Establishing Composite Steel-Frame Performance Standards Using CLT Floor Panels

Kadir Sener
Assistant Professor, Auburn University

Council on Tall Buildings and Urban Habitat
CTBUH 2022
Steel-Timber Conference

Establishing Composite Steel-Frame Performance Standards Using CLT Floor Panels

PIs: Drs. Kadir Sener and David Roueche (Auburn Univ.)

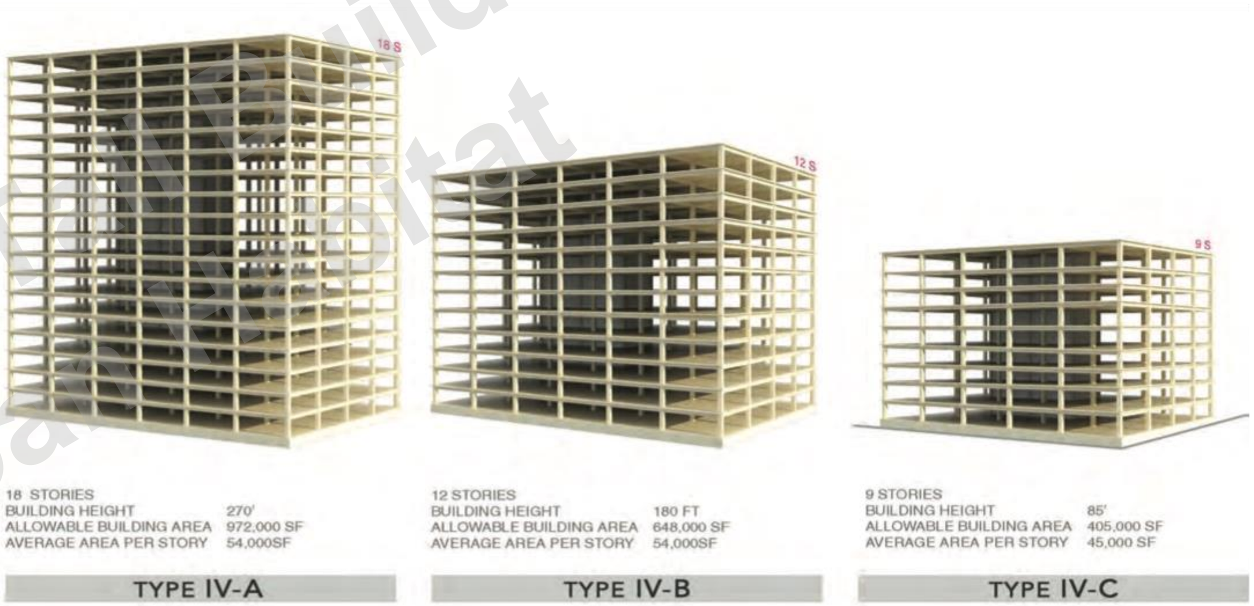
Co-PI: Dr. Brian Via (Auburn Univ.), Prof. David Kennedy (U. Arkansas)

Students: Hugh Merryday, Emma Rohde, and Megan Potuzak (AU)

CTBUH Steel-Timber Conference | 23 May 2022

Introduction: Mass Timber Use

- IBC 2021 has enabled the use of timber for buildings up to 18 stories, opening up new markets for mass-timber usage
  - Type IV-A (up to 18 stories)
  - Type IV-B (up to 12 stories)
  - Type IV-C (up to 9 stories)
- Mass-timber is widely used as framing (beam, column), walls, and floor systems
- Guidance for mass-timber usage exist for strength (gravity, lateral load) and special design considerations (vibration, acoustic, fire, outdoor use, etc.)



