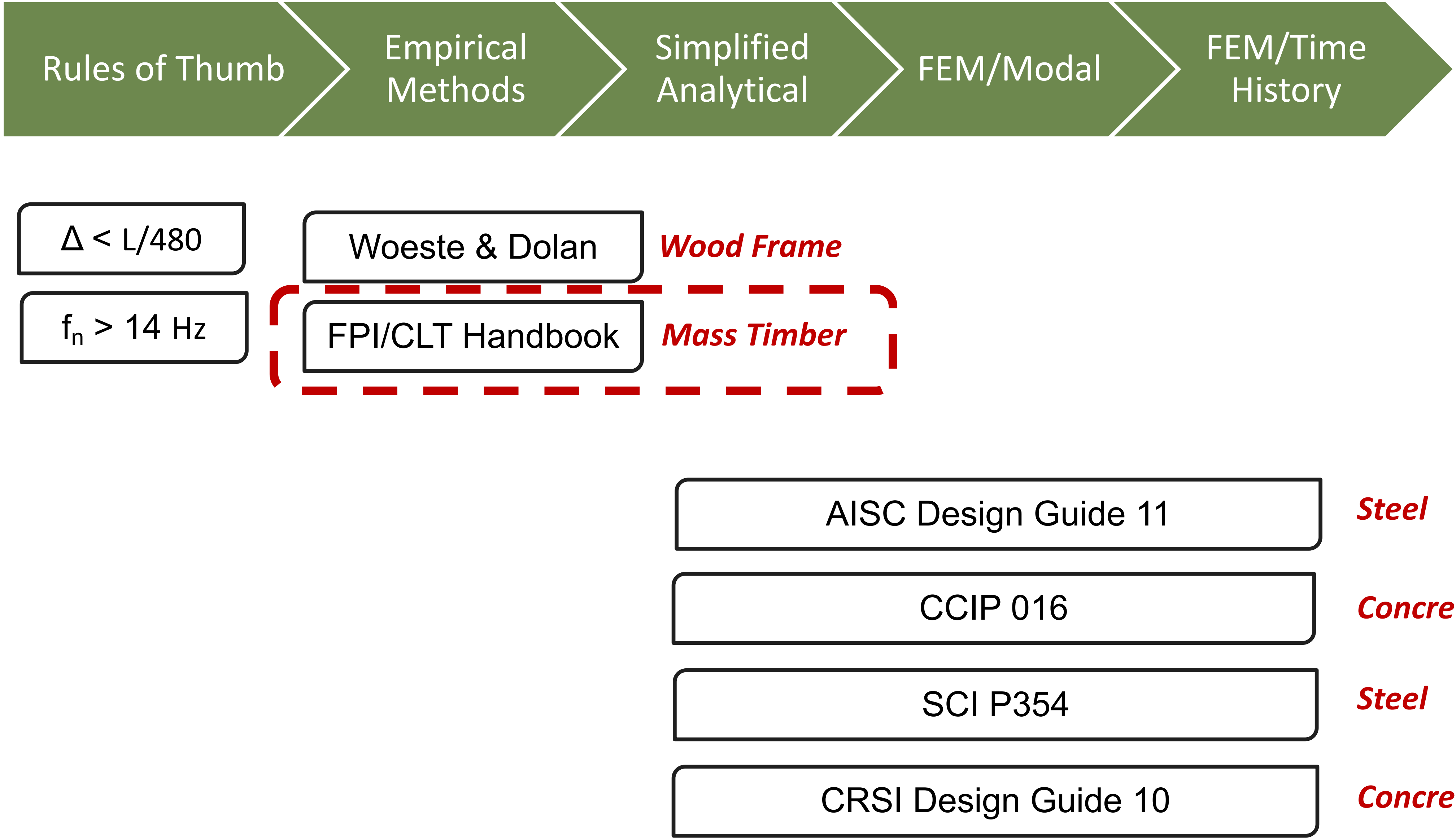
AISC Design Guide 11 *Steel*

CCIP 016 *Concrete*

SCI P354 *Steel*

CRSI Design Guide 10 *Concrete*

Vibration Design Methods



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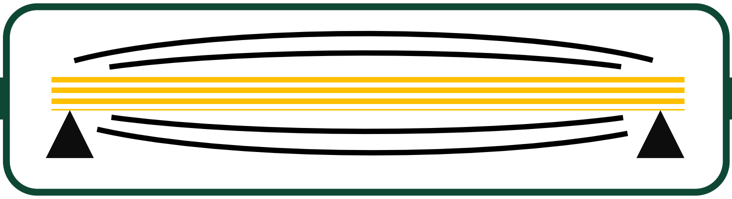
CLT Handbook Method



Limit CLT Floor Span such that

$$L_{lim} \leq \frac{1}{12.05} \frac{\left(EI_{eff}\right)^{0.293}}{(\overline{\rho}A)^{0.122}}$$

Based on:

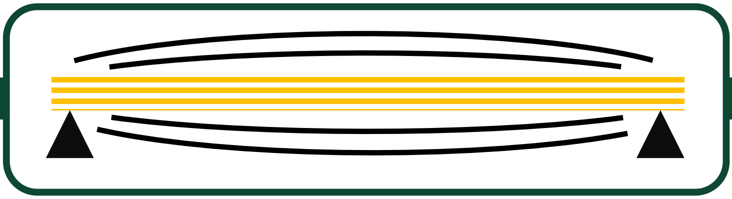
- Un-topped CLT
- Single, Simple span
- Bearing wall supports.

Does not account for:

- Supporting beam flexibility
- Multi-span conditions
- Additional floor mass (topping slab, etc)

Reference: US CLT Handbook, Chapter 7

CLT Handbook In Practice



- Experience shown it consistently produces well performing floors
- Does not consider
  - Multi-span panels
  - Flexibility of supports, e.g. beams
  - Impact of topping slabs
    (more mass, but lower frequency)

Improves Performance

Lowers Performance

Performance??

- Recommend 20% increase in acceptable span length OK for multi-span panels with non-structural elements that are considered to provide an enhanced stiffening effect, including partition walls, finishes and ceilings, etc.

CLT Handbook Base Span Limit

For PRG 320-2019 Basic CLT Grades and Layups from Solid Sawn Lumber

Grade	Layup	Thickness	Base Span Limit
E1	3ply	4 1/8”	13.1
	5ply	6 7/8”	18.2
	7ply	9 5/8”	22.7
E2	3ply	4 1/8”	12.4
	5ply	6 7/8”	17.2
	7ply	9 5/8”	21.6
E3	3ply	4 1/8”	12.0
	5ply	6 7/8”	16.7
	7ply	9 5/8”	20.9
E4	3ply	4 1/8”	12.7
	5ply	6 7/8”	17.6
	7ply	9 5/8”	22.1
E5	3ply	4 1/8”	12.6
	5ply	6 7/8”	17.5
	7ply	9 5/8”	21.9

Grade	Layup	Thickness	FPI Span Limit
V1	3ply	4 1/8”	12.6
	5ply	6 7/8”	17.6
	7ply	9 5/8”	22.0
V1(N)	3ply	4 1/8”	12.6
	5ply	6 7/8”	17.6
	7ply	9 5/8”	22.0
V2	3ply	4 1/8”	12.4
	5ply	6 7/8”	17.2
	7ply	9 5/8”	21.5
V3	3ply	4 1/8”	12.0
	5ply	6 7/8”	16.7
	7ply	9 5/8”	20.9
V4	3ply	4 1/8”	11.7
	5ply	6 7/8”	16.3
	7ply	9 5/8”	20.4
V5	3ply	4 1/8”	12.1
	5ply	6 7/8”	16.8
	7ply	9 5/8”	21.0

Reference: US Mass Timber Floor Vibration Design Guide, assuming 12% M.C.

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	5ply	6 7/8”	17.5
	7ply	9 5/8”	21.9

Approximate Base Span Limits:

4 $^{1}/_{8}$” 3-ply: ~12 to 13 ft
6 $^{7}/_{8}$” 5-ply: ~16 to 18 ft
9 $^{5}/_{8}$” 7-ply: ~20 to 22 ft

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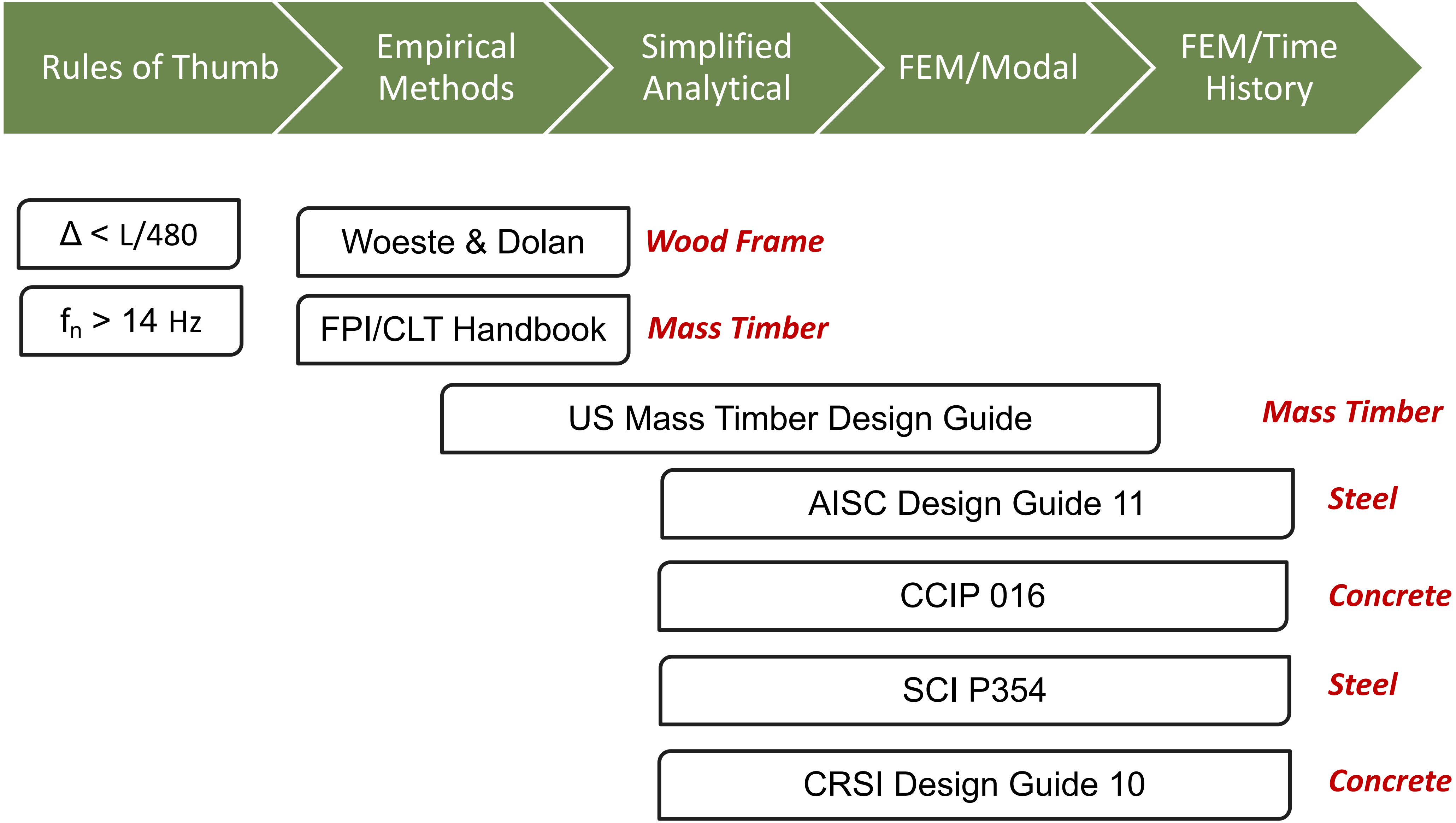
Limitations:

- **Does not account for strength or deflections**
- **Does not account for beam flexibility**
- **Does not account for project specifics**

Reference: US Mass Timber Floor Vibration Design Guide, assuming 12% M.C.

Vibration Design Methods



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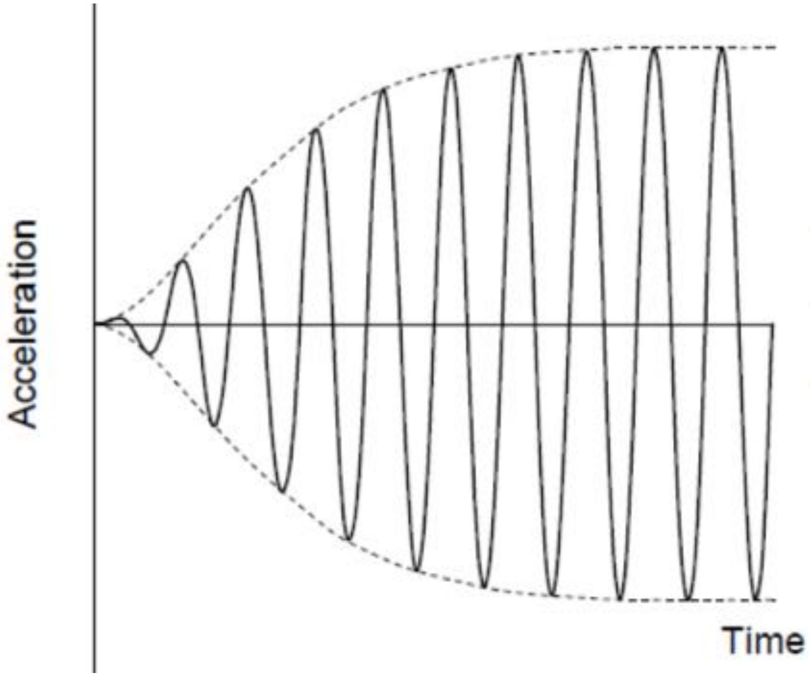
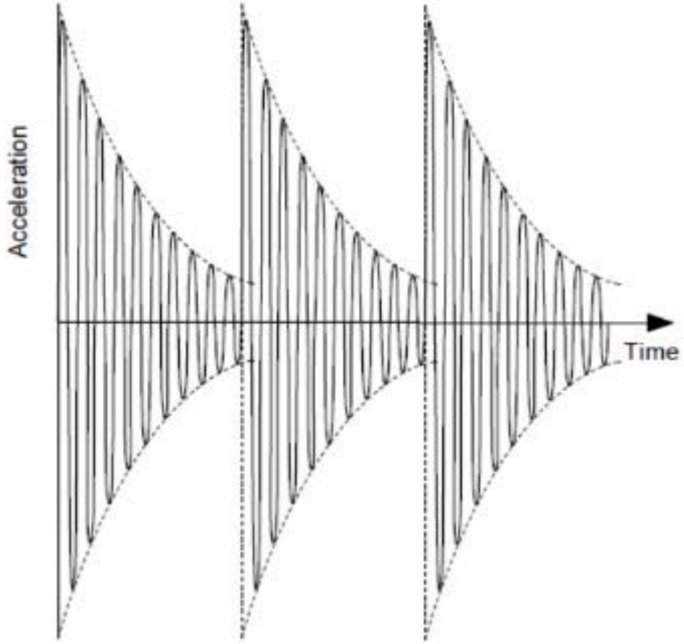
Resonant vs Impulsive Response



Excitation creates Resonant build-up of vibration



Response decays out between load impulses

Resonant Response

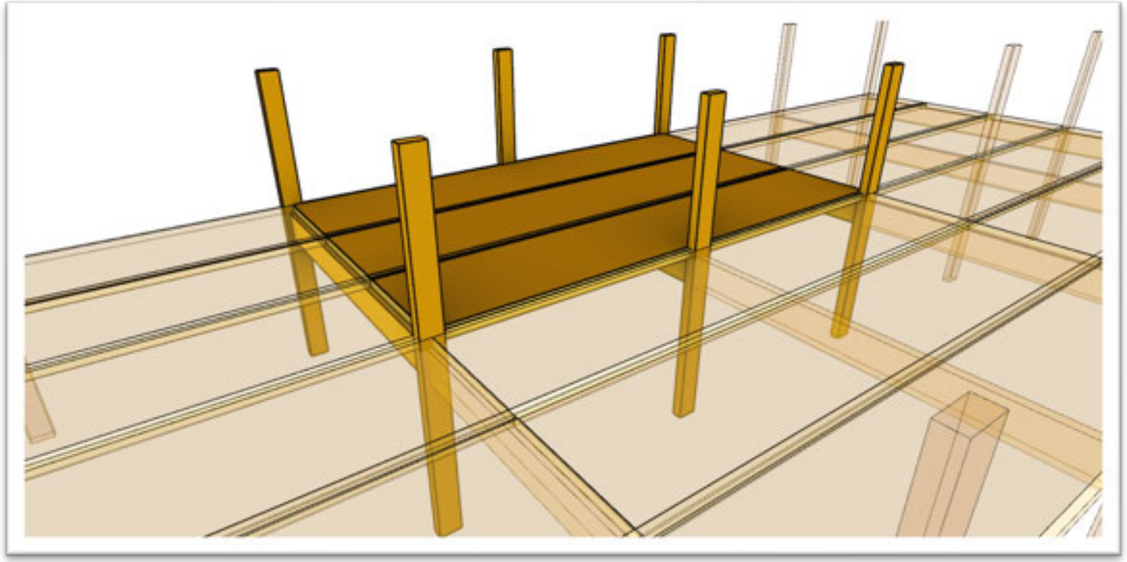
Impulsive/Transient Response

For walking excitations

f_n ~< 8-10 Hz

f_n ~> 8-10 Hz

Beam vs Wall Supported Floors



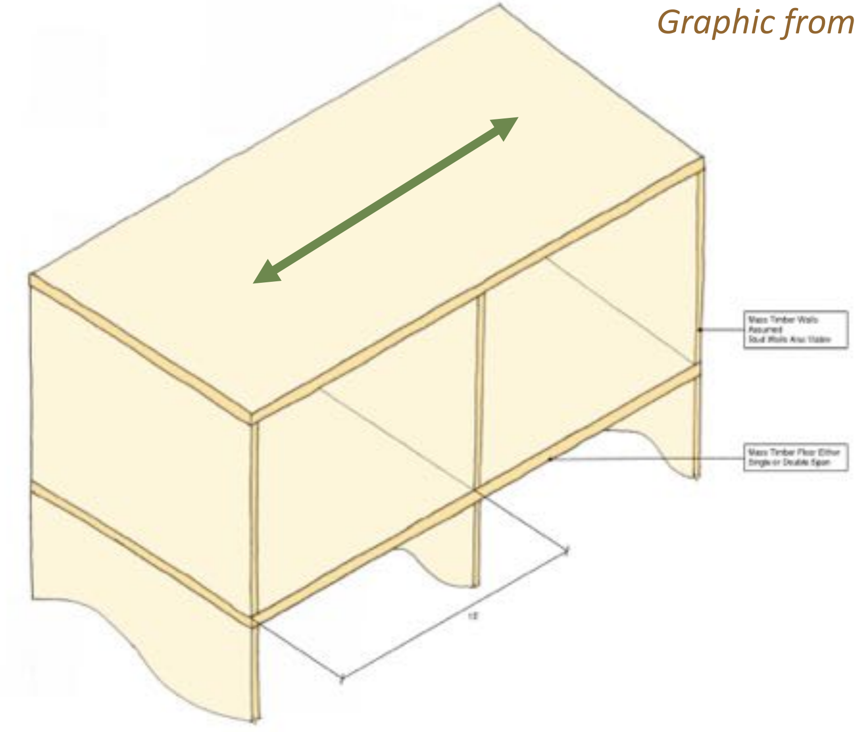
Graphic from StructureCraft

Mass Timber Panels on Grid of Beams.
Frequency of Floor < Frequency of Panel
Vibration of Floor > Vibration of Panel
Vibration Design Depends on Beams

<u>Low Frequency Floor?</u>

Maybe

Graphic from ASPECT



Mass Timber Panels on Bearing Walls

<u>High Frequency Floor?</u>

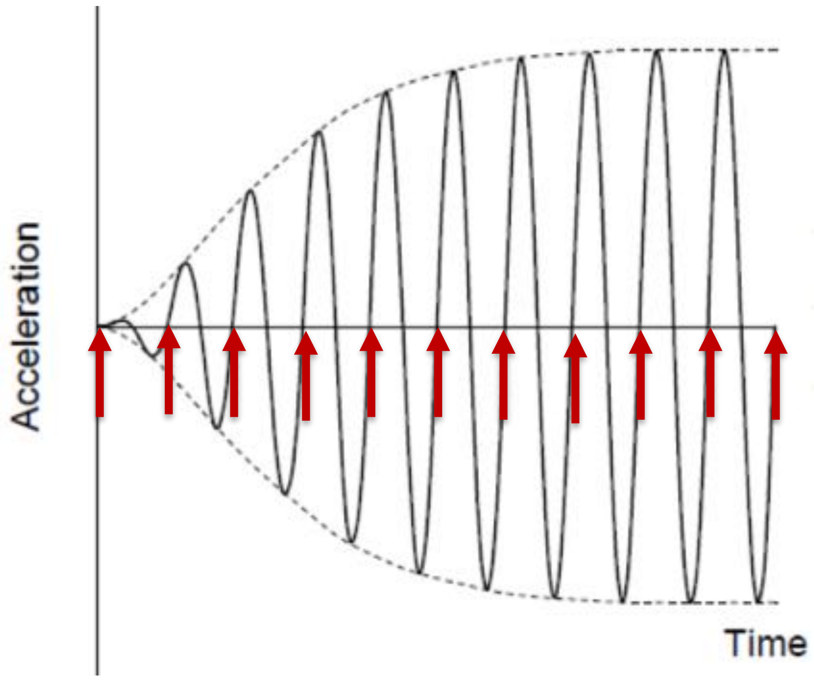
At all but long floor spans

Walking Frequency f_w

Walking Speed	**Walking Frequency**	**Steps Per Minute**
Very Slow	1.25 Hz	75 SPM
Slow	1.6 Hz	95 SPM
Moderate	1.85 Hz	110 SPM
Fast	2.1 Hz	126 SPM
Running	Up to 4.0 Hz	240 SPM
<u>Practical Tip</u> - walk to a metronome too understand the range		

The range of walking frequencies considered is
an important consideration of vibration analysis

Resonant vs Impulsive Response



Excitation Frequency not >> Natural Frequency
Excitation Creates Resonant Build-up of Vibration

Resonant Response

Resonance occurs when walking frequency = natural frequency

$$f_w = f_n$$

Also occurs when a harmonic of the walking frequency ~= natural frequency

$$n\, f_w = f_n$$

For 'n' up to around 4

Walking at f_w =2 Hz creates resonance in floor with natural frequency, f_n, at

2Hz, 4 Hz, 6 Hz, and 8Hz

Example Acceleration Performance Targets

Acceleration

5.0% g

0.5% g

0.05% g

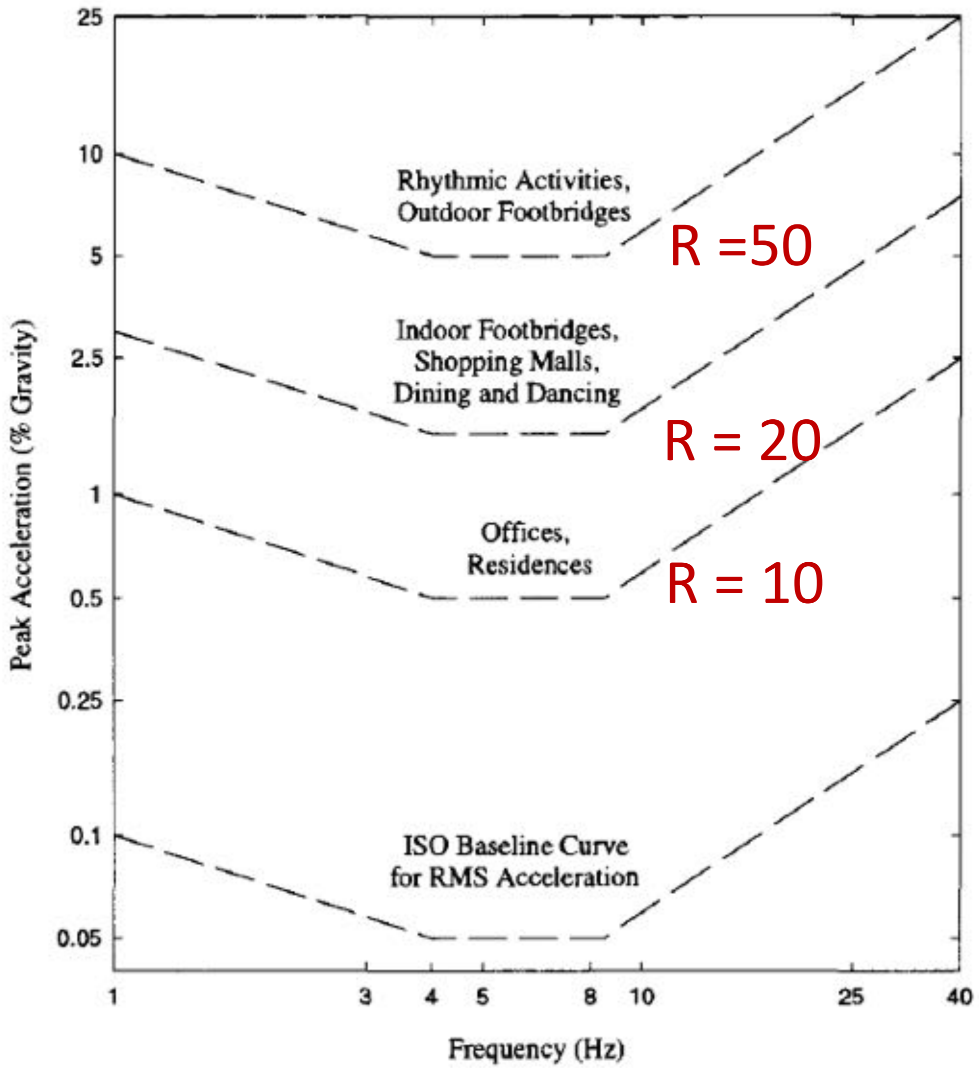


Illustration: Murray et al., 1997
AISC Design Guide 11, 1st Ed.

