Using Multiple Criteria Decision Analysis to Determine Best Approaches for High Seismic Regions

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Presentation Overview

1. Background & Motivation
2. Multiple Criteria Decision Analysis (MCDA) Methodology
3. Prototype Buildings in Seattle, WA
4. Calculation of the Input Variables
5. Results of MCDA
6. Conclusions
7. Where to go from here?

Background & Motivation

Motivation: To investigate the advantages and dis-advantages of steel and mass timber structural systems.

- Mass Timber is a hot topic.
- Increased concern by owners/architects/engineers about climate change and the impact of building materials.
- Pending Local, State & Federal legislation.

Figure 1: Steel-Timber hybrid building (6 Orsman Rd.) in London, UK with castellated steel beams, HSS columns, and CLT floors. Credit: Engenuiti Consulting.

Research Objective

Objective: To compare self-centering CLT rocking wall with mass timber gravity framing buildings to equivalent steel BRBF systems using two prototype buildings in Seattle, WA.

Study used Multiple-Criteria Decision Analysis and 3 Decision Criteria:

1. Seismic resiliency
2. Life-cycle impact
3. Construction cost.

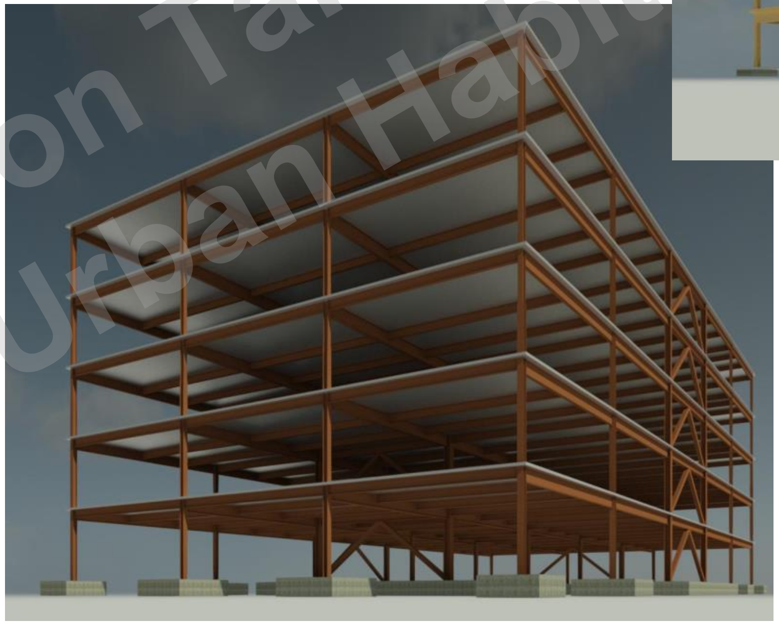


Figure 2: 5-story prototype buildings from this study. Credit: Kevin Allan, GRA, WSU

Multiple-Criteria Decision Analysis Methodology

This project used Weighted Sum Model (WSM) with normalized decision criteria. The decision criteria were:

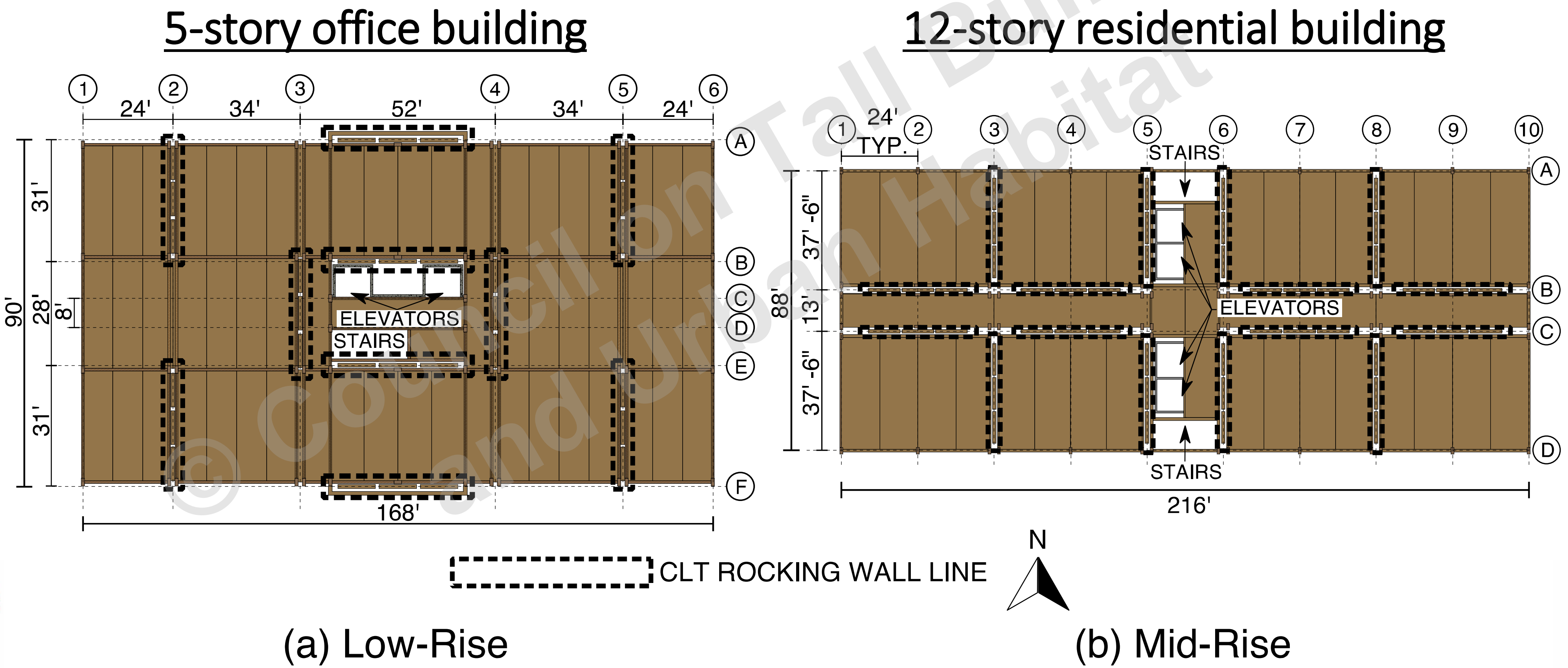
1. Seismic resiliency. Measured as median predicted annual loss.
2. Life-cycle impact. Measured as life-cycle GHG emissions, omitting Use phase and biogenic carbon.
3. Construction cost. Measured as estimated super-structure cost per square foot.

Table 1: Five decision maker cases evaluated in study.[1]

Decision Case	Life-cycle impact	Seismic resiliency	Durability/ Maintenance	Construction Cost
1: Base Case	20%	20%	20%	40%
2: Cost/Durability priority	10%	10%	20%	60%
3: Sustainability priority	50%	5%	20%	25%
4: Resiliency/Durability priority	15%	30%	30%	25%
5: High Sustainability priority	70%	5%	20%	5%

Mass Timber Prototype Buildings in Seattle, WA

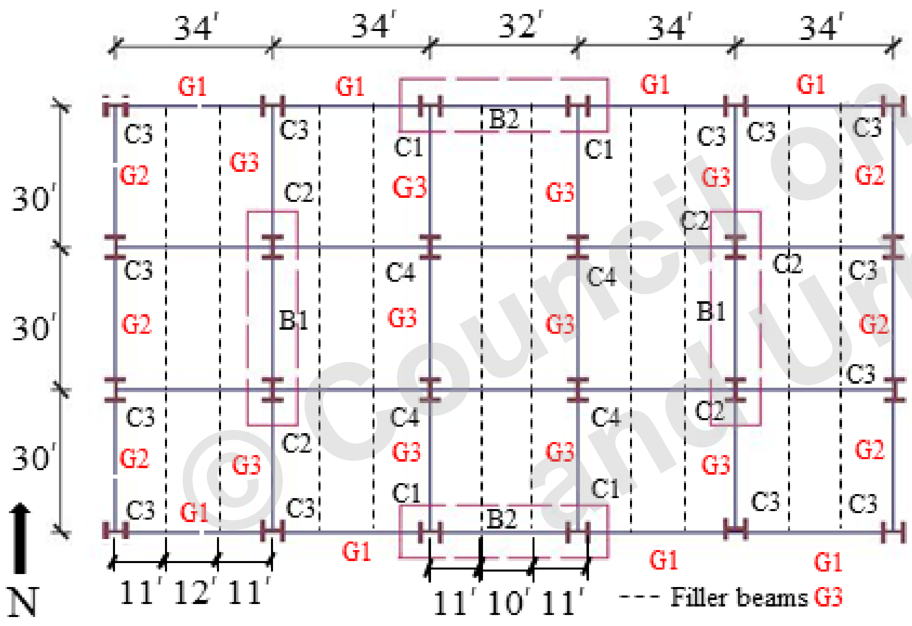
Two mass-timber prototype buildings were used for comparison. They were designed and analyzed using post-tensioned CLT rocking walls.[2,3]