Courtesy of Woodworks

Introduction: Steel-Timber Buildings

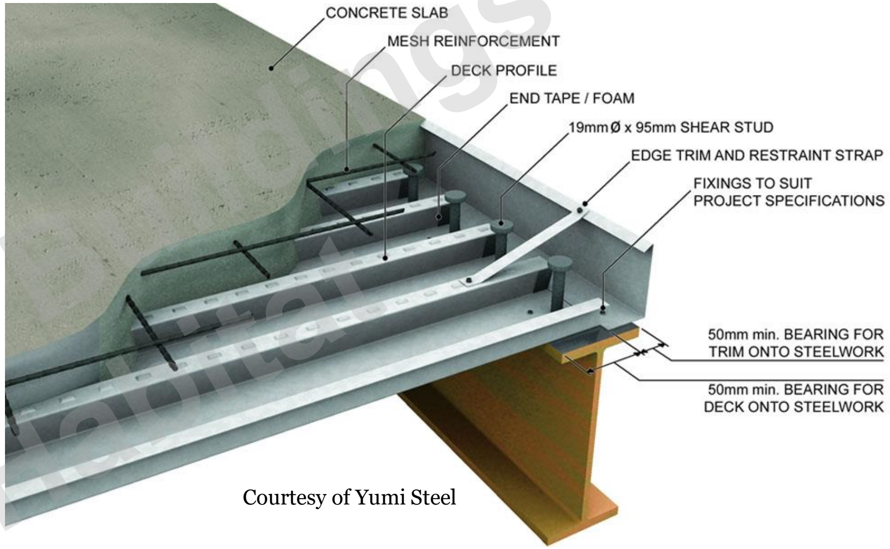
- Steel structures currently use concrete for flooring systems, which accounts for about 60–70% of the total material quantity

- Numerous advantages exist when concrete floors are replaced with CLT panels
  - Improved Sustainability
  - Reduced Weight
  - Faster and More Efficient Constructability
  - Repair/Maintenance
  - Structural performance
  - End-of-life repurposing

Courtesy of Valipour et al.