Range of Acceptable Perception of Acceleration

0.5% to 5% g (vertical)

European Methods (CCIP) use “R” values:
R = predicted value/baseline value

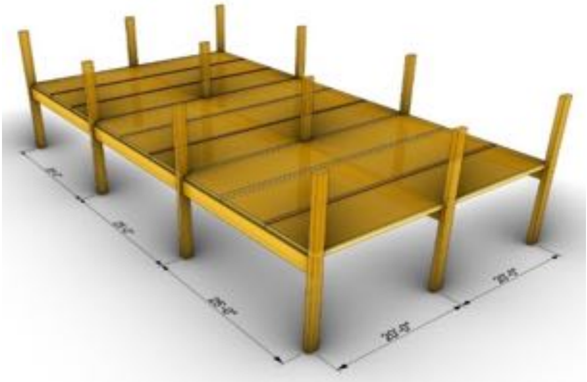
US MTFVDG Suggested Performance Targets

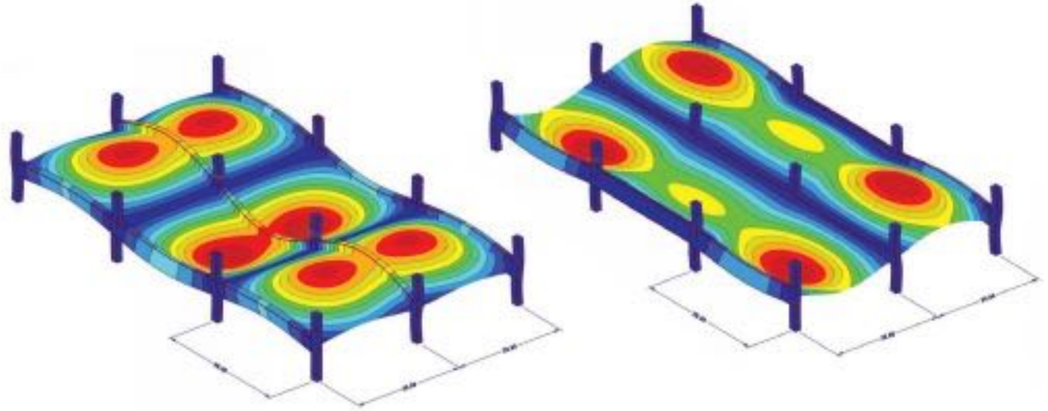
Place	Peak Acceleration Target	RMS Velocity Target
Offices, residences	0.5% g	16,000 – 32,000 mips
Premium offices or luxury residences	0.3% g	8,000 – 16,000 mips

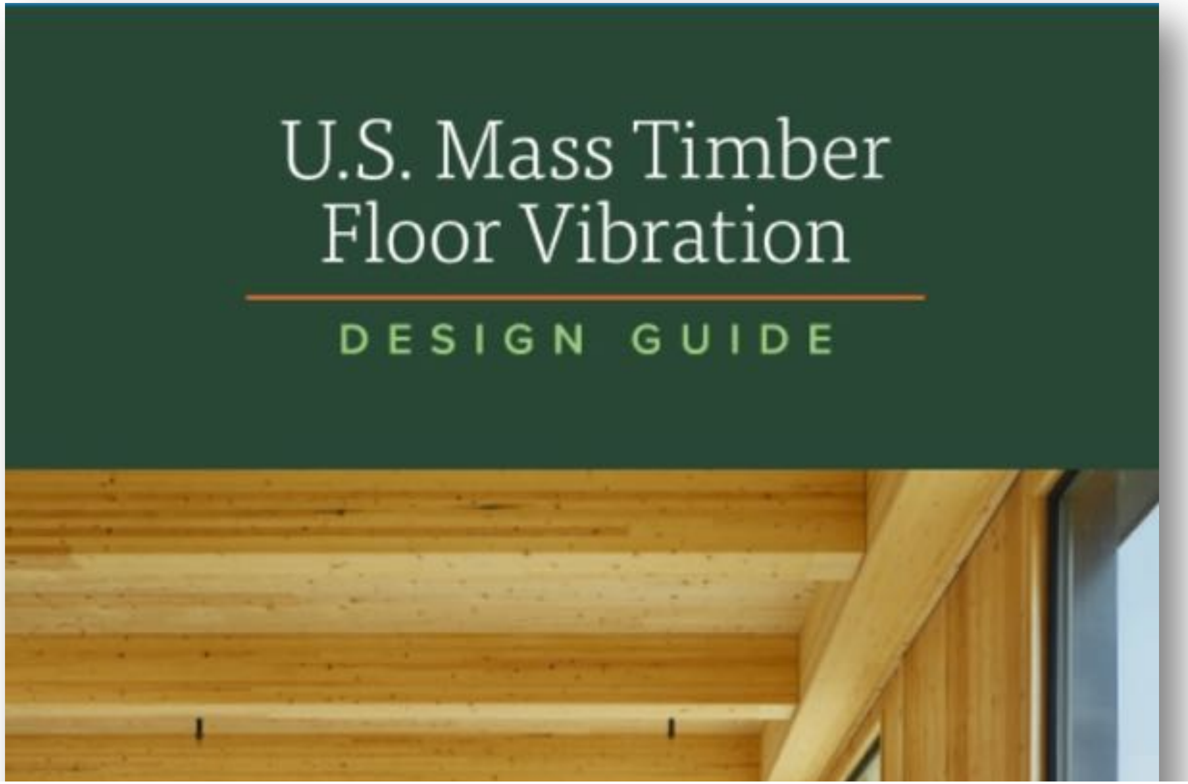
There are many assumptions and judgements which go into predicting the response.

This is not an exact compliance check.

U.S. Mass Timber Floor Vibration Design Guide






U.S. Mass Timber
Floor Vibration
DESIGN GUIDE

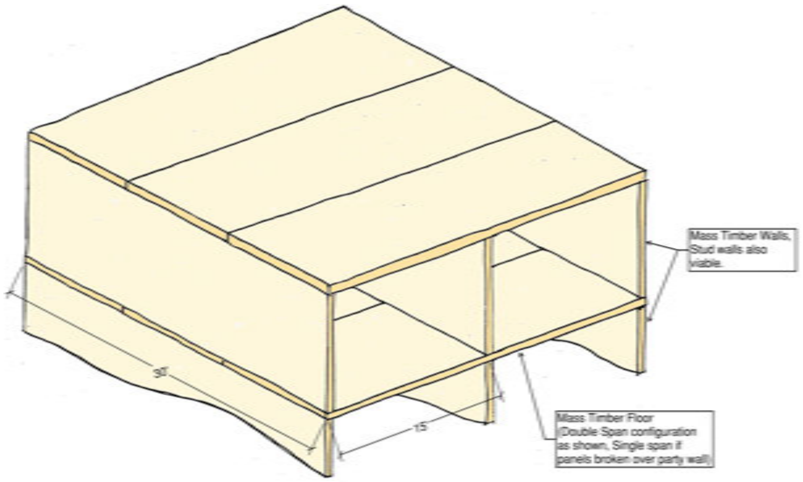
Worked office, lab and residential Examples

Covers simple and complex methods for bearing wall and frame supported floor systems

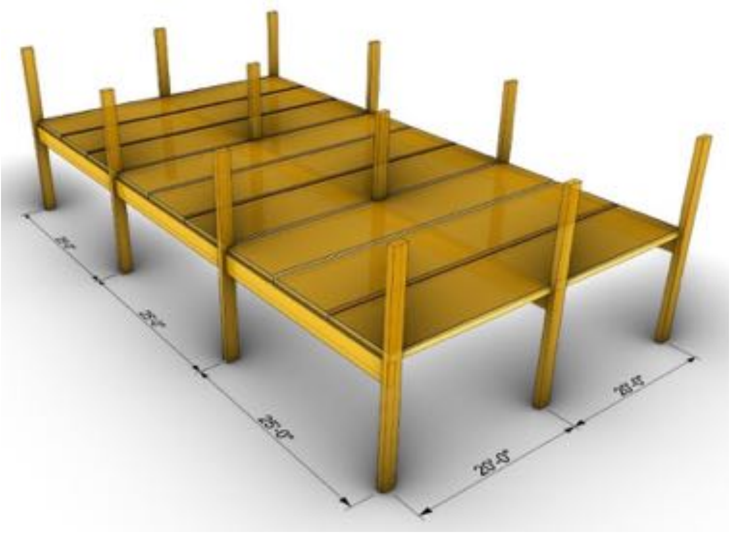
Available for free from www.woodworks.org/resources/us-mass-timber-floor-vibration-design-guide/

Details of U.S. Mass Timber Floor Vibration Design Guide

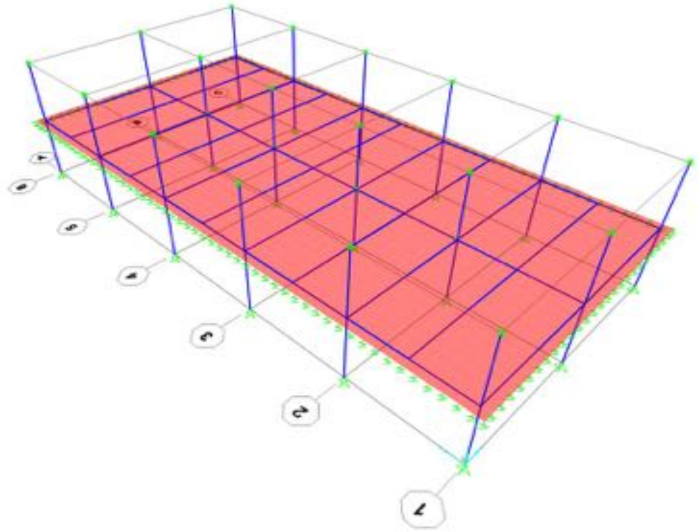
Vibration Design Examples



Residential Bearing Wall Building with CLT



Open Office with NLT on Glulam Frame



High Performance Lab Space with CLT on Glulam Frame

SB

MEPF Integration

MEP Layout & Integration

MEP Layout & Integration

Photo credit: WoodWorks

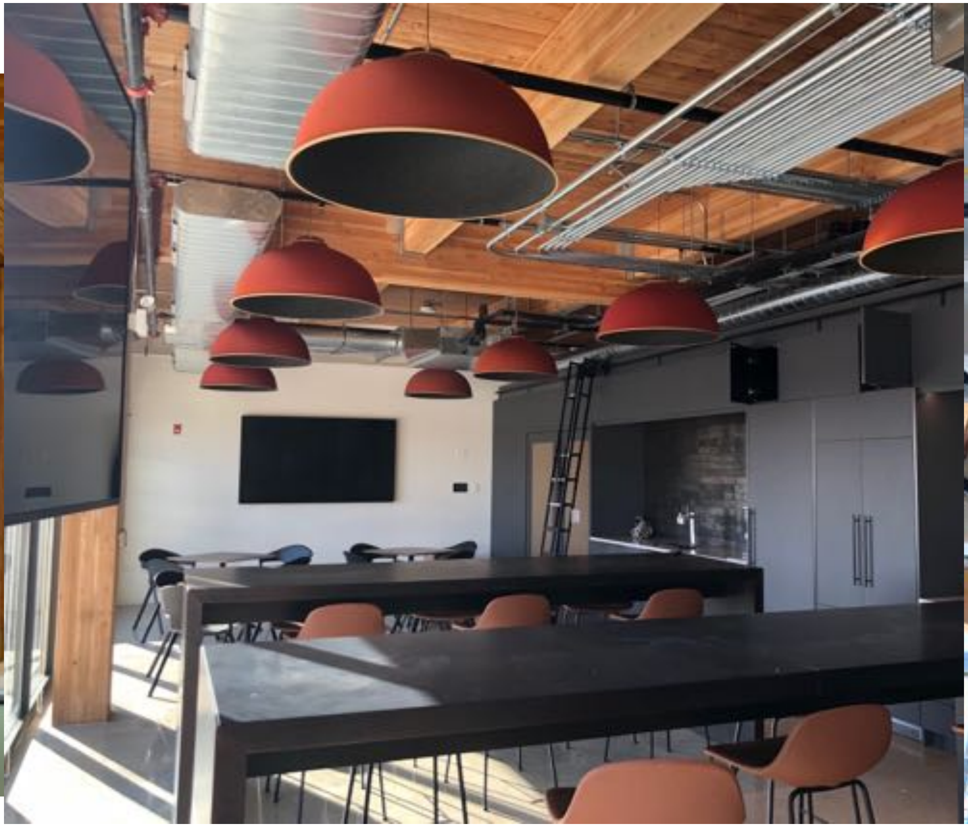
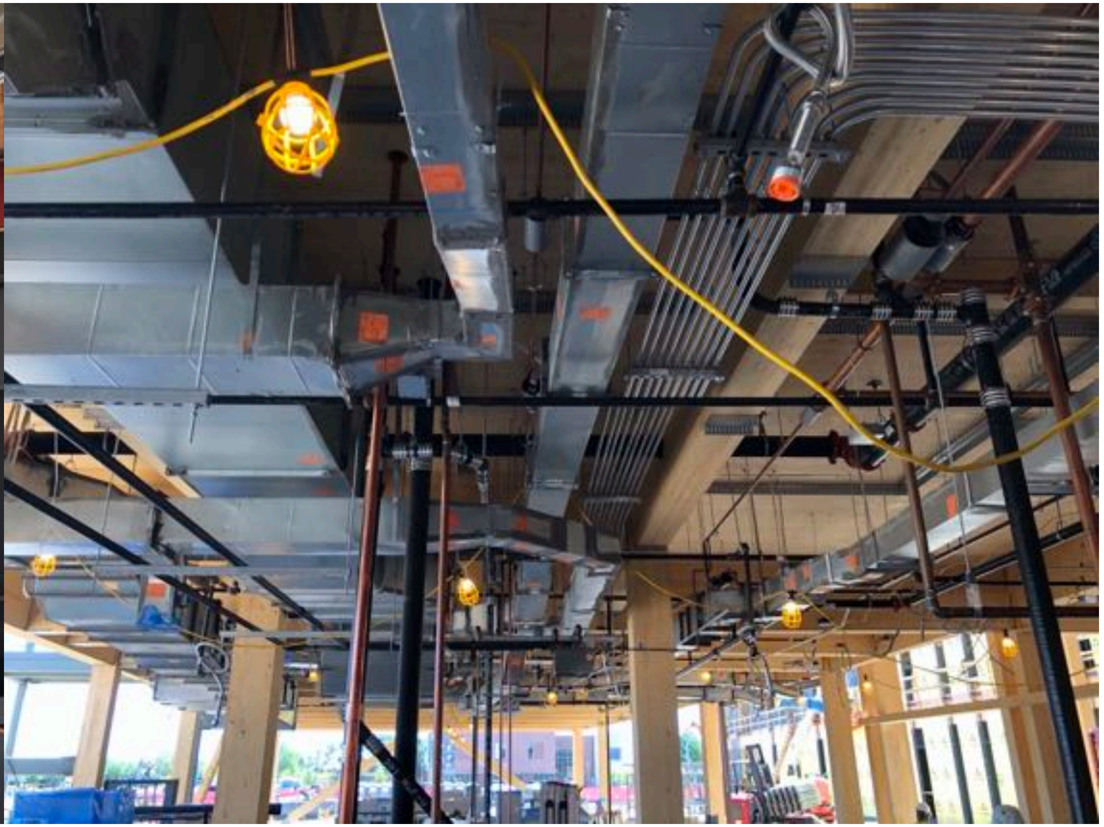
Exposed MEP

MEP items often left exposed on the ceiling side of floor assembly

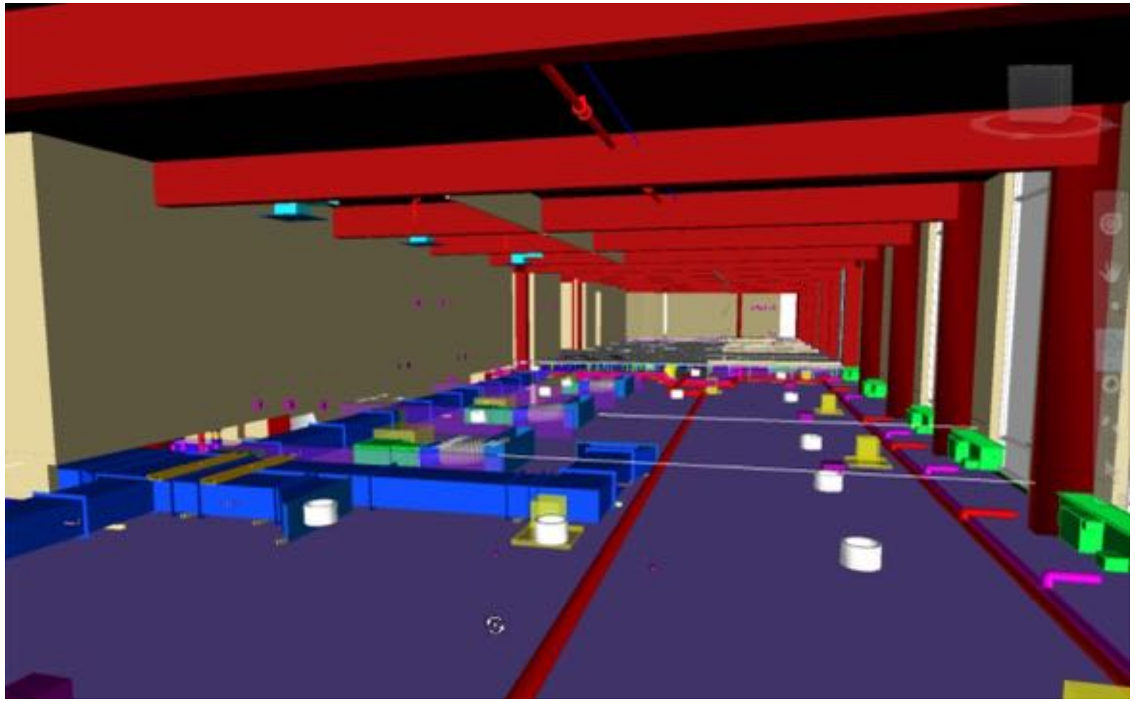
MEP Layout & Integration

Set Realistic Owner Expectations About Aesthetics

- MEP fully exposed with MT structure, or limited exposure?
- Also consider acoustic impacts of MEPF routing

Embracing BIM for Fabrication



Photos: Swinerton

MEP Layout & Integration

Key considerations:

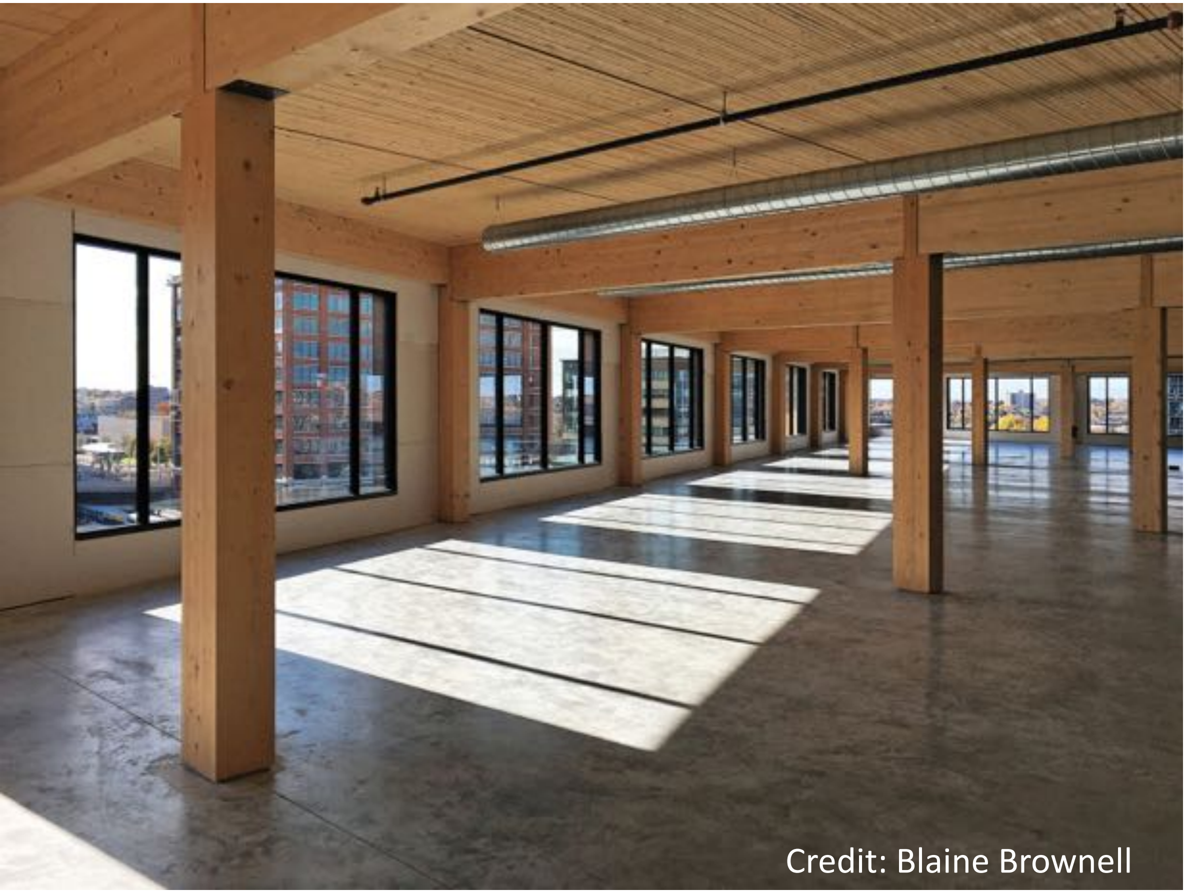
- Level of exposure desired
- Floor to floor, structure depth & desired head height
- Building occupancy and configuration (i.e. central core vs. double loaded corridor)
- Grid layout and beam orientations
- Need for future tenant reconfiguration
- Impact on fire & structural design: concealed spaces,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

Credit: WoodWorks

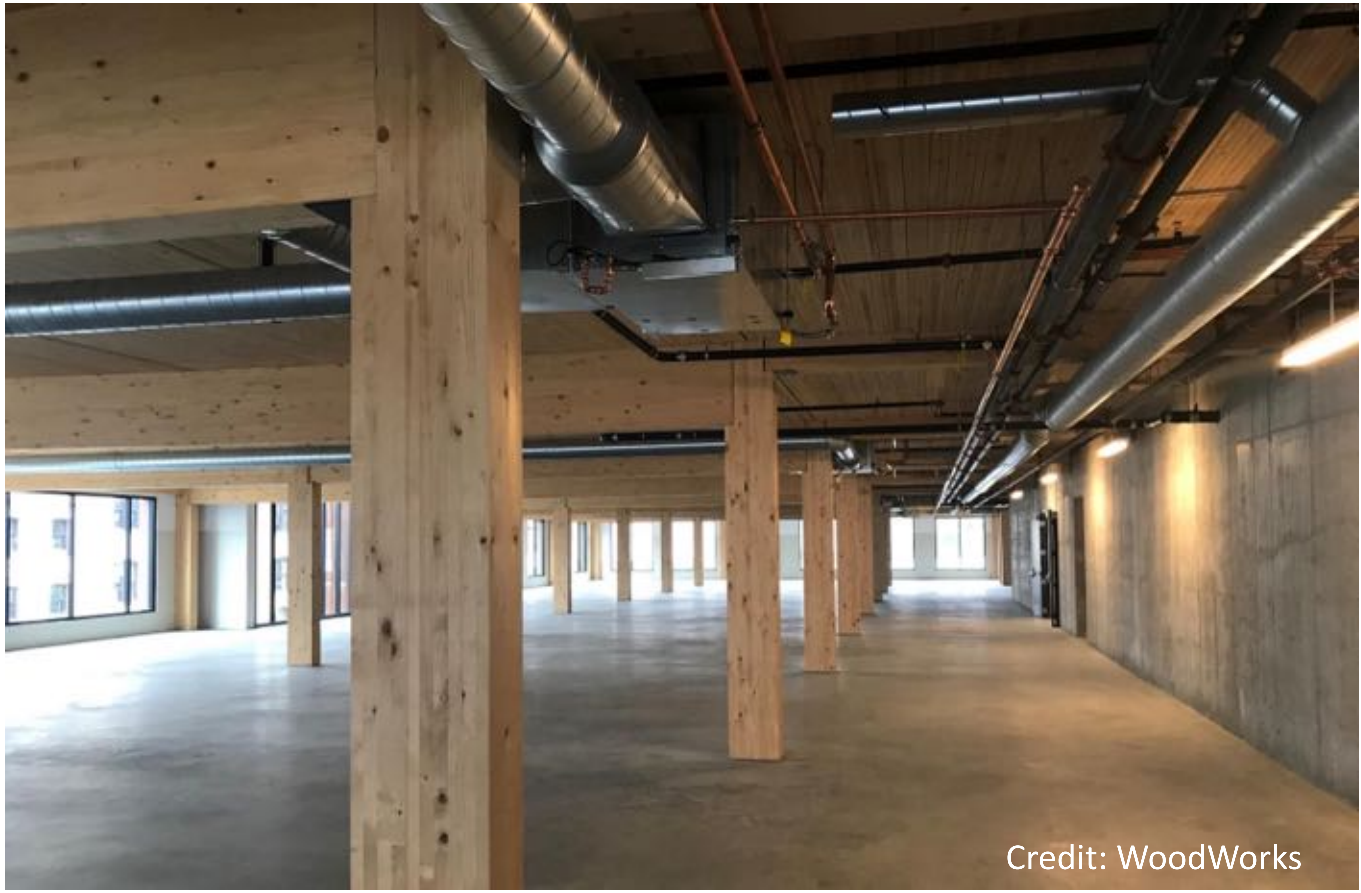
MEP Layout & Integration

Smaller grid bays at central core (more head height)

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

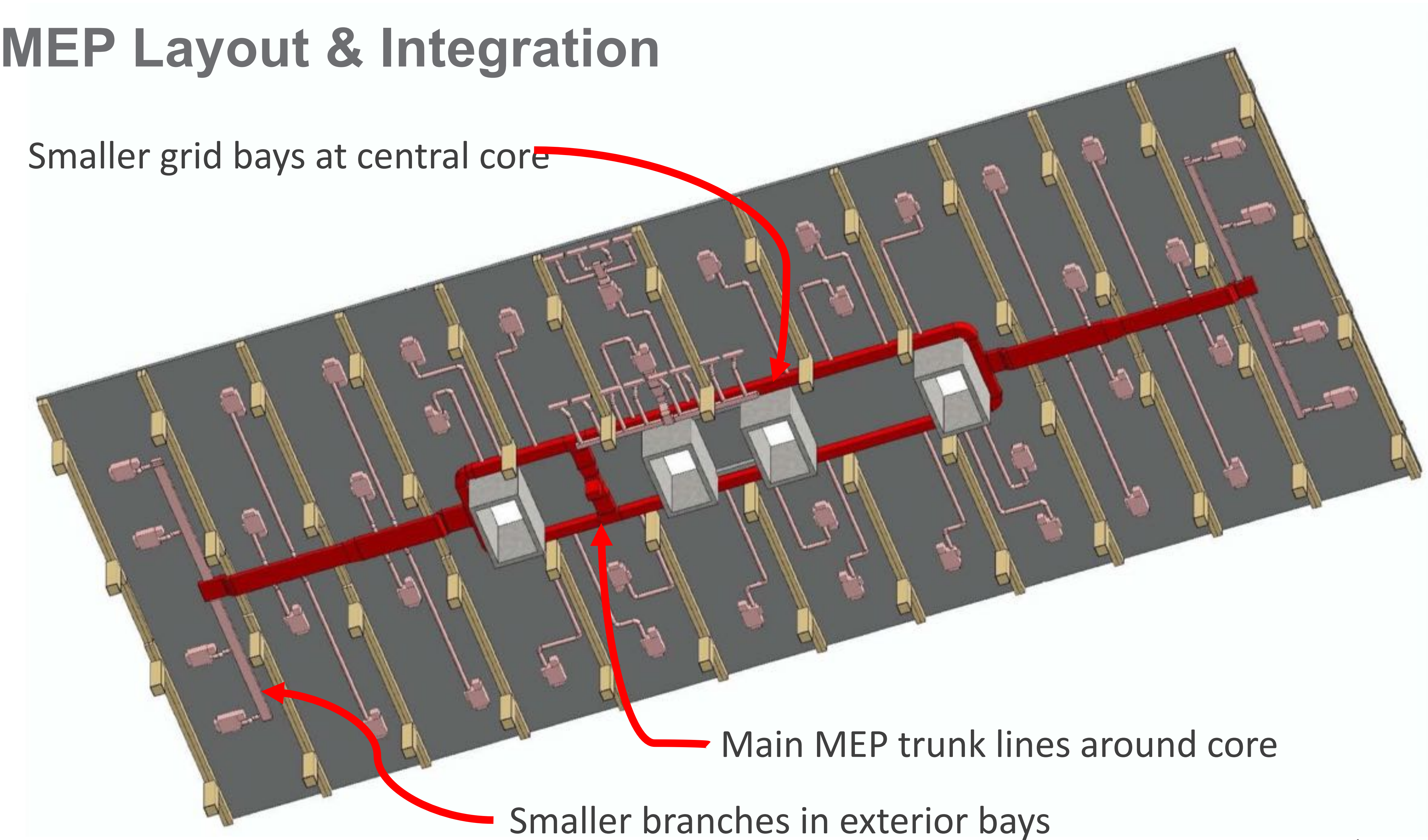


Credit: Blaine Brownell



Credit: WoodWorks

MEP Layout & Integration



Smaller grid bays at central core

Main MEP trunk lines around core

Smaller branches in exterior bays

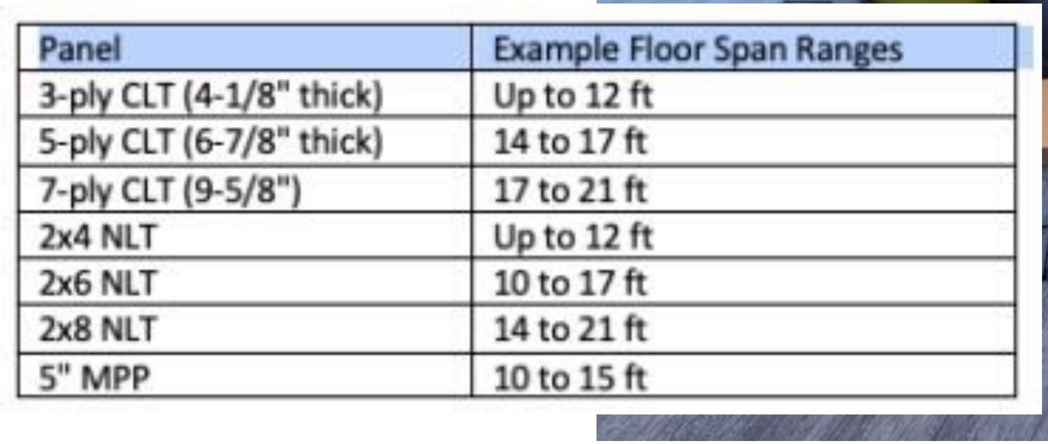
Credit: ARUP

MEP Layout & Integration

Grid impact: Relies on one-way beam layout. Columns/beams spaced at panel span limits in one direction.

Beam penetrations are minimized/eliminated

Recall typical panel span limits:



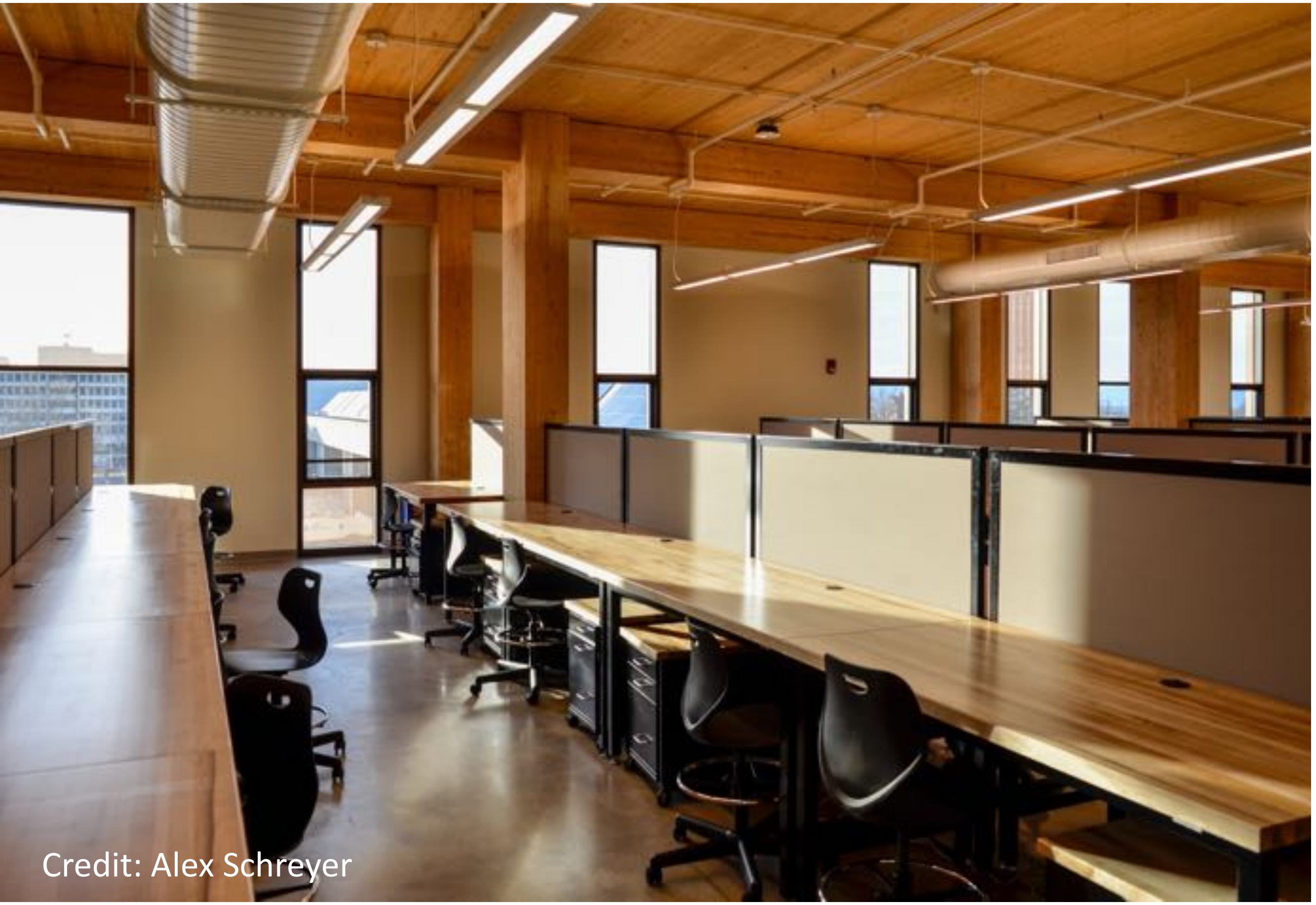
Panel	Example Floor Span Ranges
3-ply CLT (4-1/8" thick)	Up to 12 ft
5-ply CLT (6-7/8" thick)	14 to 17 ft
7-ply CLT (9-5/8")	17 to 21 ft
2x4 NLT	Up to 12 ft
2x6 NLT	10 to 17 ft
2x8 NLT	14 to 21 ft
5" MPP	10 to 15 ft

Credit: Hacker Architects

MEP Layout & Integration

Dropped below MT framing

- Can simplify coordination (fewer penetrations)
- Bigger impact on head height

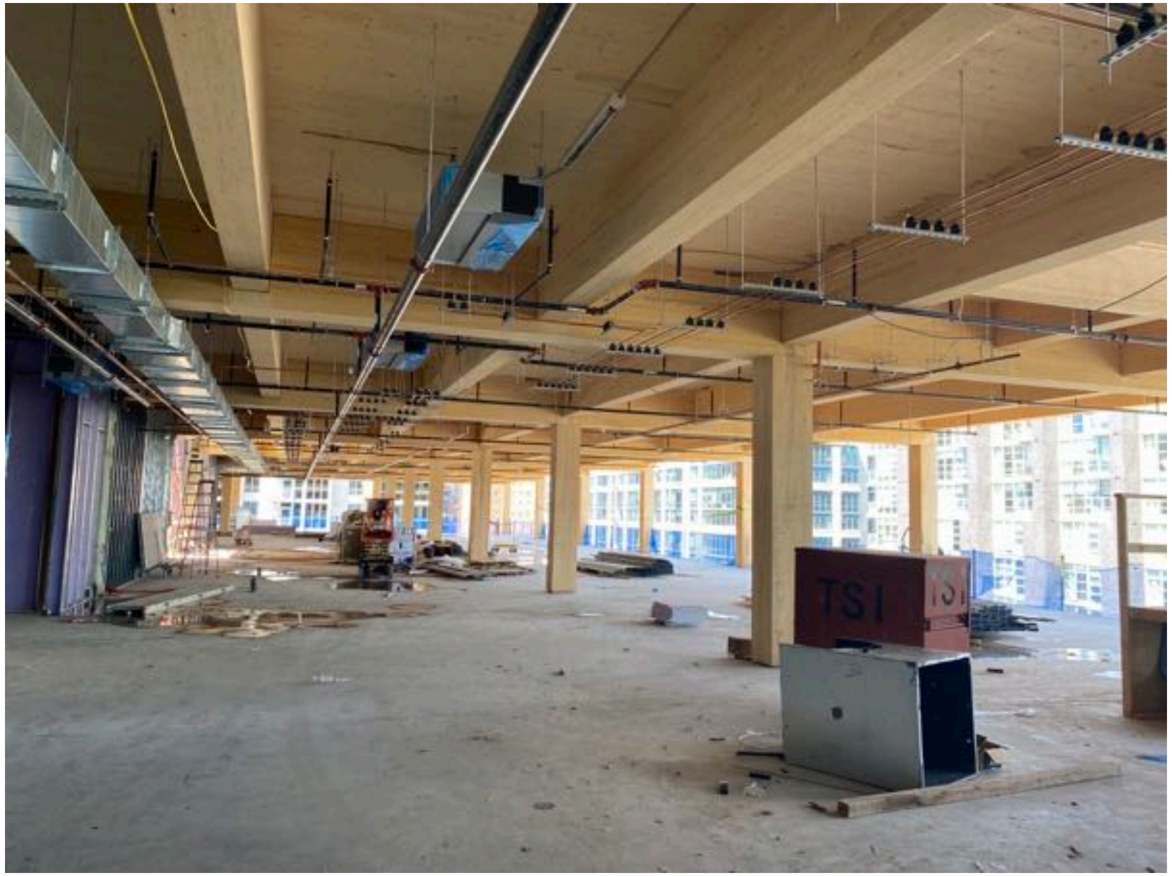


Credit: Alex Schreyer

Credit: WoodWorks

MEP Layout & Integration

Grid impact: Usually more efficient when using a square-ish grid with beams in two directions



Credit: SOM Timber Tower Report

MEP Layout & Integration

In penetrations through MT framing

- Requires more coordination (penetrations)
- Bigger impact on structural capacity of penetrated members
- Minimal impact on head height

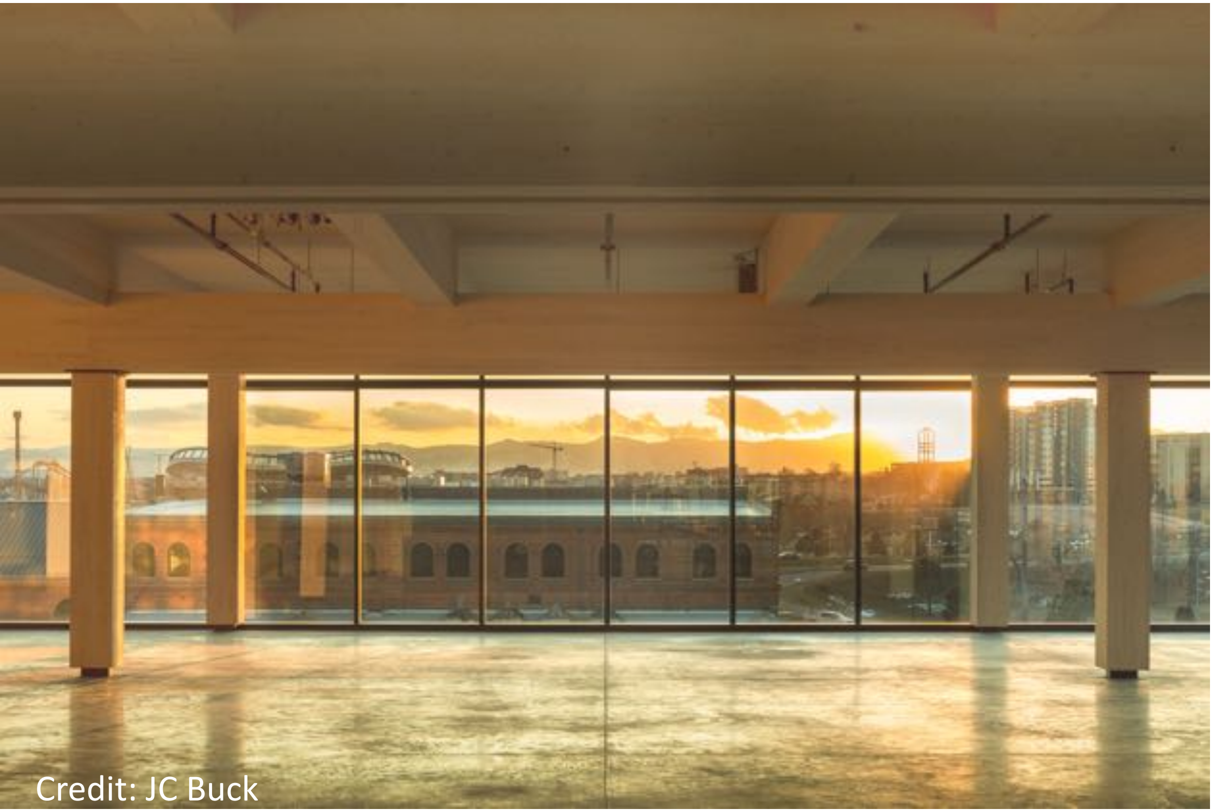
Credit: WoodWorks

Credit: WoodWorks

MEP Layout & Integration

In chases above beams and below panels

- Fewer penetrations
- Bigger impact on head height (overall structure depth is greater)
- FRR impacts: top of beam exposure