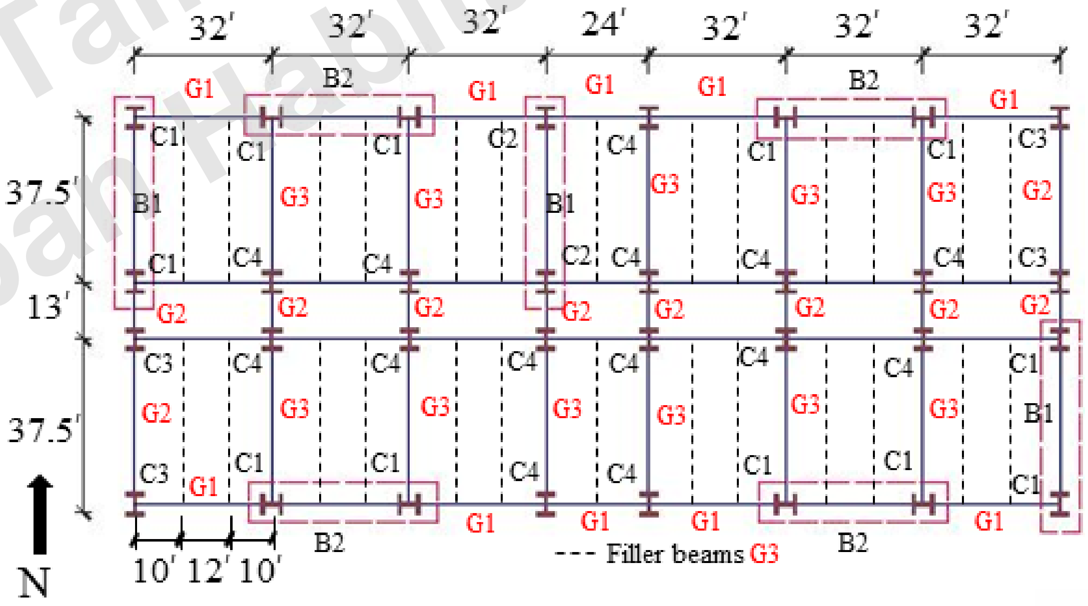
Prototype Steel BRBF Buildings

The two prototype buildings were re-designed as equivalent structural steel buildings using concrete composite floors and buckling restrained braced frames.

5-story office building



12-story residential building



Seismic Resiliency

- For the buildings, site specific seismic performance and loss were analyzed using methods in line with FEMA P-58.[1, 3]

Table 2: Median predicted annual losses (0% discount rate).

Decision Case	Mass Timber	Steel
5-story Buildings	$17,400	$16,000
12-story Buildings	$24,500	$15,900