Steel-Timber Floors

Steel-Concrete Floors



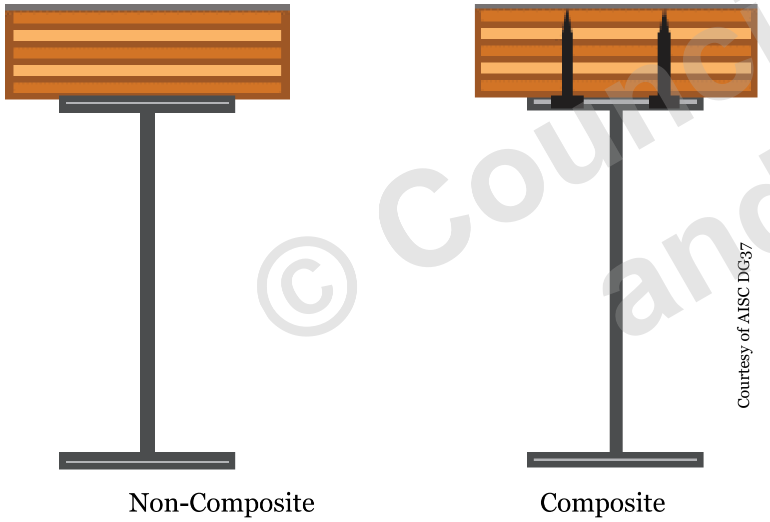
Courtesy of Yumi Steel

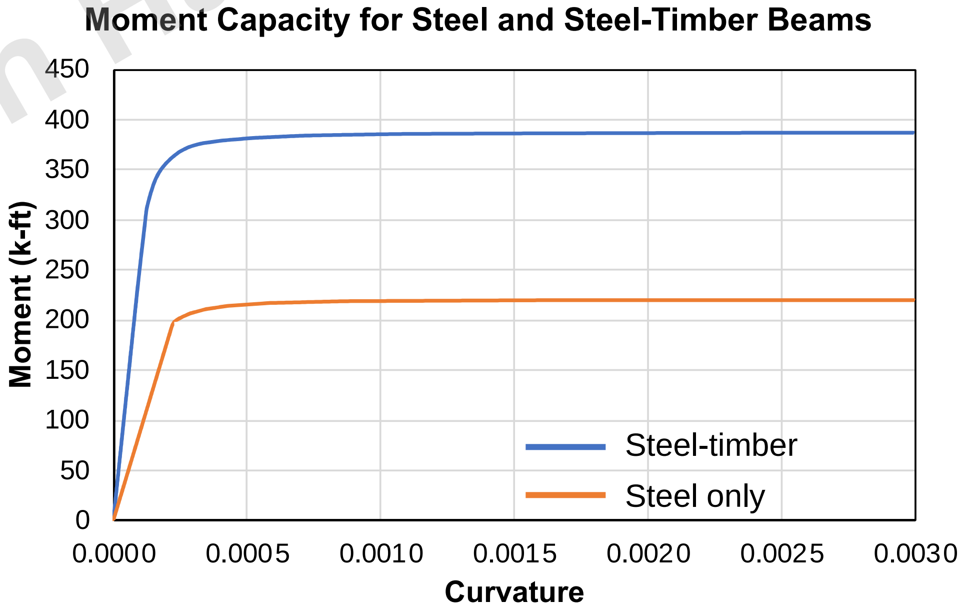

Steel-Timber Floors

Courtesy of David Barber

Motivation: Hybrid vs. Composite

- Limited guidance exists for designing steel-timber floor systems,
- No guidance exists for composite steel-timber floor members due to lack of experimental research to demonstrate the structural behavior
- Comparative construction cost, speed, and LCA studies are needed to highlight the advantages of steel-timber composite systems against the current state of practice of using concrete floor systems





Objective and Research Needs

Objective

The goal of the research project is to facilitate the development of experimentally validated design-detailing configurations and establish consensus design specifications to open up new markets for mass timber CLT panels in the commercial building industry.

- ## Research Tasks:
    - Demonstrate Structural Performance
    - Conduct Comparative Constructability Studies
    - Conduct Comparative LCA Studies

Structural Performance Testing

The experimental research will consist of three major phases:

- Phase 1: Pushout Testing
  - Characterize interfacial mechanical fastener behavior
- Phase 2: Beam Testing
  - Demonstrate member-level behavior
- Phase 3: Connections
  - Demonstrate connection behavior

All experimental testing will focus on US-based materials (Steel, CLT, Mechanical fasteners) and construction practices

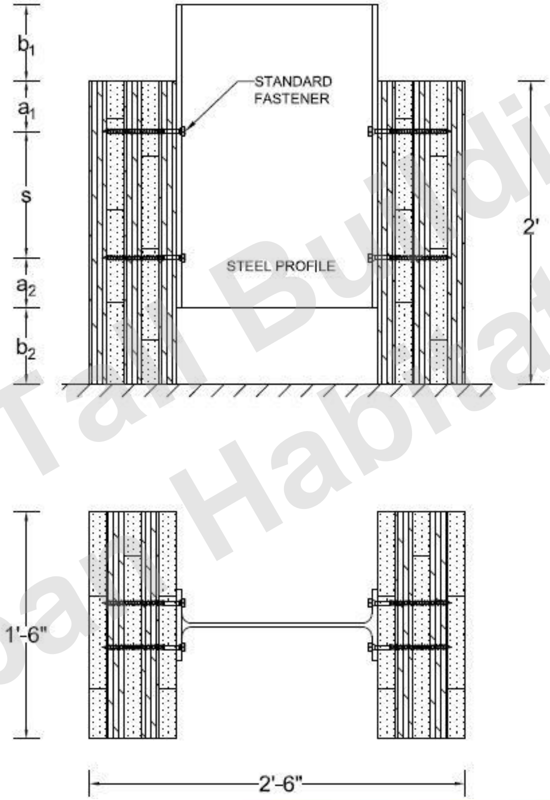
Advanced Structural Engineering Laboratory