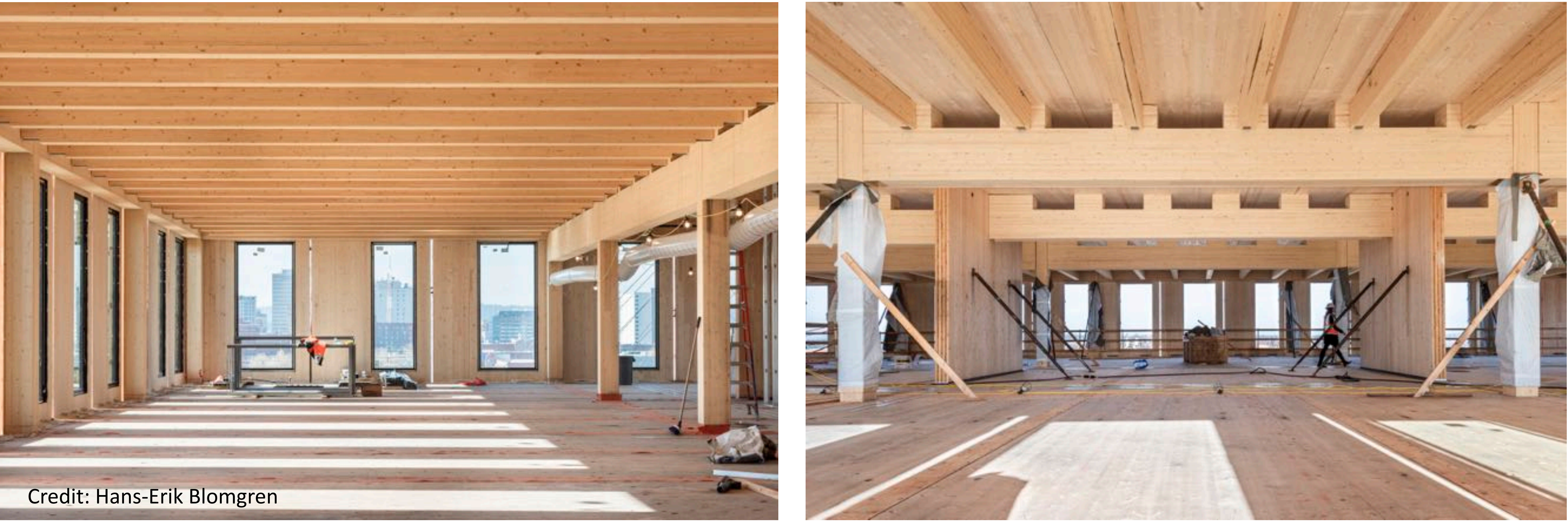
Credit: JC Buck

Credit: KL&A Engineers & Builders

MEP Layout & Integration

In chases above beams and below panels at Catalyst

- 30x30 grid, 5-ply CLT ribbed beam system



Credit: Hans-Erik Blomgren

MEP Layout & Integration

In gaps between MT panels

- Fewer penetrations, can allow for easier modifications later

Credit: Ema Peter/MGA

Credit: Hacker Architects

MEP Layout & Integration

In gaps between MT panels

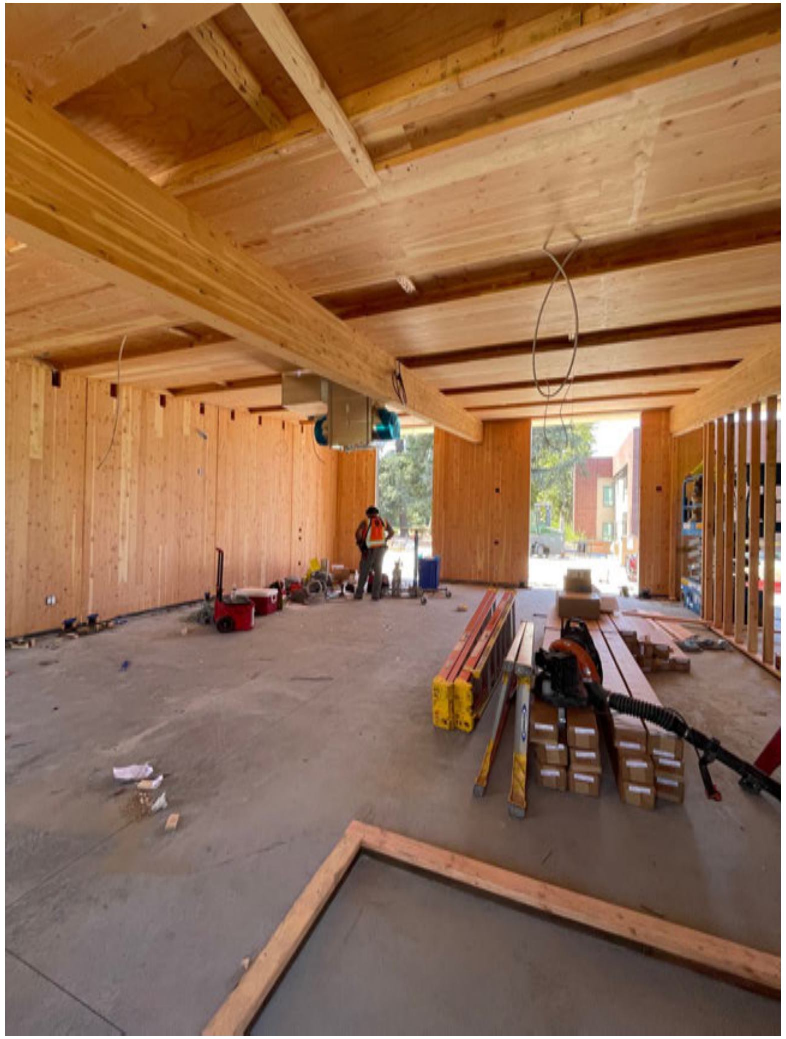
- FRR impacts: generally topping slab relied on for FRR

Credit: KPFF

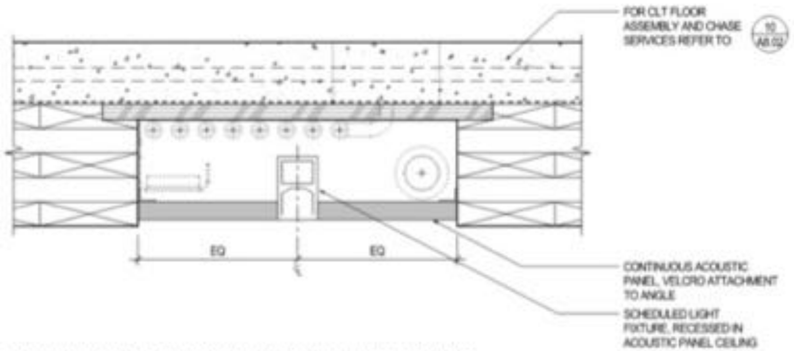
MEP Layout & Integration

In gaps between MT panels

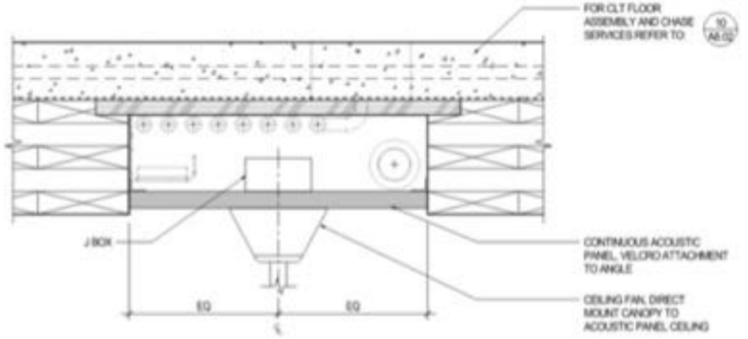
- Greater flexibility in MEP layout



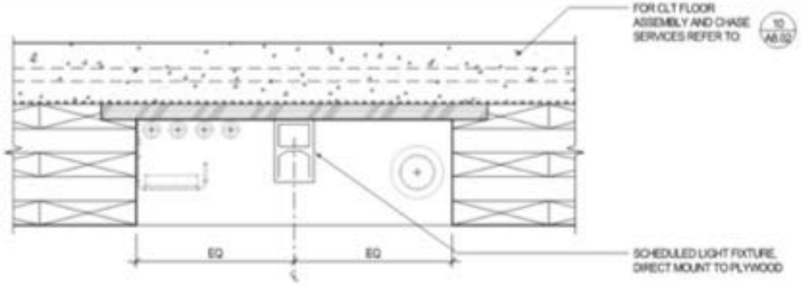
Credit: WoodWorks



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

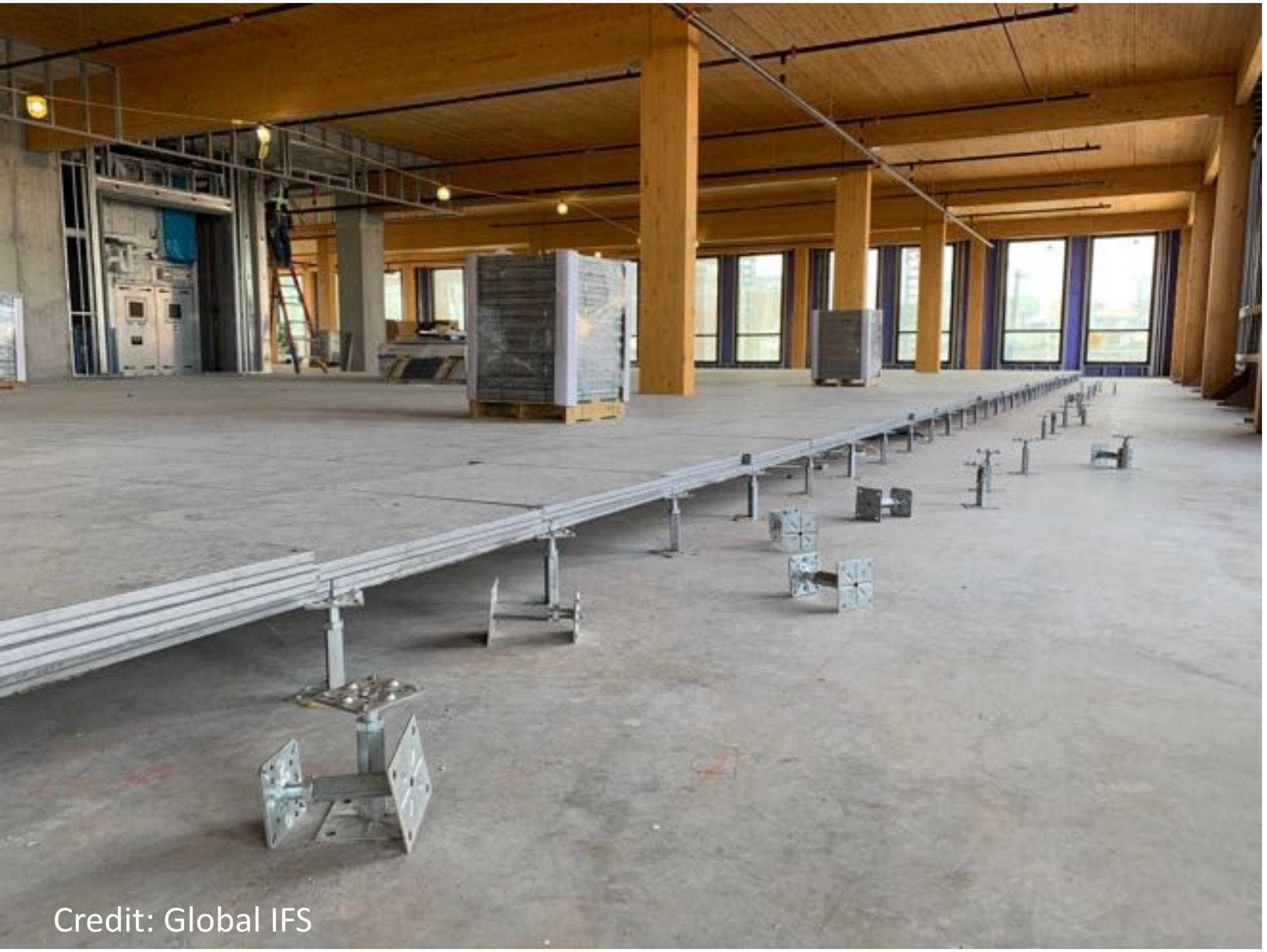
- Aesthetics (minimal exposed MEP)
- Acoustic impacts (usually thinner topping req'd)

Credit: BOKA Powell

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 topping slab above MT

- Greater need for coordination prior to slab pour
- Limitations on what can be placed (thickness of topping slab)
- No opportunity for renovations later

Credit: Alex Schreyer

MEP Layout & Integration

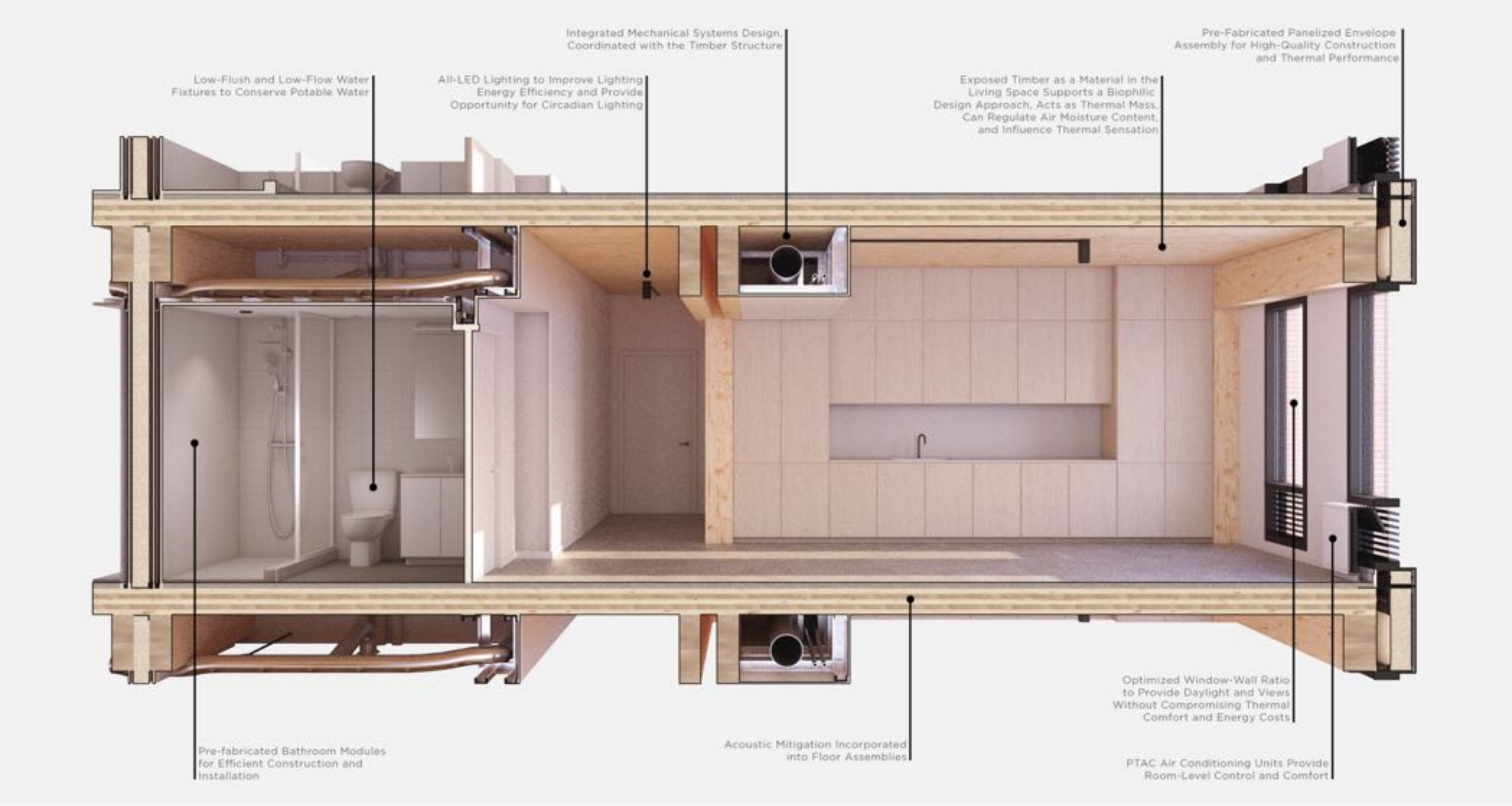
Embedded conduit in Wall Panels

PHOTO CREDIT:
CHARLES JUDD

Accommodating Vertical Movement

Beyond structural connections, consider movement impacts on MEPF services. Flex/compression connections

MEP Systems, Routing, Integration



Integrated Mechanical Systems Design, Coordinated with the Timber Structure

Pre-Fabricated Panelized Envelope Assembly for High-Quality Construction and Thermal Performance

Low-Flush and Low-Flow Water Fixtures to Conserve Potable Water

All-LED Lighting to Improve Lighting Energy Efficiency and Provide Opportunity for Circadian Lighting

Exposed Timber as a Material in the Living Space Supports a Biophilic Design Approach, Acts as Thermal Mass, Can Regulate Air Moisture Content, and Influence Thermal Sensation

Optimized Window-Wall Ratio to Provide Daylight and Views Without Compromising Thermal Comfort and Energy Costs

Pre-fabricated Bathroom Modules for Efficient Construction and Installation

Acoustic Mitigation Incorporated into Floor Assemblies

PTAC Air Conditioning Units Provide Room-Level Control and Comfort

INTEGRATED SYSTEMS

The Tallhouse building system prioritizes the integration of design, engineering, and construction. This results in a high performance building finely tuned to meet energy, comfort, acoustic, and design criteria that has been vetted by constructability experts to ensure fast, efficient production.

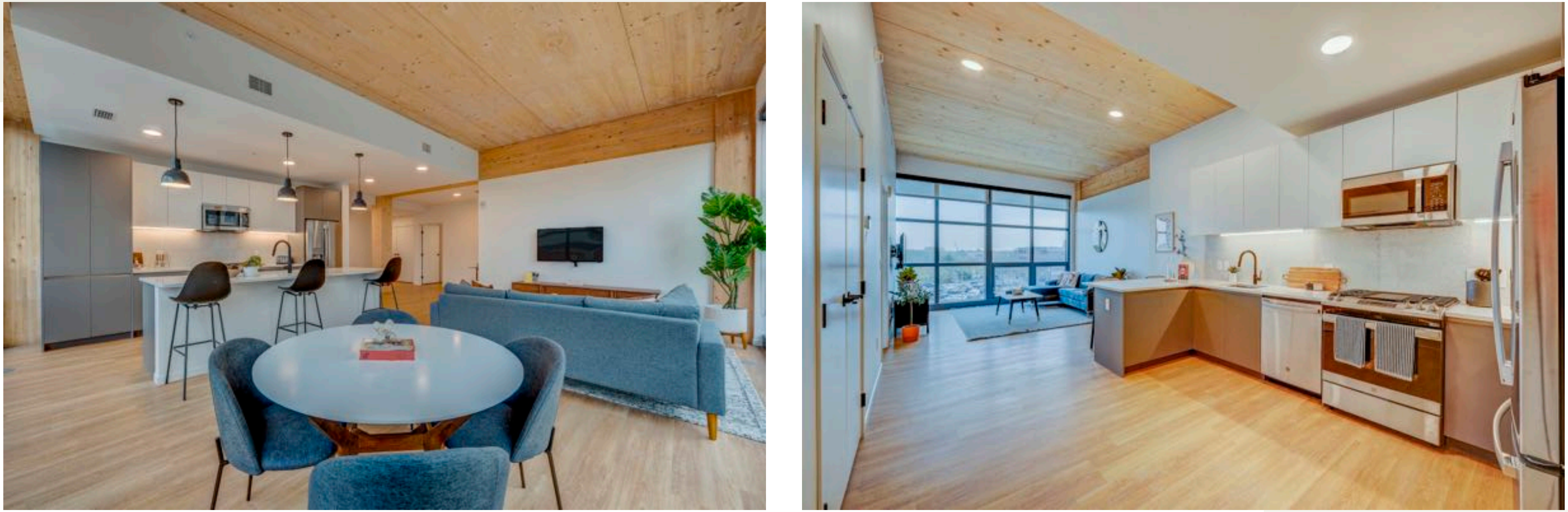
Utilizing Pre-Fabricated Facade Panels and Bathroom Modules that are manufactured off-site in factories allows for reducing construction time on-site, higher quality control practices, and safer labor conditions for construction workers. Efficient routing of duct-work conserves material, and associated embodied carbon, allowing more exposed timber all while providing the air quality needed for healthy living. Water conserving fixtures reduce potable water use as a precious resource, while maintaining reliable performance.

Credit: John Klein, Generate Architecture

INTRO

Cleveland, OH

- One of the first to utilize new IV-B construction type.
- Worked with the city to expose 50% of MT ceilings.



Photos: Nick Johnson, Tour D Space

Hartshorne Plunkard Architecture
Forefront Structural Engineers

Timber Lofts

Milwaukee, WI

68,400 sf, 4 stories

Type III-B

Multi-Family

Completed 2020

W N PROFILE

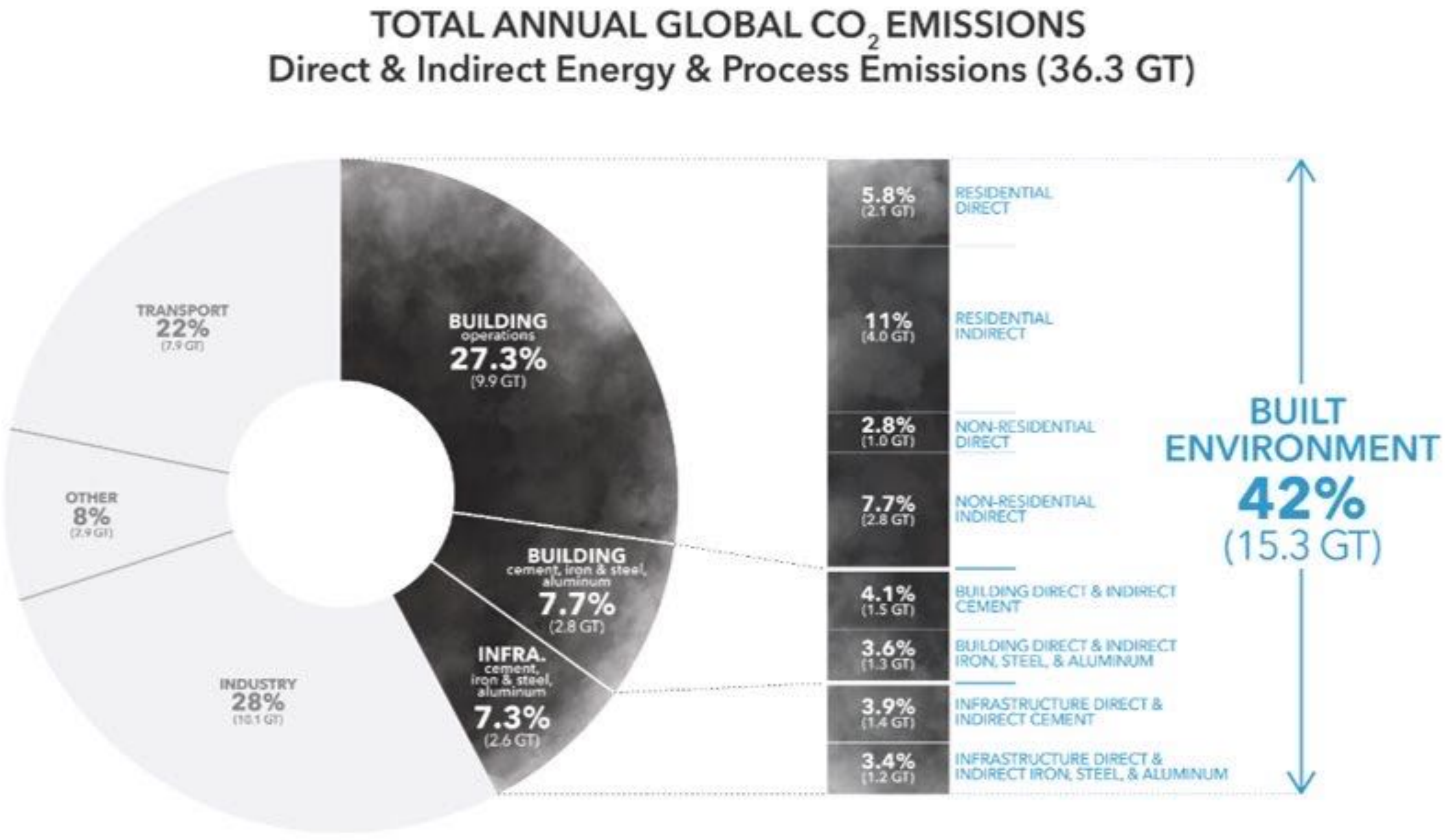
BUSINESS CASE STUDY

WOOD DESIGN AWARD WINNER

Enberg Anderson Architects
Pierce Engineers
Photo: Enberg Anderson Architects

Embodied Carbon and LCA

The Built Environment & Carbon Dioxide Emissions



TOTAL ANNUAL GLOBAL CO_2 EMISSIONS
Direct & Indirect Energy & Process Emissions (36.3 GT)

© Architecture 2030. All Rights Reserved.
Analysis & Aggregation by Architecture 2030 using data sources from IEA & Statista.

Built environment generate about **42%** of annual carbon dioxide emissions

- *Building Operations*
- *Embodied Carbon*

Embodied carbon: **15%**

- Cement
- Iron
- Steel
- Aluminum

Measuring Greenhouse Gases (GHG)

Global Warming Potential (GWP)

- Allows comparisons of global warming impacts of different gases
- Measures energy emissions 1 ton of gas absorbs over a given period of time relative to emissions of 1 ton of carbon dioxide (CO_2)
- Time period usually **100 years** (EPA)

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

Carbon Dioxide Equivalents (CO_{2eq})

- International standard to express greenhouse gases in terms of CO_2 equivalents

Embodied vs. Operational Impacts

Traditional Non-Wood Building

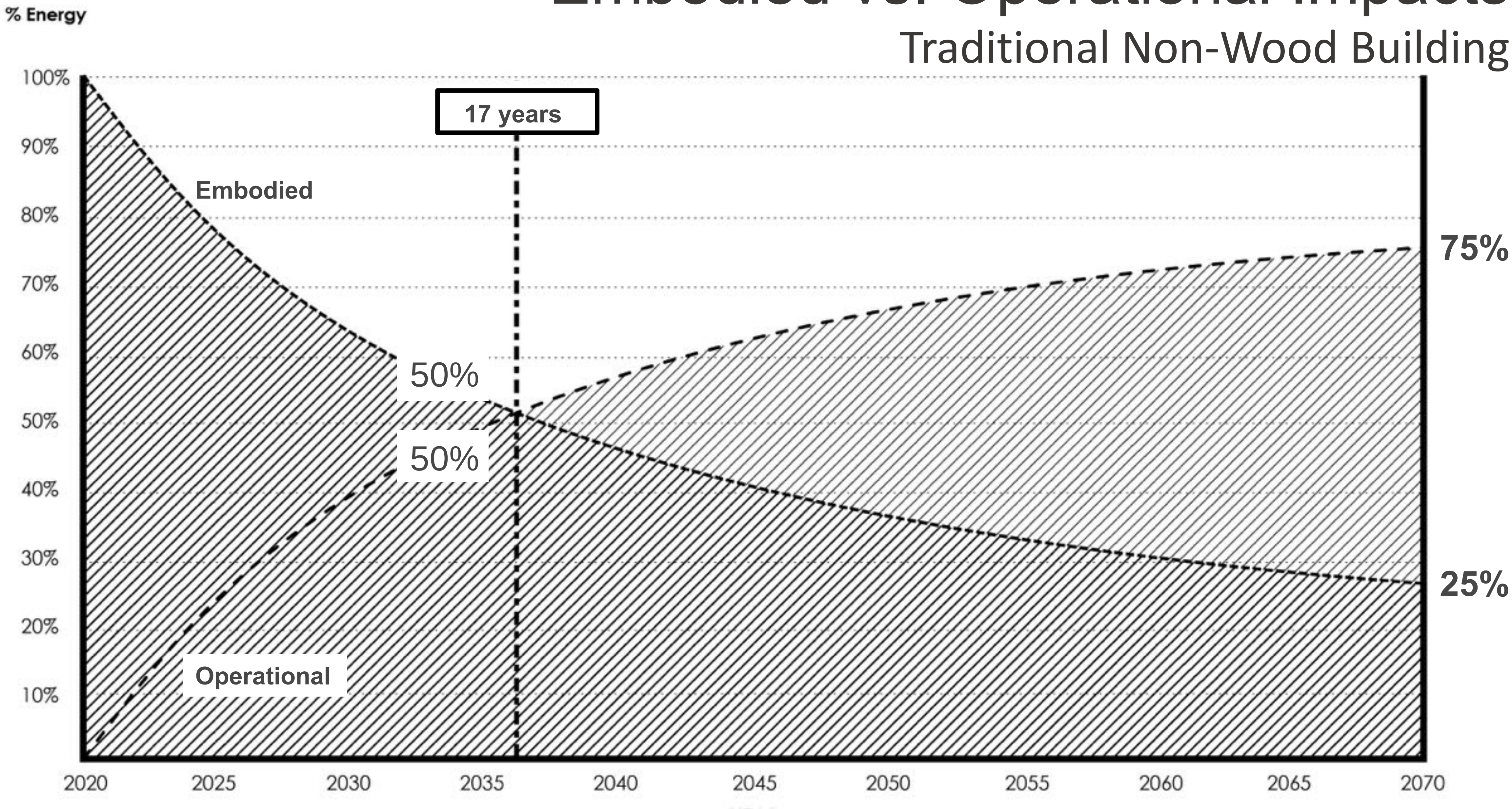


Image Credit: Gray Organschi Architecture[2]

Embodied Carbon

- Primarily related to **manufacturing of materials**
- More significant than many people realize, has been **historically overlooked**
- Big upfront Greenhouse Gas (GHG) "cost" - which makes it a **good near-term target** for climate change mitigation

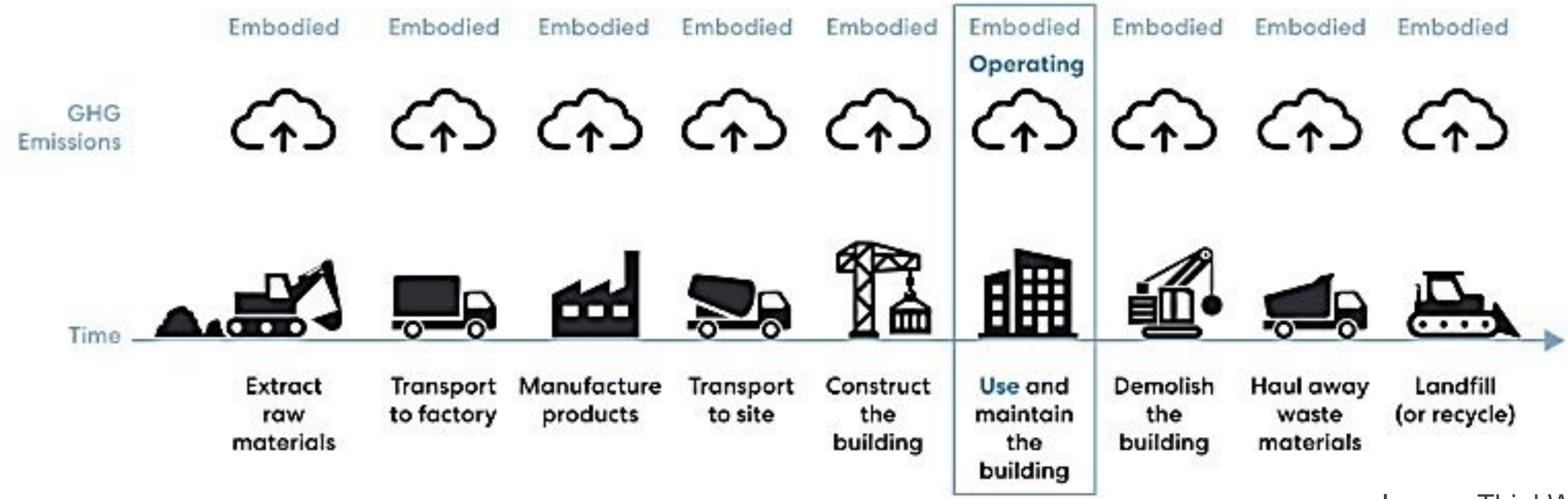


Image: ThinkWood

Carbon Storage

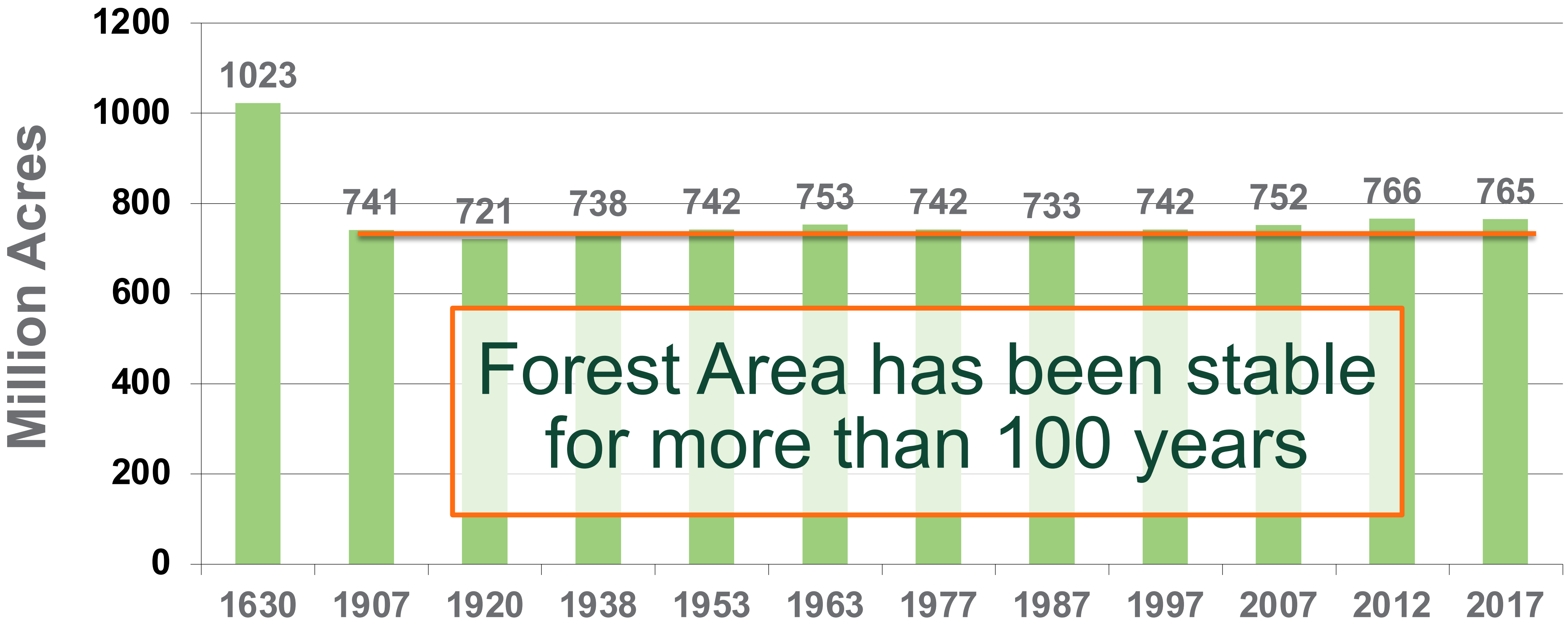
Wood ≈ 50% Carbon (dry weight)

Image: Kaiser + Path

Image: Lever Architecture

U.S. Forest Land:

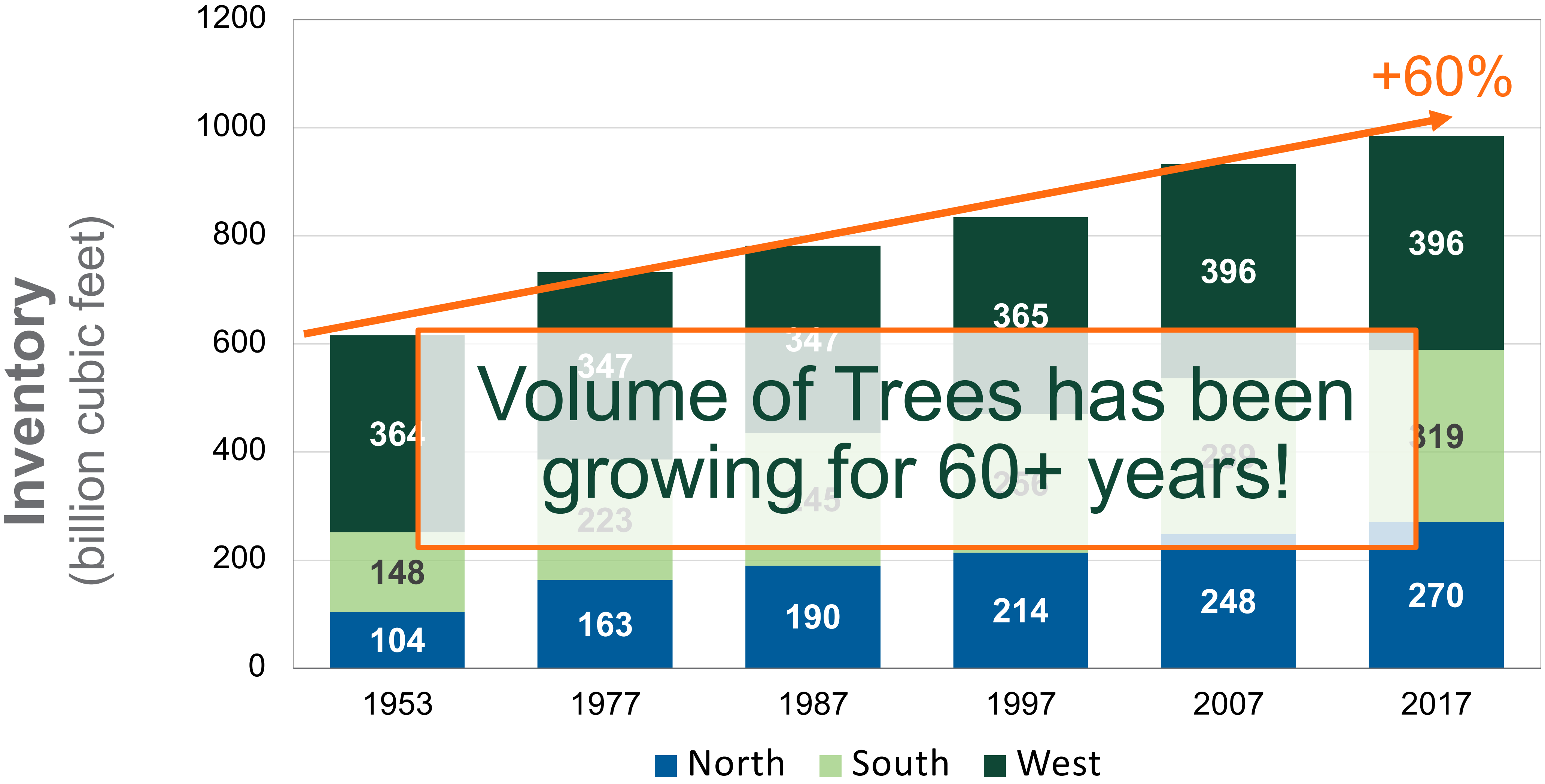
Forest **Area** in the United States 1630 – 2017



Forest Area has been stable for more than 100 years

Source: USDA-Forest Service, Forest Resources of the United States, 2017 (2018)

State of our Forests: US Timber Volume on Timberland



Volume of Trees has been growing for 60+ years!

Source: USDA-Forest Service, Forest Resources of the United States, 2017 (2018)

Carbon Benefits of Wood

- **Lower embodied carbon** compared to other common building materials
- **Less fossil fuel consumed** during manufacture
- **Avoid process emissions**
- Extended carbon **storage in products**
- **Carbon sequestration** in forests
- Promotes **forest health**

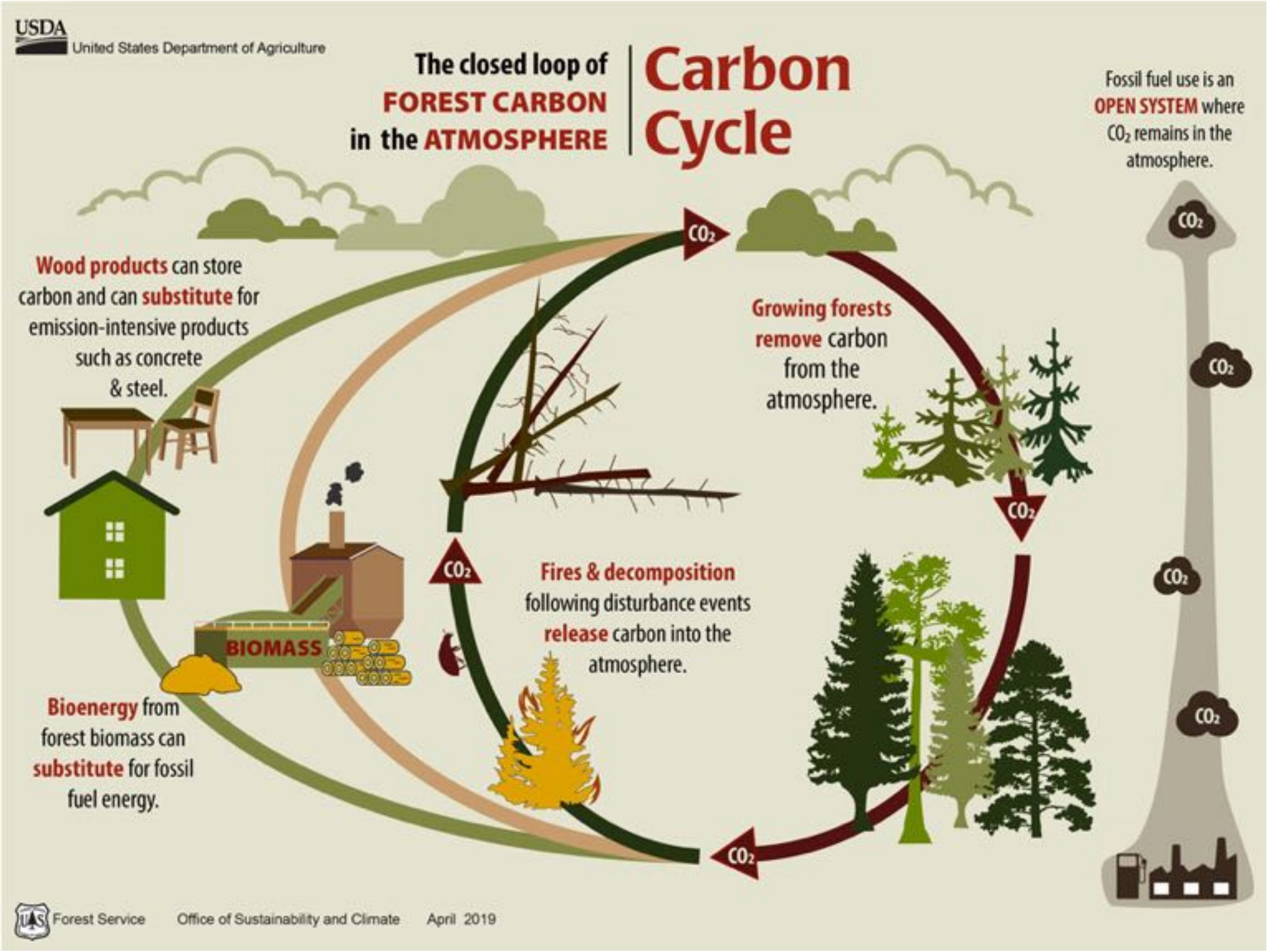


Image: USDA US Forest Service

Carbon vs CO_2

+ 2 *

= 44 CO_2

1 ton Carbon ≠ 1 ton CO_2

1 ton Carbon = (44/12=) **3.67 tons 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/

WoodWorks Carbon Calculator

- Available at **woodworks.org**
- Estimates total wood mass in a building
- Relays **estimated** carbon impacts:
  - Amount of **carbon stored** in wood
  - Amount of **greenhouse gas emissions avoided** by choosing wood over a non-wood material

Volume of wood used:
208,320 cubic feet

U.S. and Canadian forests grow this much wood in:
17 minutes

Carbon stored in the wood:
4,466 metric tons of CO_2

Avoided greenhouse gas emissions:
9,492 metric tons of CO_2

TOTAL POTENTIAL CARBON BENEFIT:
13,958 metric tons of CO_2

EQUIVALENT TO:

2,666 cars off the road for a year

Energy to operate a home for 1,186 years

Source: US EPA

http://www.woodworks.org/carbon-calculator-download-form/

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

Life Cycle of a Building

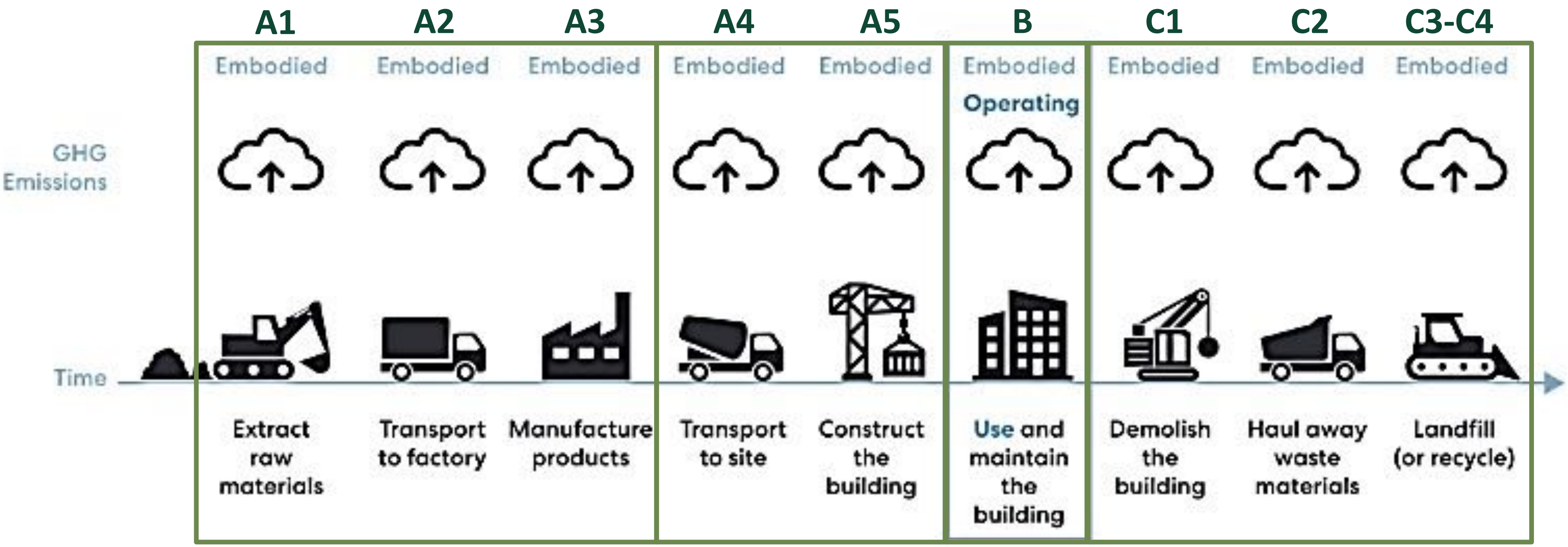
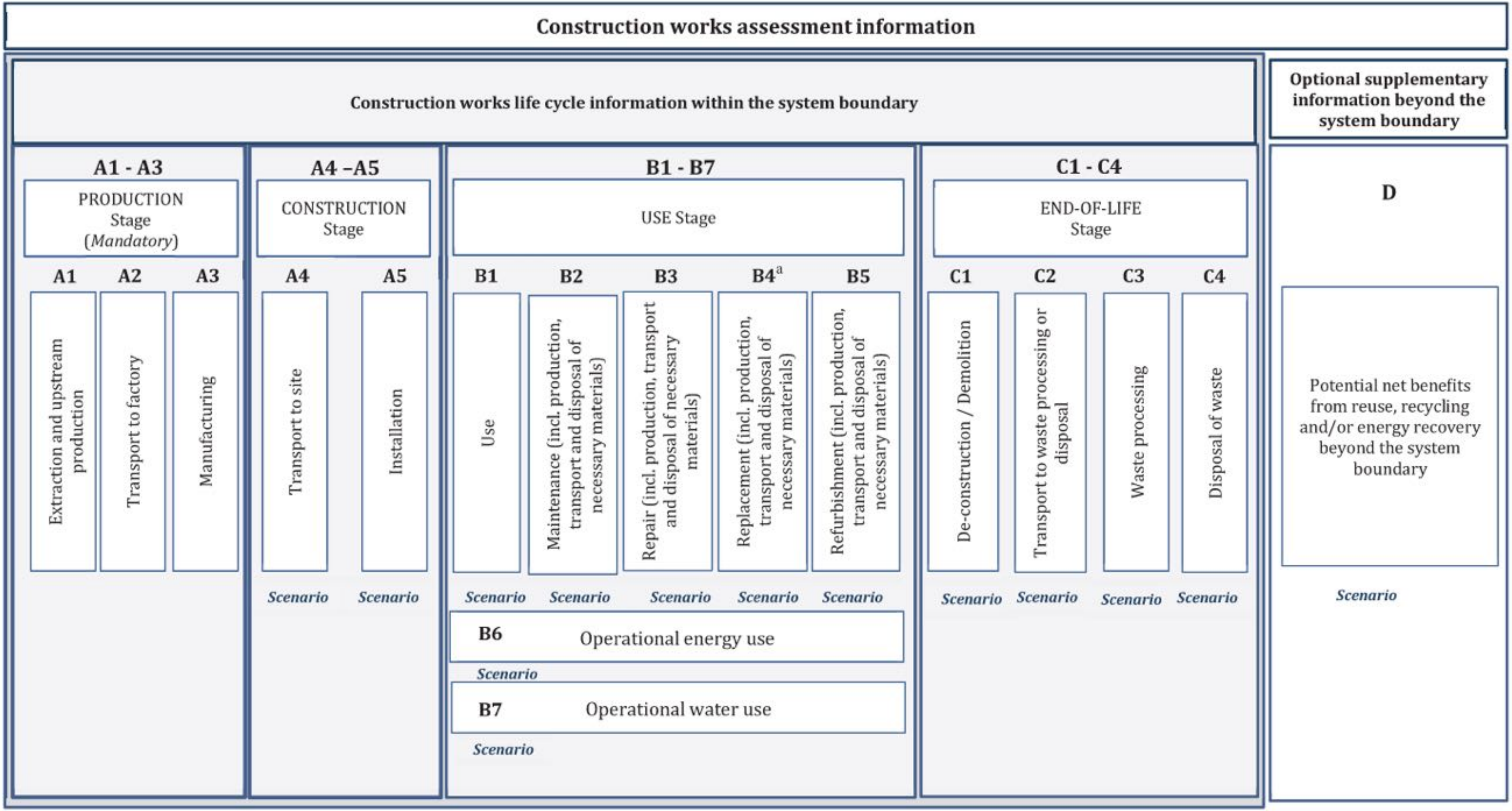


Image: Think Wood



Construction works assessment information

Construction works life cycle information within the system boundary

A1 - A3
PRODUCTION Stage (*Mandatory*)
- **A1** Extraction and upstream production
- **A2** Transport to factory
- **A3** Manufacturing

A4 – A5
CONSTRUCTION Stage
- **A4** Transport to site — *Scenario*
- **A5** Installation — *Scenario*

B1 - B7
USE Stage
- **B1** Use — *Scenario*
- **B2** Maintenance (incl. production, transport and disposal of necessary materials) — *Scenario*
- **B3** Repair (incl. production, transport and disposal of necessary materials) — *Scenario*
- **B4**[a] Replacement (incl. production, transport and disposal of necessary materials) — *Scenario*
- **B5** Refurbishment (incl. production, transport and disposal of necessary materials) — *Scenario*
- **B6** Operational energy use — *Scenario*
- **B7** Operational water use — *Scenario*

C1 - C4
END-OF-LIFE Stage
- **C1** De-construction / Demolition — *Scenario*
- **C2** Transport to waste processing or disposal — *Scenario*
- **C3** Waste processing — *Scenario*
- **C4** Disposal of waste — *Scenario*

Optional supplementary information beyond the system boundary

D
Potential net benefits from reuse, recycling and/or energy recovery beyond the system boundary — *Scenario*

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

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

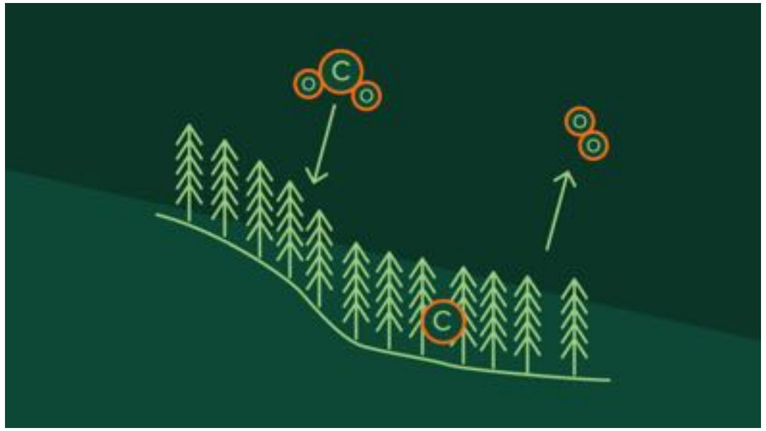
What makes wood different?
Biogenic Carbon

Biogenic Carbon

“**Carbon derived from… material of biological origin** excluding material embedded in geological formations or transformed to fossilized material and excluding peat.”

Photosynthesis:

$$6\ CO_2 + 6\ H_20 \rightarrow \mathbf{C_6}H_{12}O_6\ (\mathbf{stored}) + 6\ O_2\ (\mathrm{released})$$



Source: ISO 21930:2017(E), 3.7

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

-1 in

Removal of carbon from the atmosphere

+1 out

Note that “exports” are not direct emissions to the atmosphere.

Emission or export of carbon from product system

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.

Option 2: (NOTE 2)

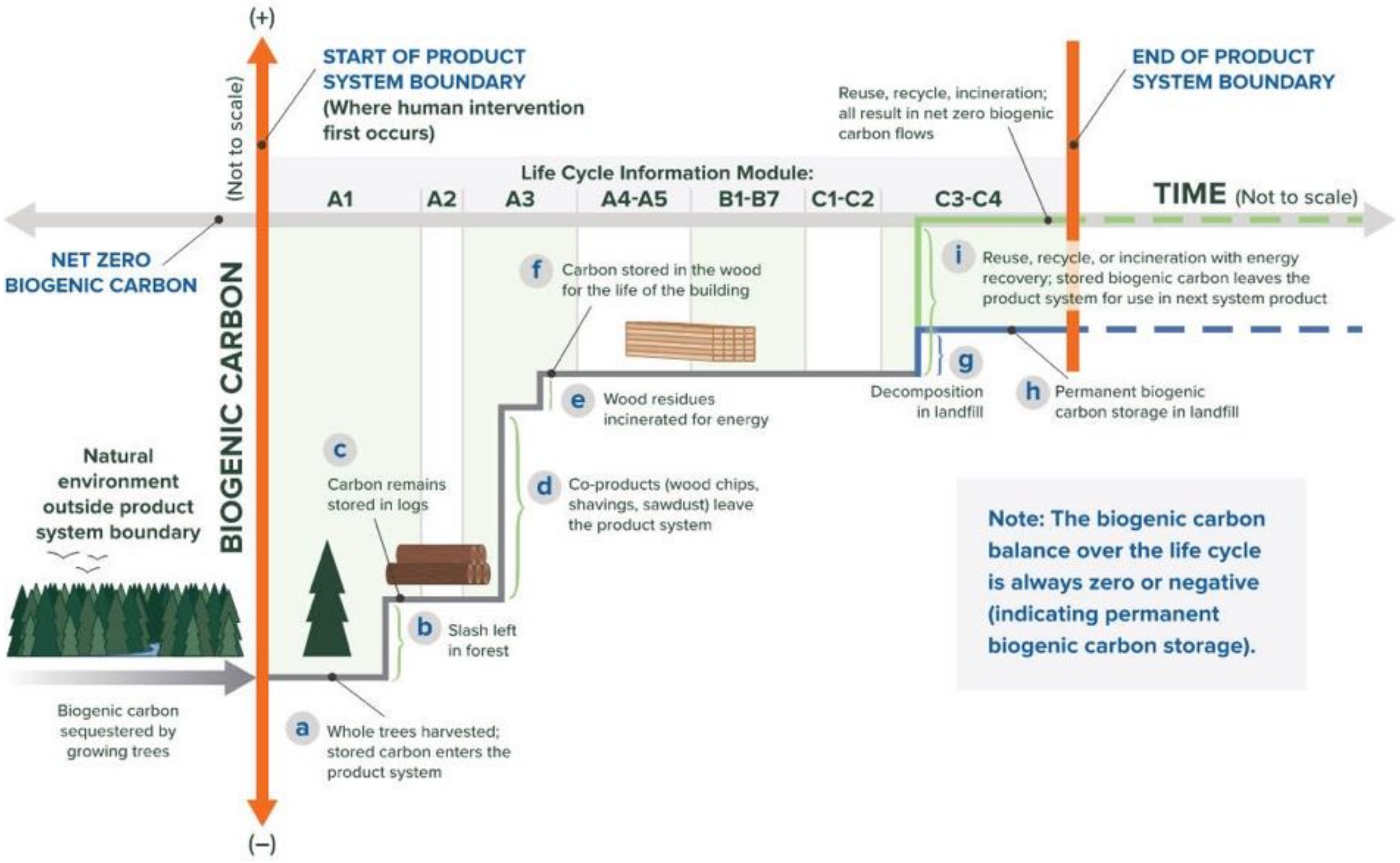
- “The concept of sustainably managed forests is linked but not limited to respective certification schemes”
- Evidence such as national reporting under UNFCCC to identify forests with stable or increasing forest carbon stocks

Source: ISO 21930:2017(E), 7.2.11

Should I include biogenic carbon?

Yes! But how?

BIOGENIC CARBON FLOWS



START OF PRODUCT SYSTEM BOUNDARY (Where human intervention first occurs)

END OF PRODUCT SYSTEM BOUNDARY

NET ZERO BIOGENIC CARBON

Natural environment outside product system boundary

Biogenic carbon sequestered by growing trees

Reuse, recycle, incineration; all result in net zero biogenic carbon flows

a Whole trees harvested; stored carbon enters the product system

b Slash left in forest

c Carbon remains stored in logs

d Co-products (wood chips, shavings, sawdust) leave the product system

e Wood residues incinerated for energy

f Carbon stored in the wood for the life of the building

g Decomposition in landfill

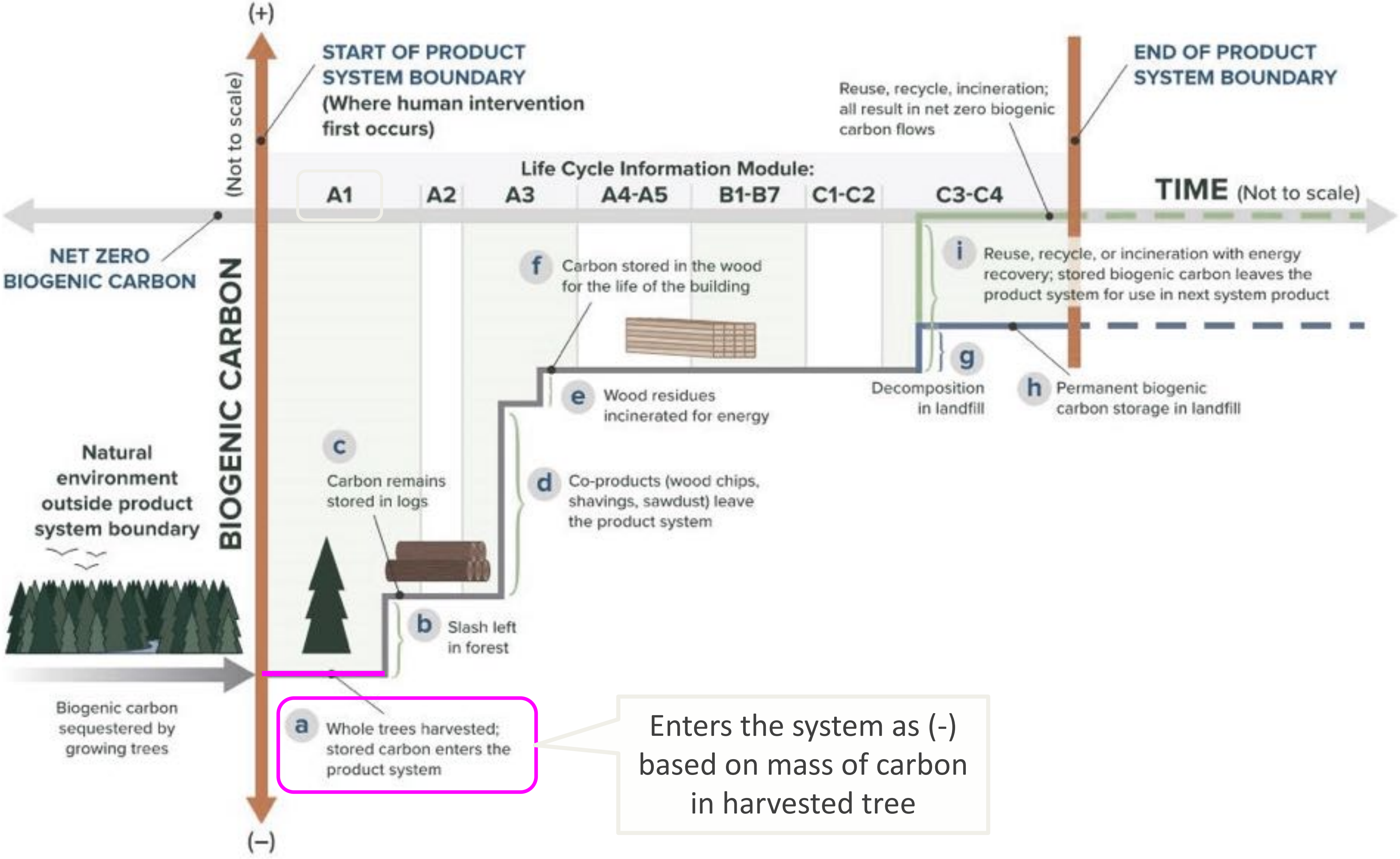
h Permanent biogenic carbon storage in landfill

i Reuse, recycle, or incineration with energy recovery; stored biogenic carbon leaves the product system for use in next system product

Note: The biogenic carbon balance over the life cycle is always zero or negative (indicating permanent biogenic carbon storage).

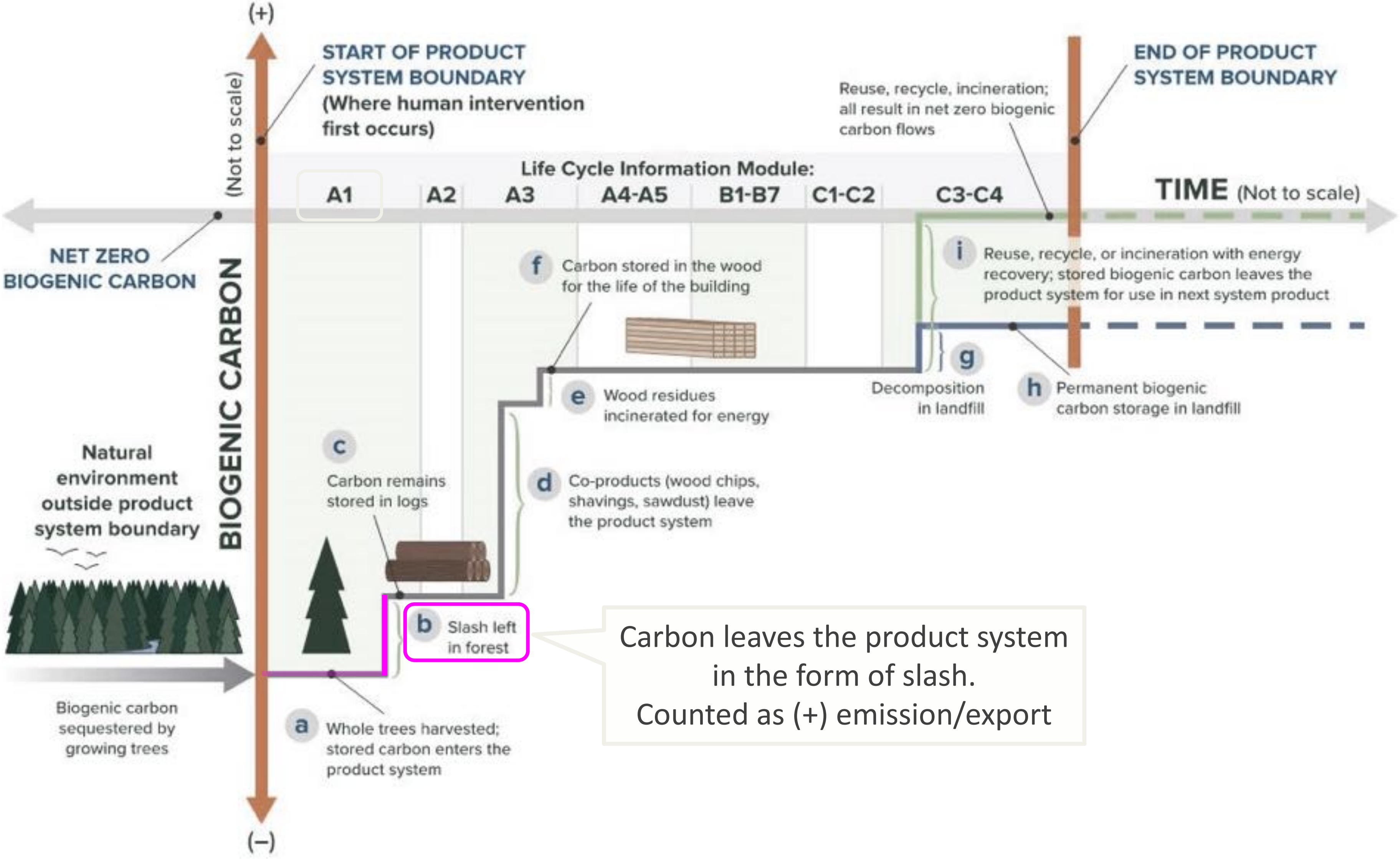
https://www.woodworks.org/resources/how-to-include-biogenic-carbon-in-an-lca/