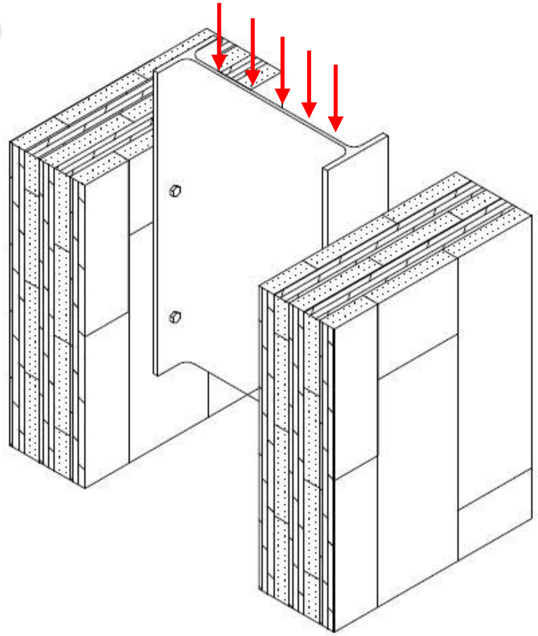
Phase 1: Push-out testing

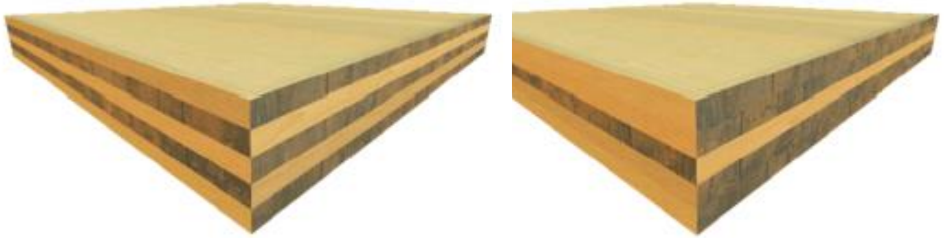
Specimen Design Parameters

- Anchor types
  1. Self-tapping screw (full vs. partial thread)
  2. Lag screws
  3. Threaded bolts

- Panel Properties
  1. Grain orientation (⊥, //)
  2. Thickness (3-5-7 plies)
  3. Layup (alt, maxx)







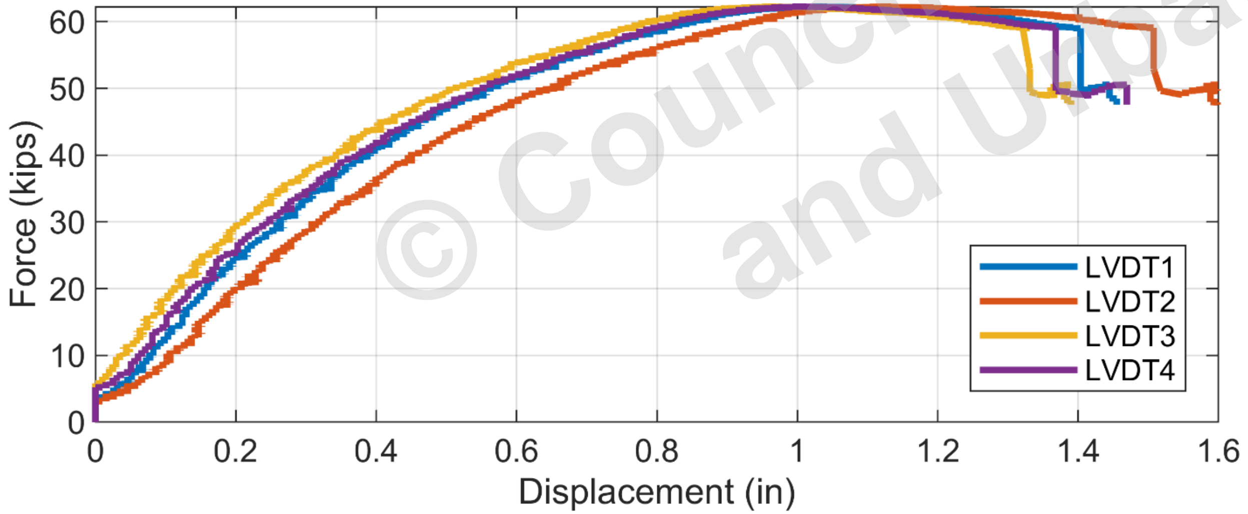
5-alt

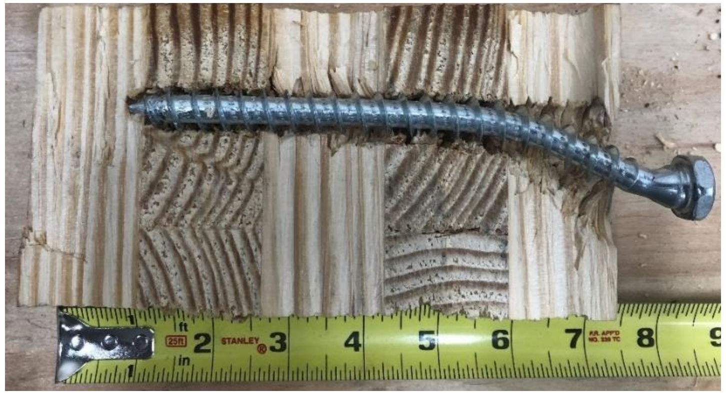
5-maxx

Phase 1: Push-Out Tests

Pushout Test Outcomes:

- Failure mode
- Strength (timber vs. fastener)
- Stiffness (initial and pre-peak)
- Slip Capacity (ductility)
- Force vs. deformation (slip) response

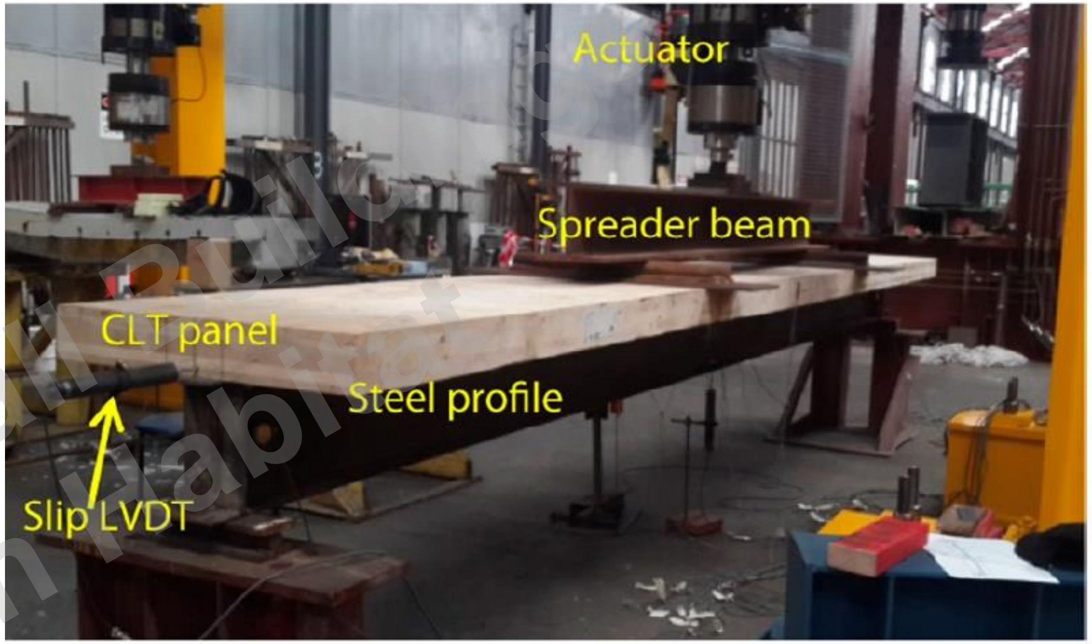


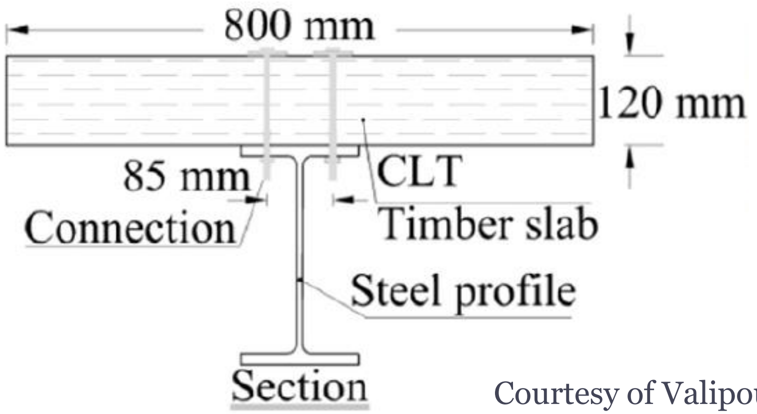


Phases 2: Member-Level Testing

Test Outcomes:

- Flexural strength
  Evaluating the applicability of existing design methodologies
- Composite action (full vs. partial)
- Stiffness / Serviceability
- Shear strength
- Ductility (deformation capacity)
- CLT effective width