BIOGENIC CARBON FLOWS



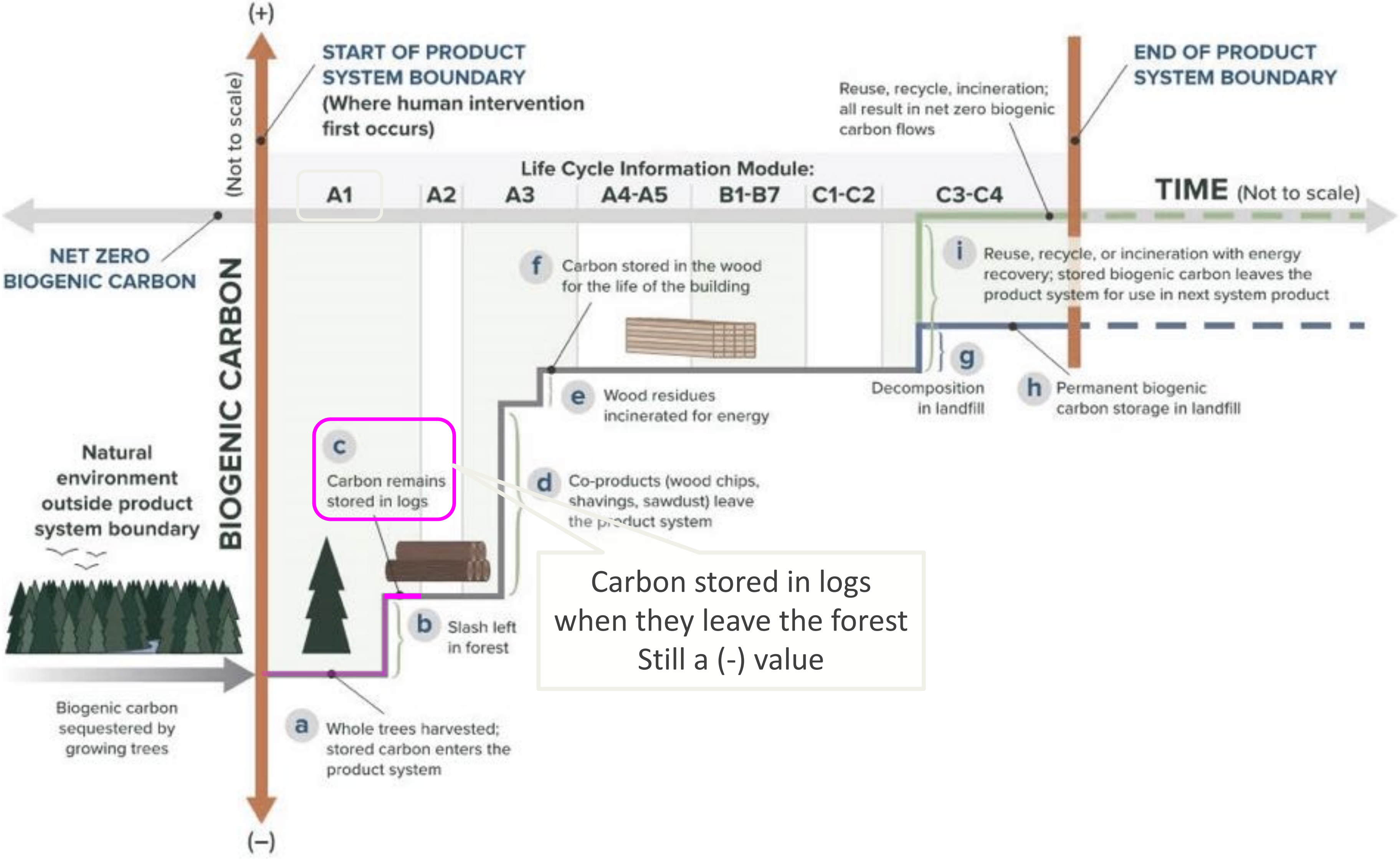
Enters the system as (-) based on mass of carbon in harvested tree

BIOGENIC CARBON FLOWS



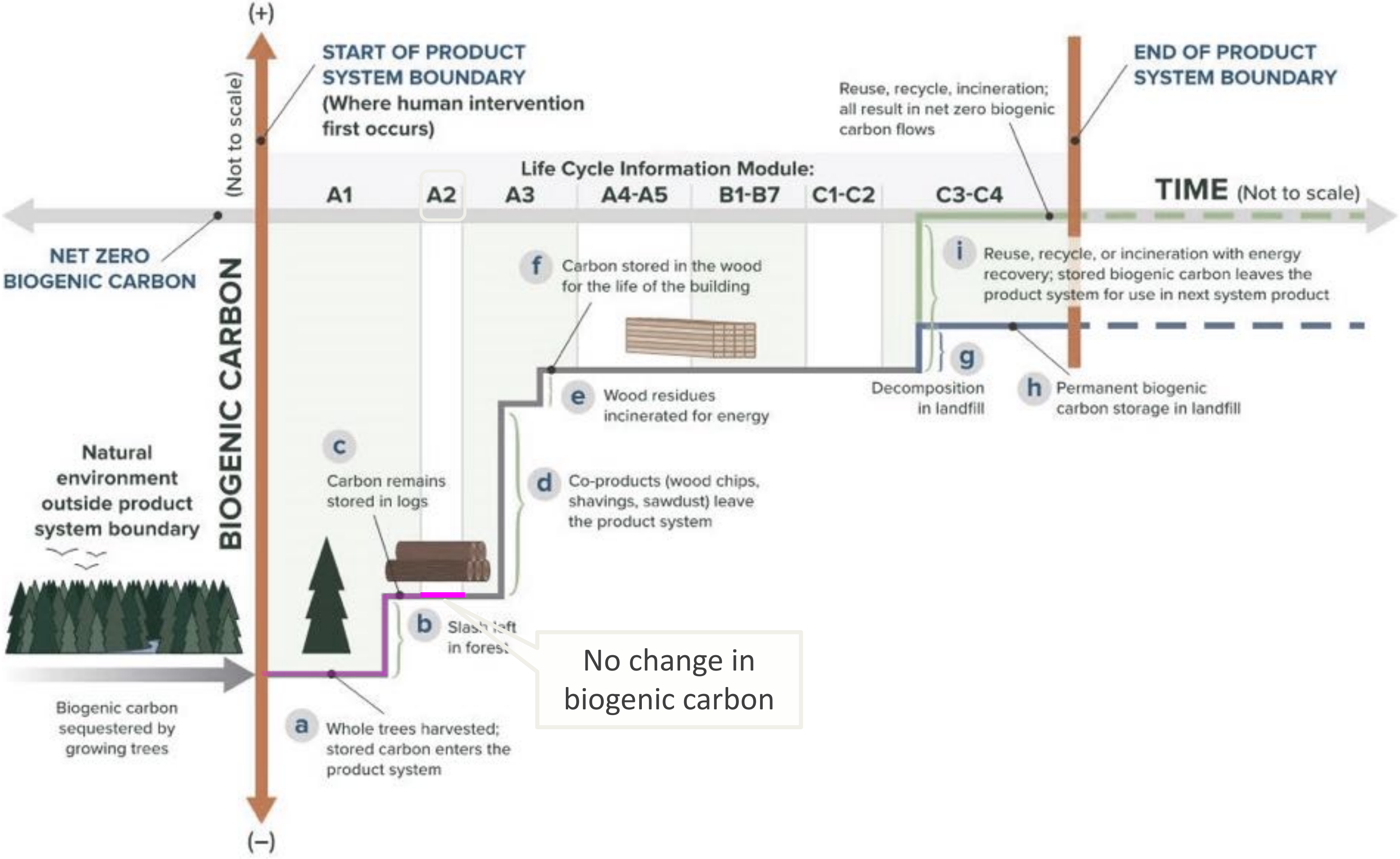
Carbon leaves the product system in the form of slash.
Counted as (+) emission/export

BIOGENIC CARBON FLOWS



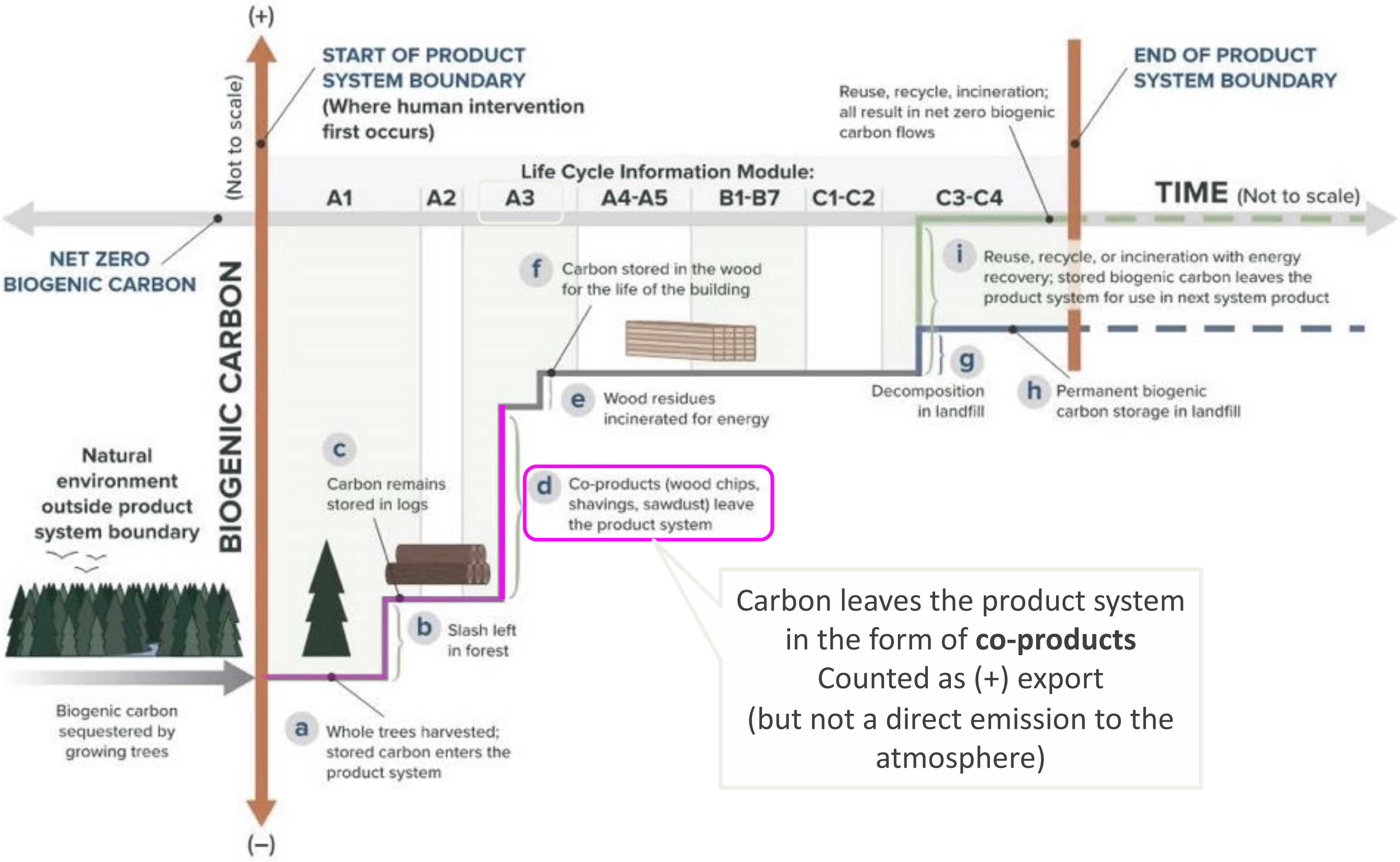
Carbon stored in logs
when they leave the forest
Still a (-) value

BIOGENIC CARBON FLOWS



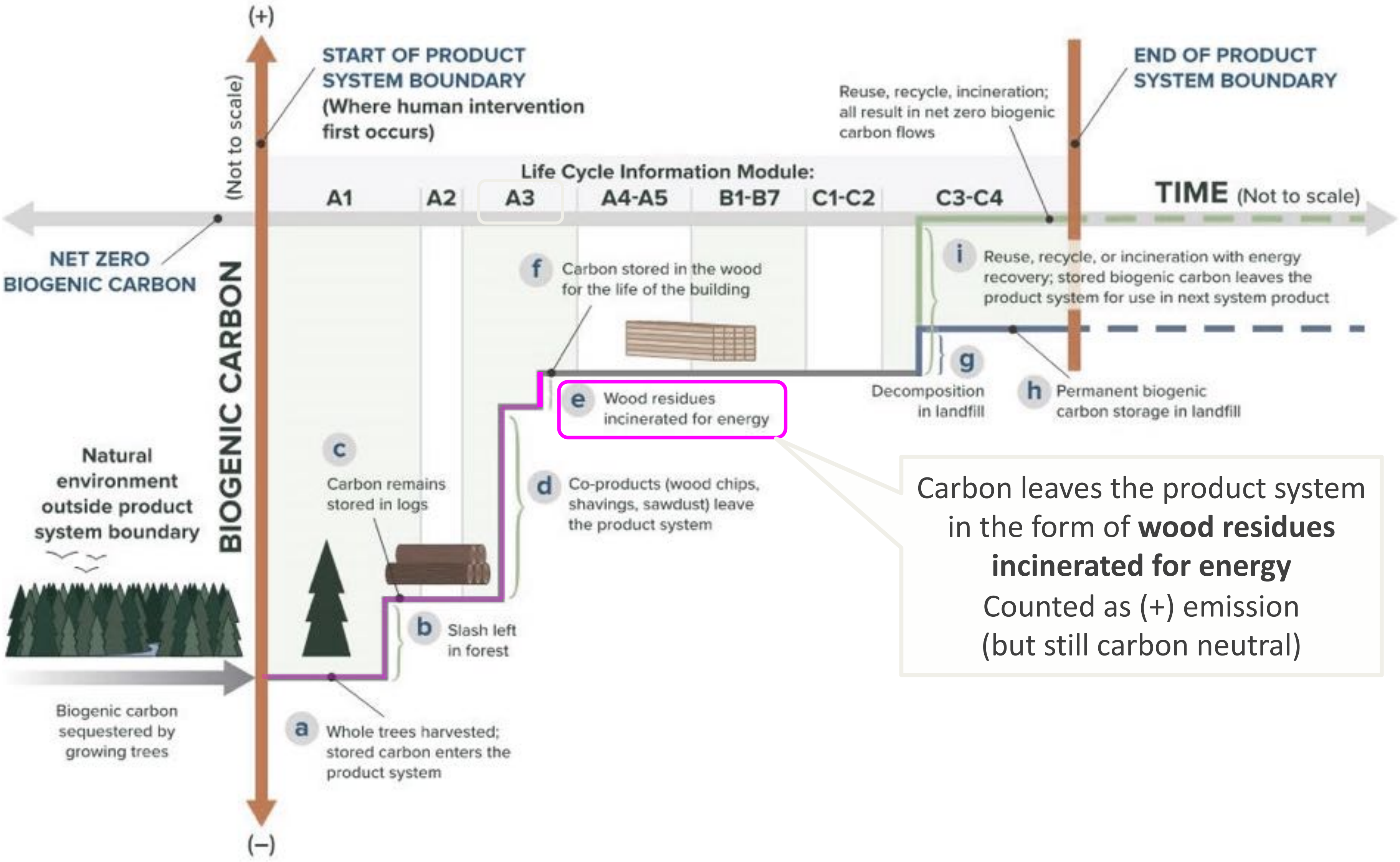
No change in biogenic carbon

BIOGENIC CARBON FLOWS



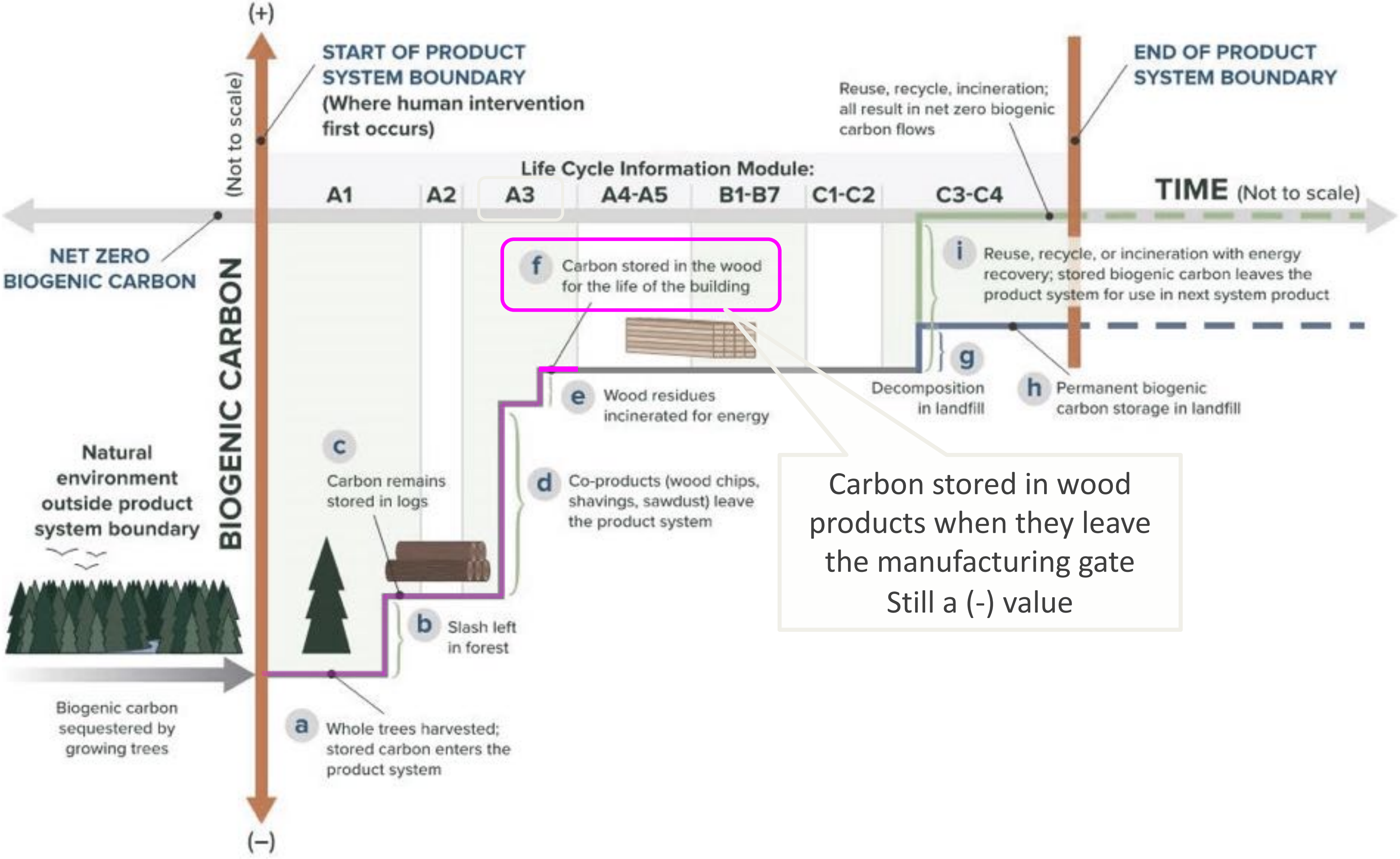
Carbon leaves the product system in the form of **co-products**
Counted as (+) export
(but not a direct emission to the atmosphere)

BIOGENIC CARBON FLOWS



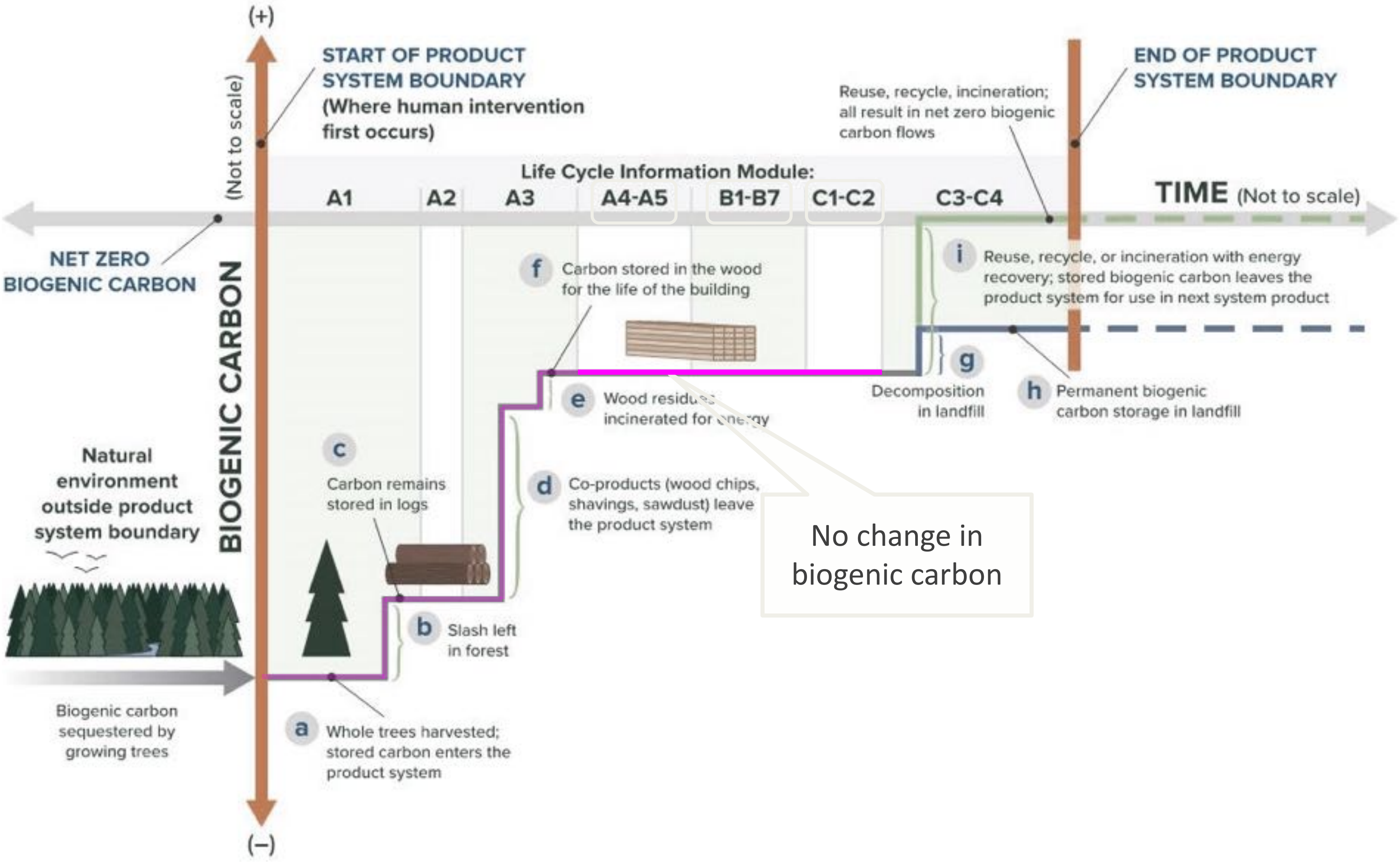
Carbon leaves the product system in the form of **wood residues incinerated for energy**
Counted as (+) emission
(but still carbon neutral)

BIOGENIC CARBON FLOWS



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

BIOGENIC CARBON FLOWS



No change in biogenic carbon

End-of-Life Fates for Wood Products

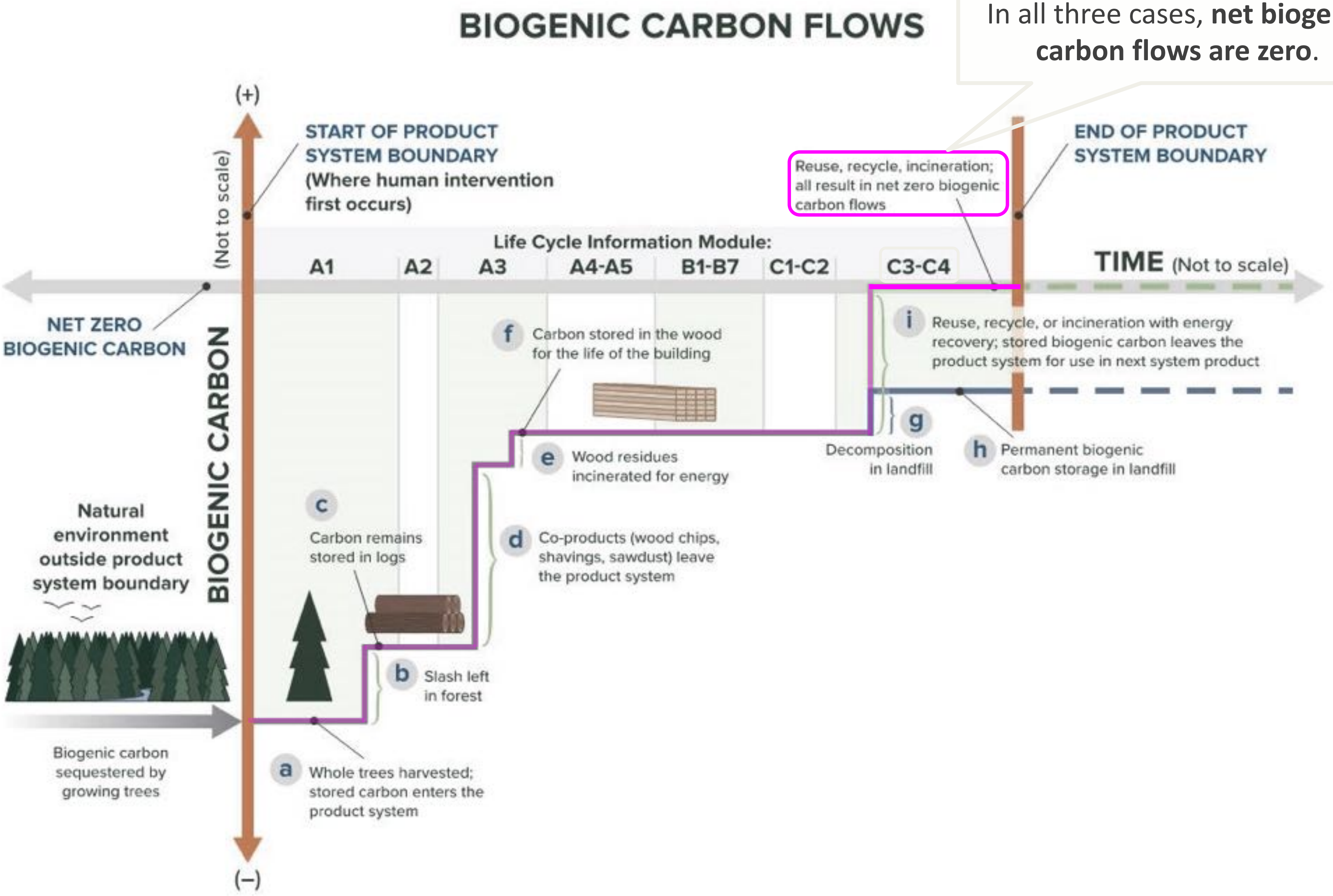
1. **Landfill**
2. **Incineration (for energy recovery)**
3. **Recycle**
4. **Direct Reuse**

End-of-Life Fates for Wood Products

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

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

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



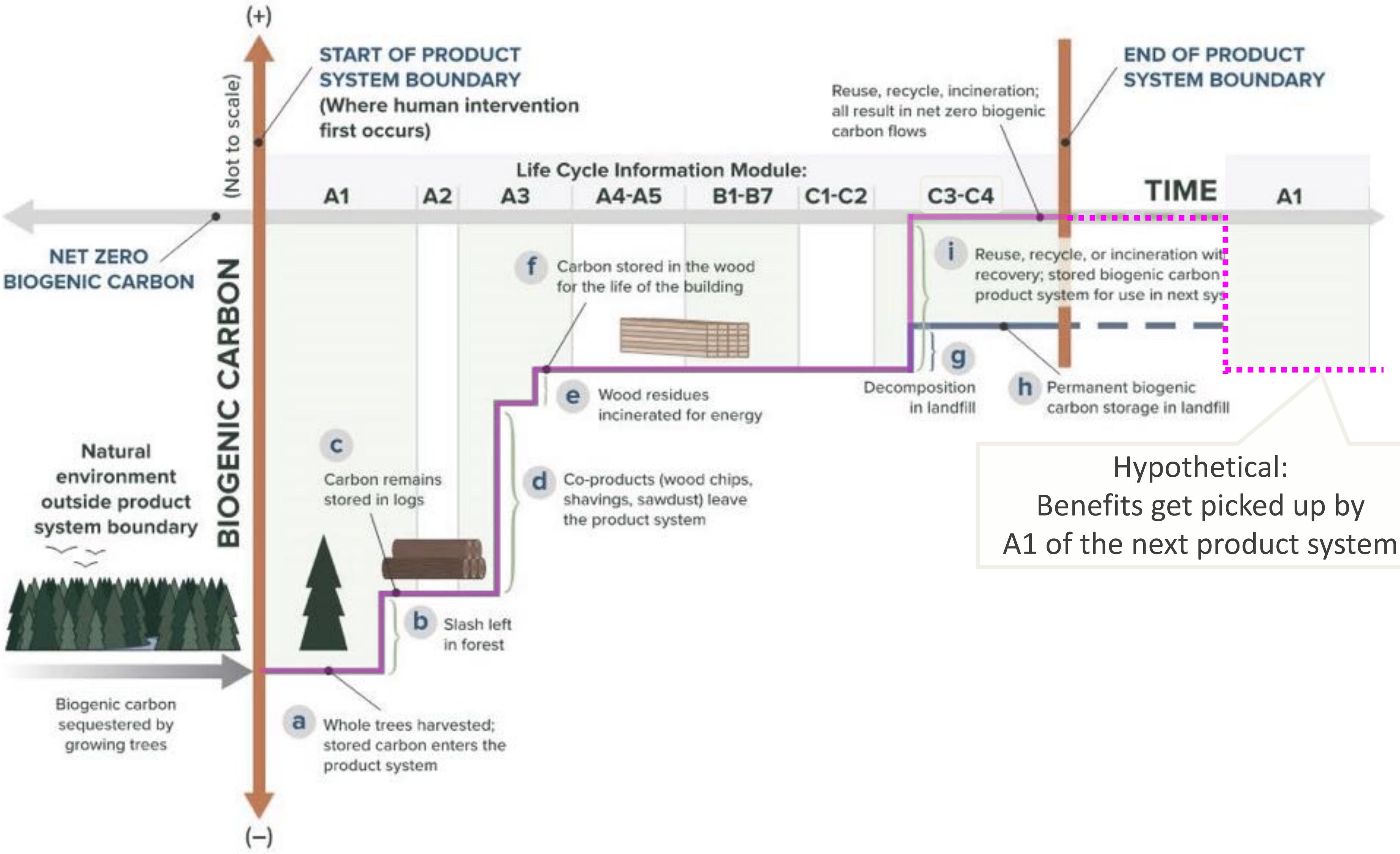
BIOGENIC CARBON FLOWS

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

BIOGENIC CARBON FLOWS



Hypothetical:
Benefits get picked up by
A1 of the next product system

End-of-Life Fates for Wood Products

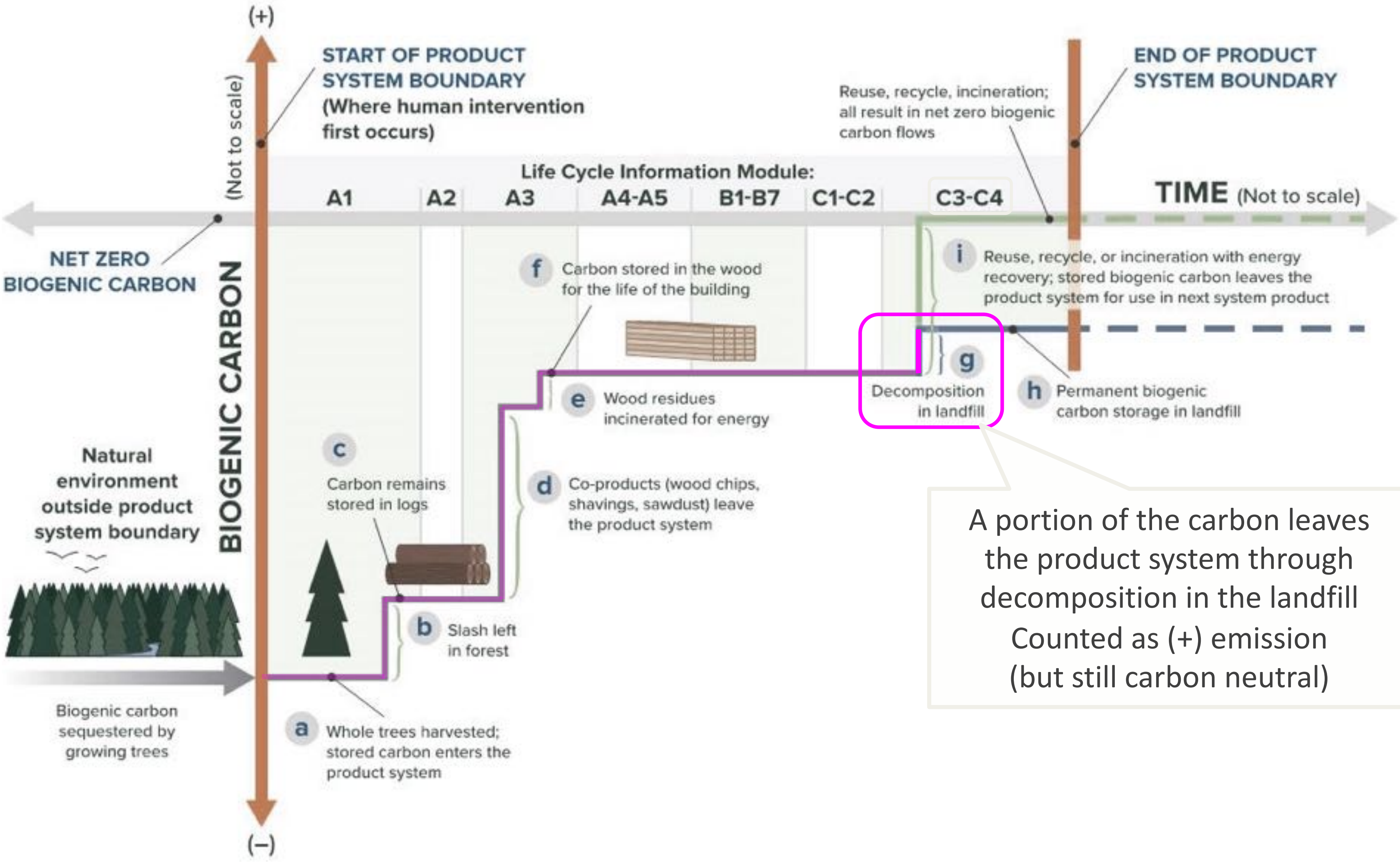
1. **Landfill**
2. Incineration (for energy recovery)
3. Recycle
4. Direct Reuse

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

Does not include benefits of using recovered energy

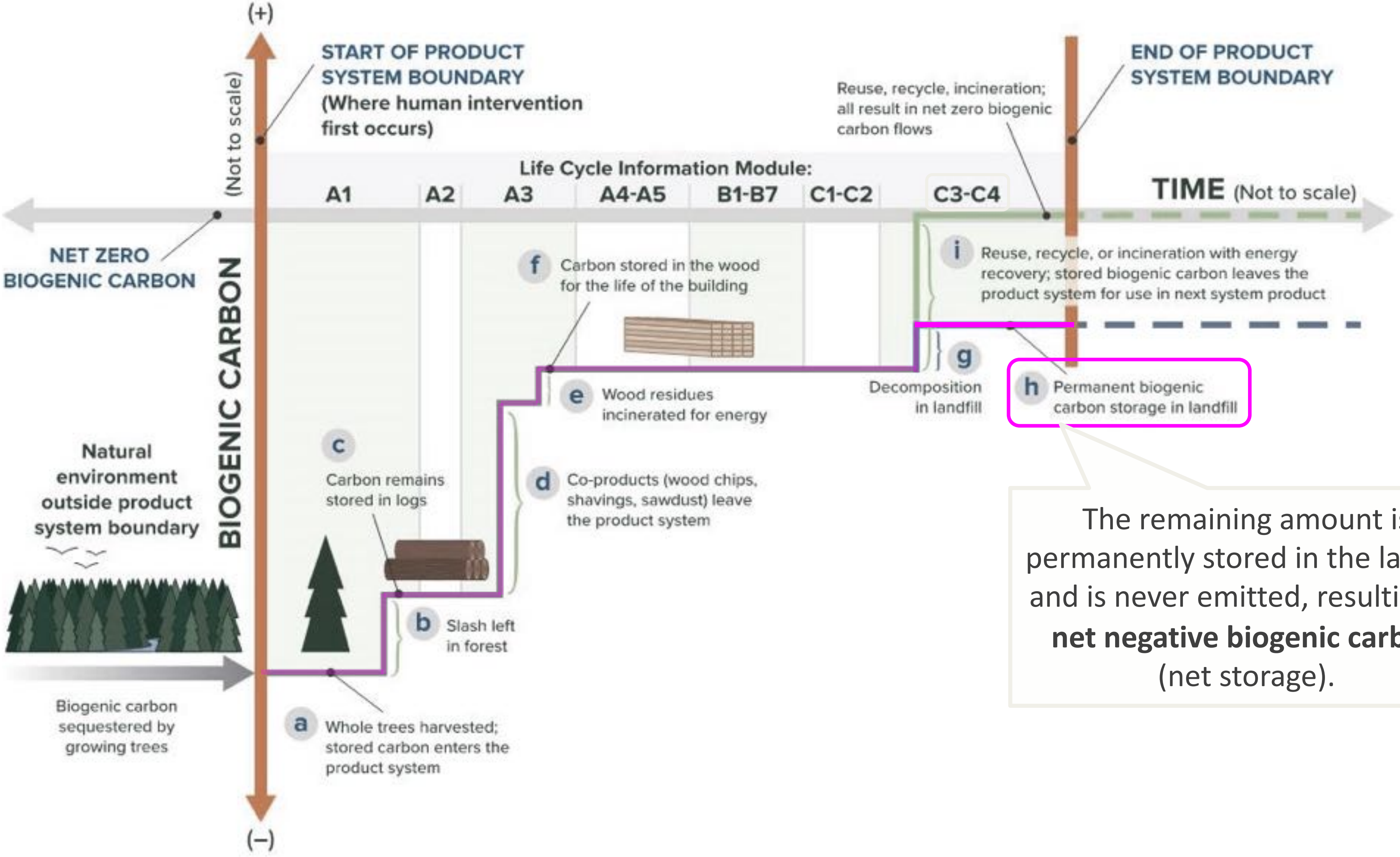
Most biogenic carbon is **permanently stored** in the landfill. The rest is released through decay as an ***emission*** (+1).

BIOGENIC CARBON FLOWS



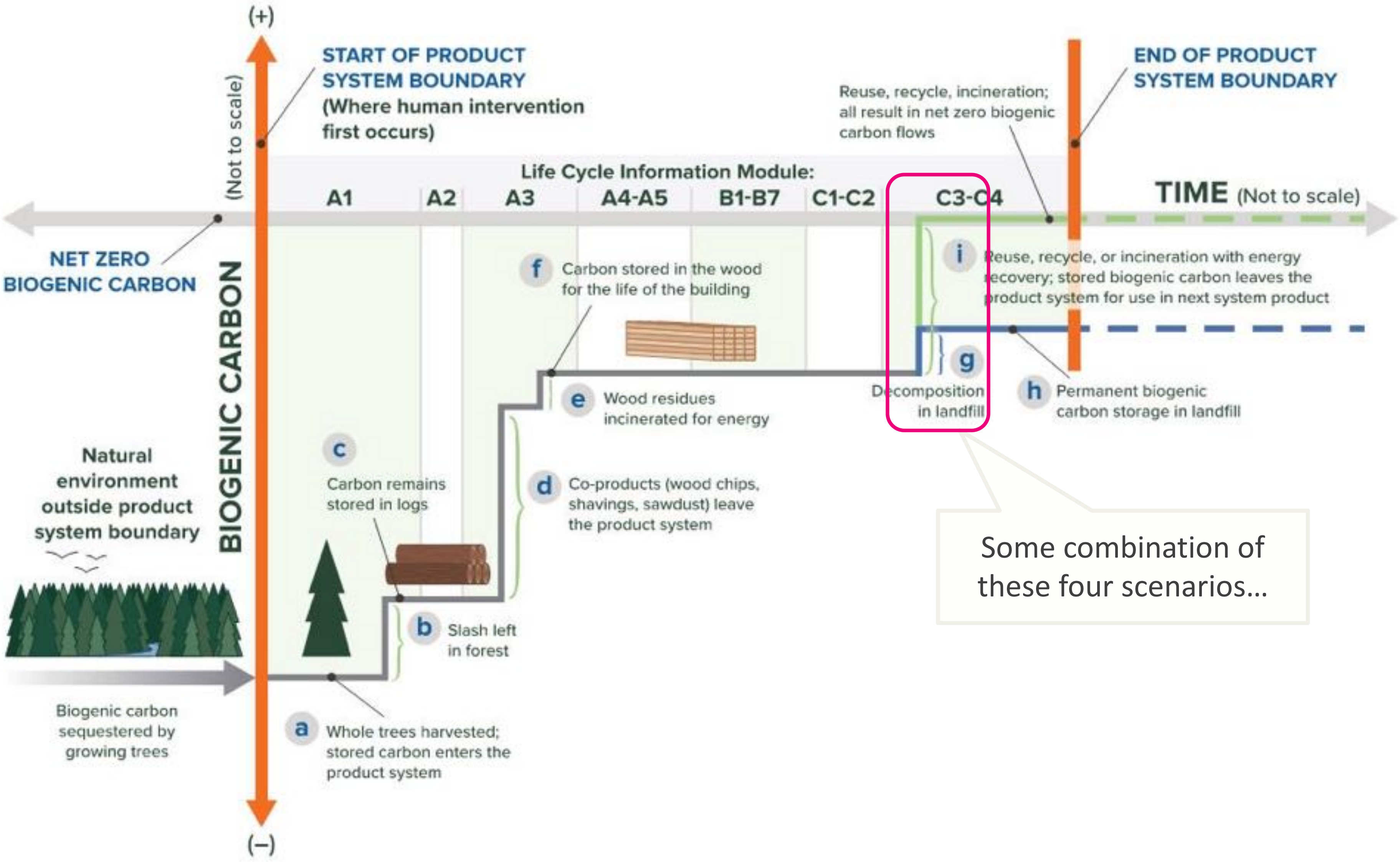
A portion of the carbon leaves the product system through decomposition in the landfill
Counted as (+) emission
(but still carbon neutral)

BIOGENIC CARBON FLOWS



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

BIOGENIC CARBON FLOWS



Some combination of these four scenarios…

A Note About Tools:

In addition to differences in end-of-life scenarios:

- Where end-of-life effects are reported (C3-C4 vs Module D)
- Methodology (ISO compliance)
- LCI Databases (background data)
- User interface, workflow

https://www.woodworks.org/resources/biogenic-carbon-accounting-in-wblca-tools/
https://www.woodworks.org/resources/calculating-the-embodied-carbon-of-different-structural-systems/

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

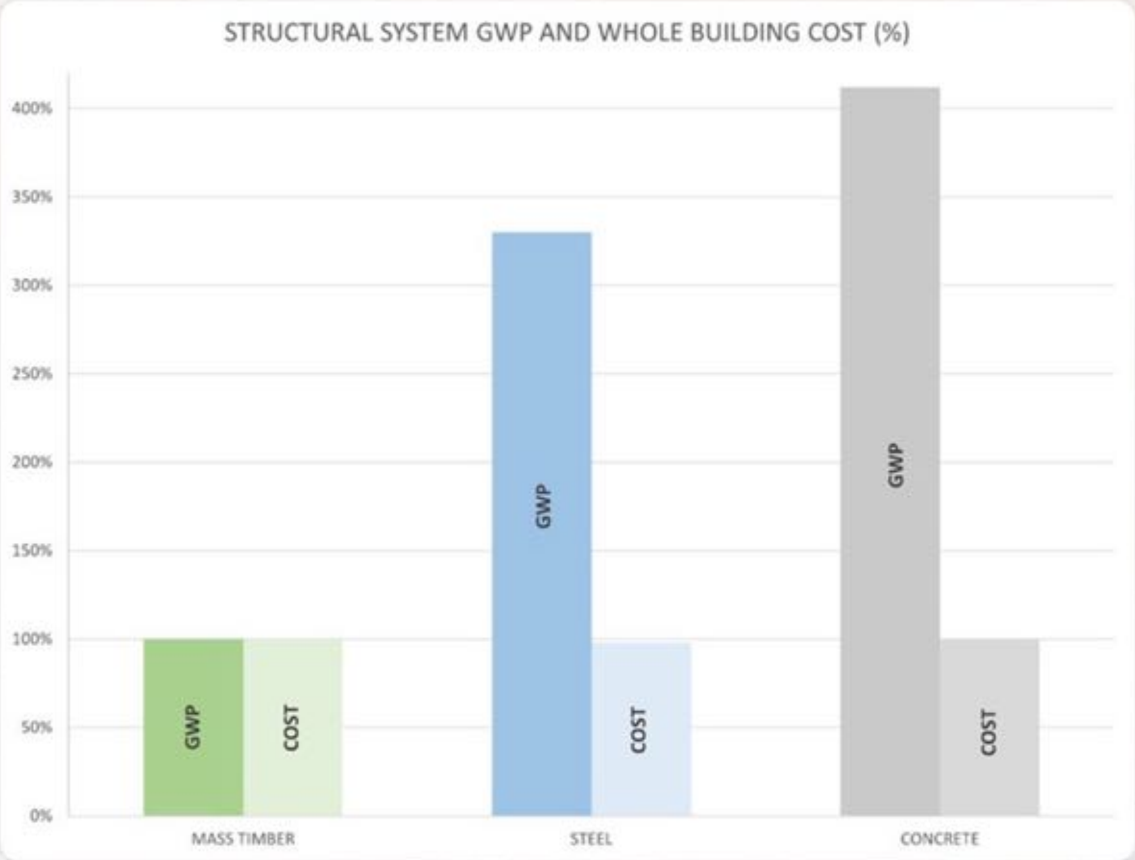
Platte Fifteen

Denver's First CLT Commercial Office Building Puts Sustainability to Work

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

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