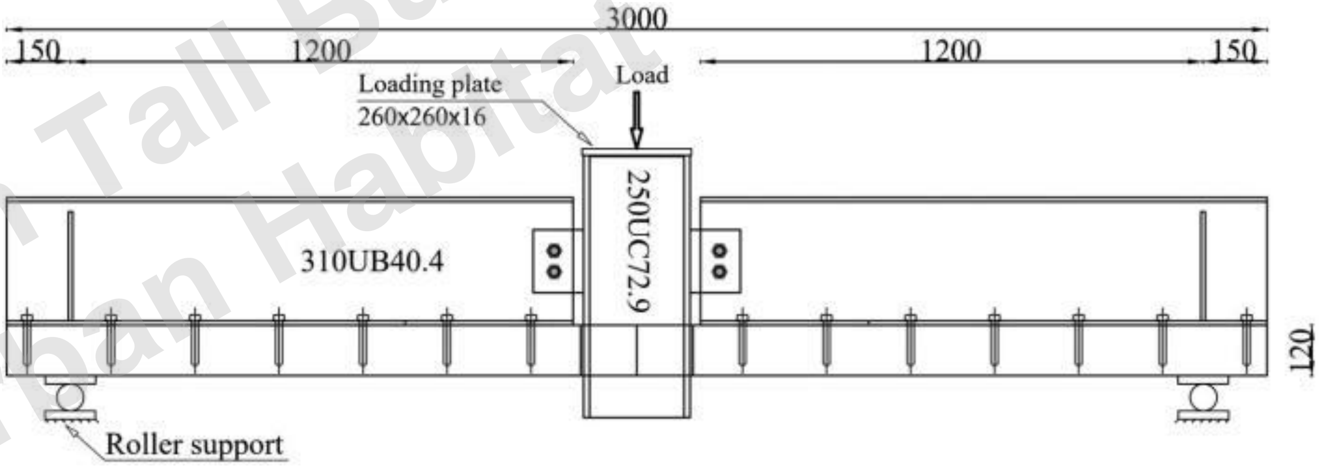


Courtesy of Valipour et al.

Phases 3: Member-Level Testing

Connection tests:

- Panel adjoining methods
  - Splines
  - Lap joint
  - Continuity Plates
- Connections
  - Shear-resisting
  - Moment+Shear Resisting
- Positive & Negative moment transfer

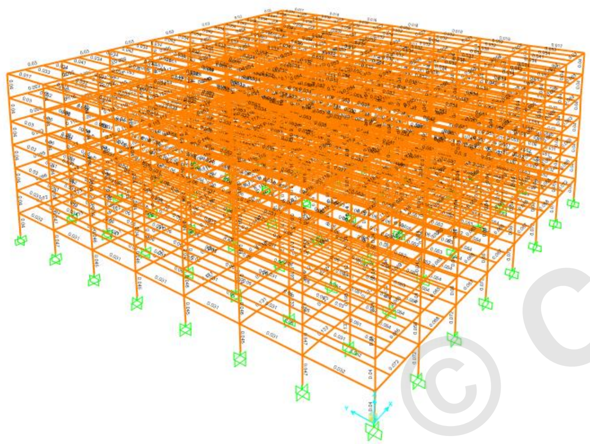


Courtesy of Valipour et al.

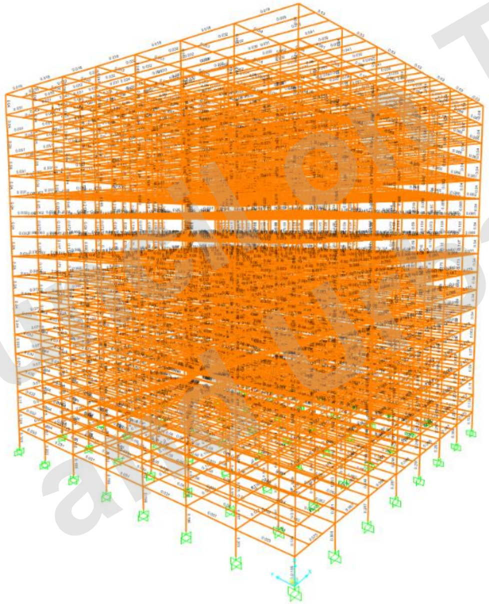
Benchmark Studies: Schedule, Cost, LCA

Design of buildings according to IBC 2021 with different stories using;

- Steel-Concrete (Composite Concrete Floor)
- Steel-Timber (Composite Timber Floor)
- Reinforced Concrete



7-Story Building



18-Story Building

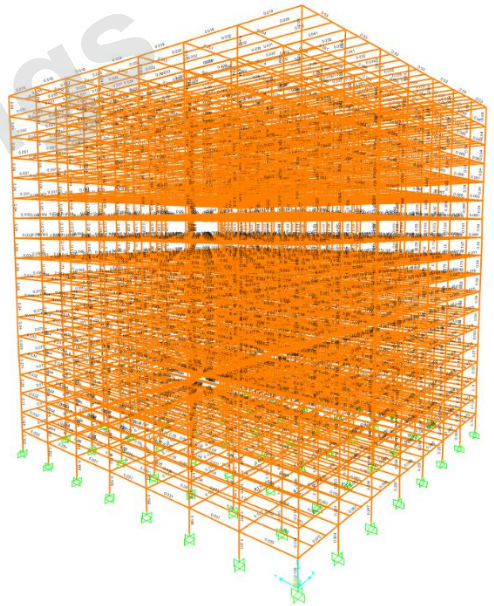
Building Type	Type IV-C	Type IV-A
No. of Stories	7-story (9)	18-story (18)
Building Height	84 ft (85 ft)	216 ft (270 ft)
Column Spacing	30 ft	30 ft
Floor Area (ft^2)	44,100 (45,000)	44,100 (54,000)

Benchmark Studies: Schedule, Cost, LCA

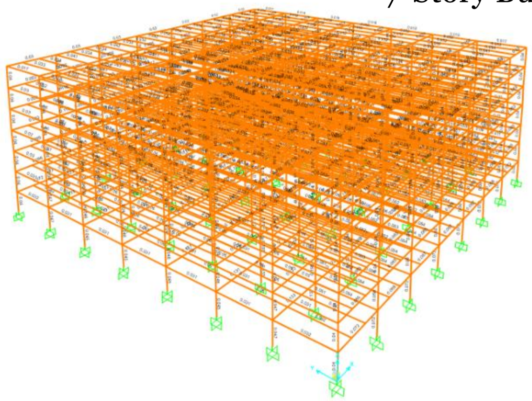
Study Parameters:

- Location
  - Seismic-controlled region (LA)
  - Wind-controlled region (NYC)
- Lateral Force Resisting System
  - Moment-resisting frame
  - Braced or Shear Walls
- CLT Layers (3- 5- 7-Ply)
  - Topping layer for fire, acoustic, vibration considerations
- Level of composite action
  - Partial vs. Full CA
- Inclusion of foundation

18-Story Building

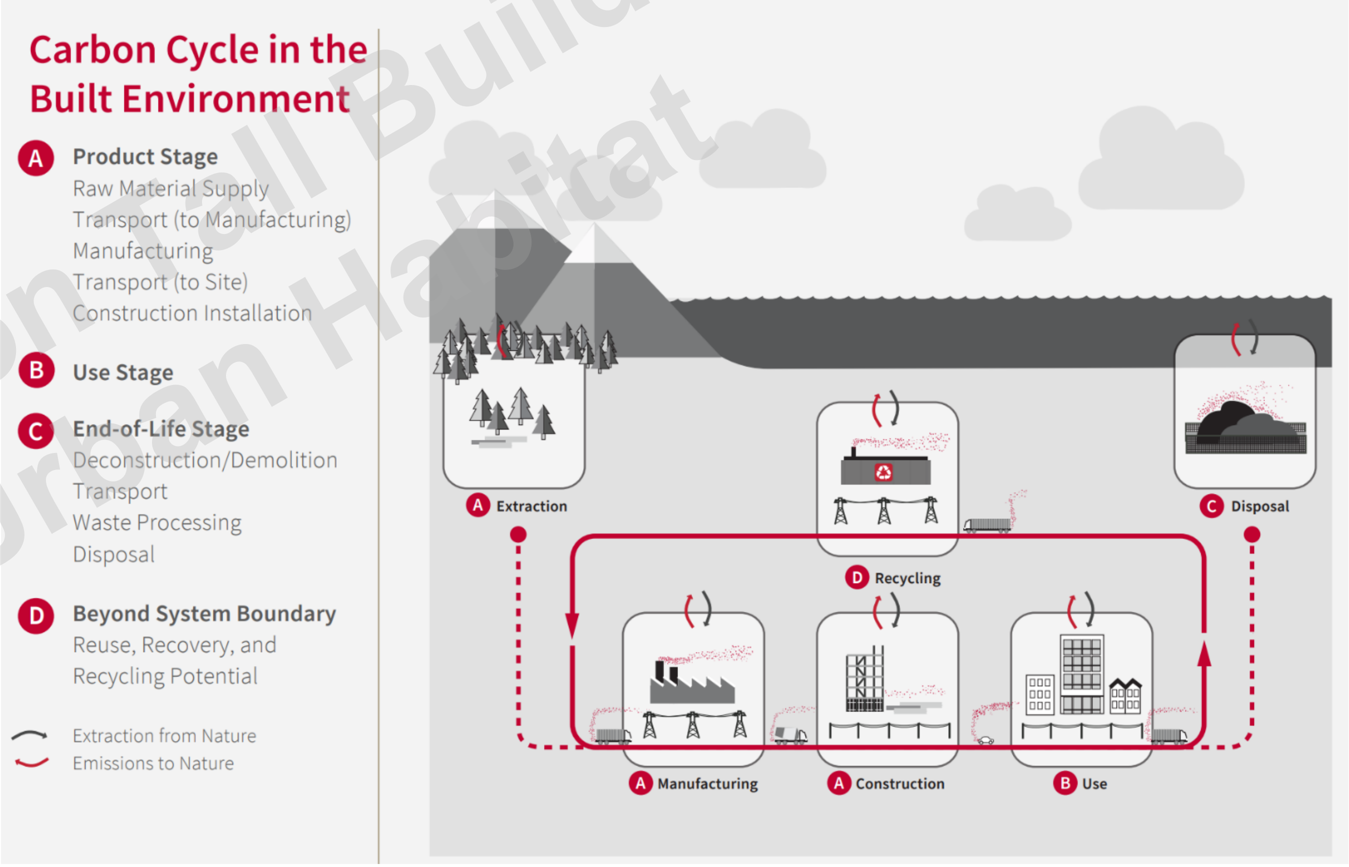


7-Story Building



Benchmark Studies: LCA Outcomes

- Focus on the impact of structurally utilizing the composite behavior
- Cradle-to-grave LCA studies using different software/database
  - Tally/GaBi
  - Athena/Athena
  - One-Click LCA/EU Databases
- Expected life cycle analyses outputs
  - Potential global warming impact
  - Total embodied energy
  - Stage specific life-cycle energy
  - Combined life-cycle energy
- Sensitivity analysis



Source: Life Cycle Assessment of Buildings: A Practice Guide

Benchmark Studies: Constructability

- Cost Studies
  - Material cost
  - Labor cost
    - Construction crew size
  - Prefabrication

- Schedule Duration Studies
  - Prefabrication
  - Formwork elimination
  - Erection
    - Ease of installment using small crane
  - Shoring
  - Camber

Courtesy of ARUP

Current Progress / Expected Future Timeline

- Structural Performance Demonstrative Testing
  - Pushout Tests – Ongoing
  - Beam Tests – Summer '22
  - Connection Tests – Fall '22

- Sustainability & Constructability
  - Benchmark Building Designs - Ongoing
    - Concrete – Completed
    - Timber/Steel – Summer '22
    - Concrete/Steel – Summer '22
  - Construction Schedule/Cost – Fall '22
  - LCA – Fall '22

THANK YOU!

FUTURE: Expanding Mass Timber for Protective Structures

Upcoming AU project with US Air Force on advancing use of mass timber for protective designs

- Hybrid panels
- Projectile/debris protection
- Blast loads
- Connection design
- High strain-rate material characterization

Continue the Conversation

sener@auburn.edu | dbr0011@auburn.edu

References

Hassanieh, A., Valipour, H.R., and Bradford, M.A., (2017). “Composite connections between CLT slab and steel beam: Experiments and empirical models,” *Journal of Constructional Steel Research*, Elsevier, Volume 138, pp. 823-836. doi: 10.1016/j.jcsr.2017.09.002.

Simonen, K., Huang, M., Rodriguez, B. X., & Todaro, L. (2019). Life Cycle Assessment of Buildings: A practice guide.

Yang, R., Li, H., Lorenzo, R., Ashraf, M., Sun, Y., and Yuan, Q., (2020). “Mechanical behaviour of steel timber composite shear connections,” *Construction and Building Materials*, Elsevier, Volume 258. doi: 10.1016/j.conbuildmat.2020.119605.

Funding Acknowledgement

USDA United States Department of Agriculture | SLB Softwood Lumber Board | AISC | SmartLam North America | Simpson Strong-Tie | MTC Solutions