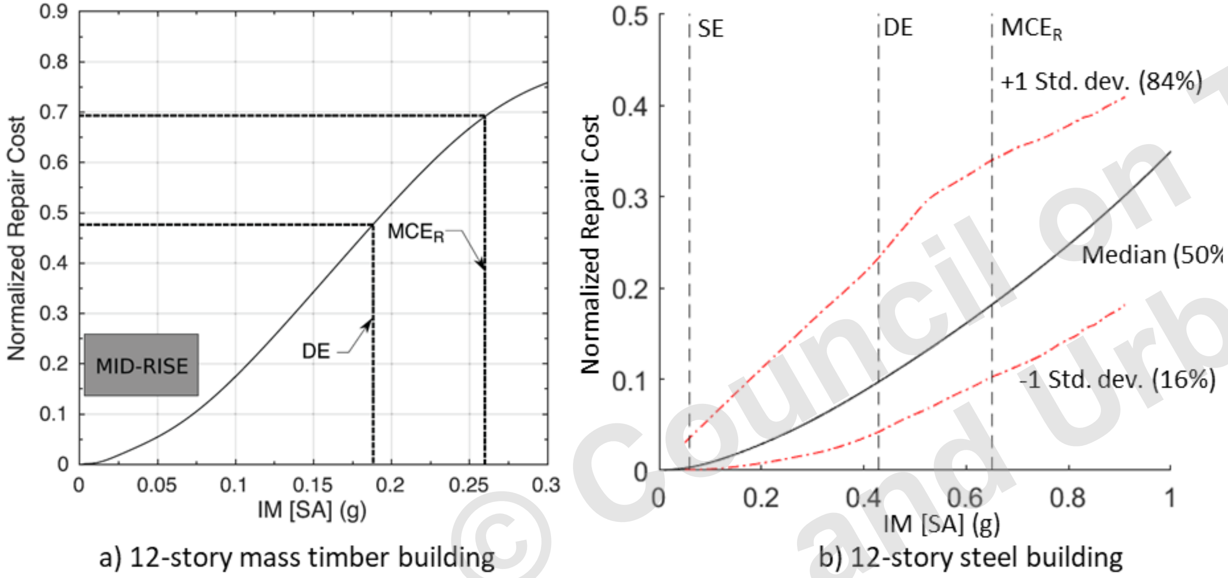


Figure 3: 12-story prototype building predicted loss curves. [1]

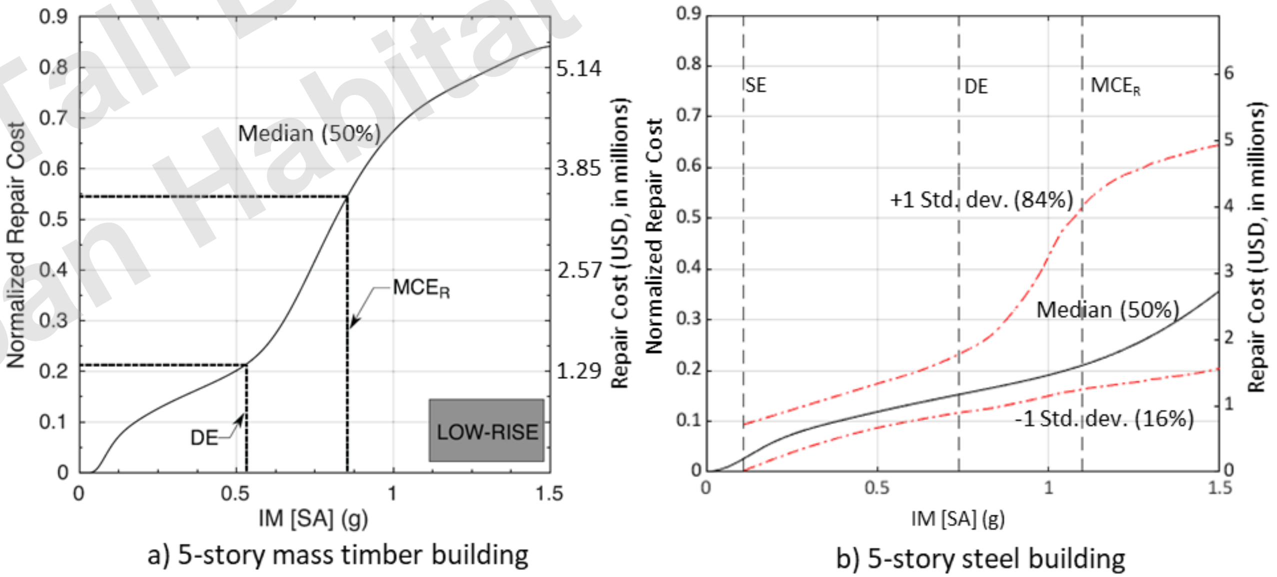


Figure 4: 5-story prototype building predicted loss curves. [1]

Life-Cycle Impact

This project used the Athena Impact Estimator for Buildings[4] tool to assess cradle-to-grave life-cycle impact.

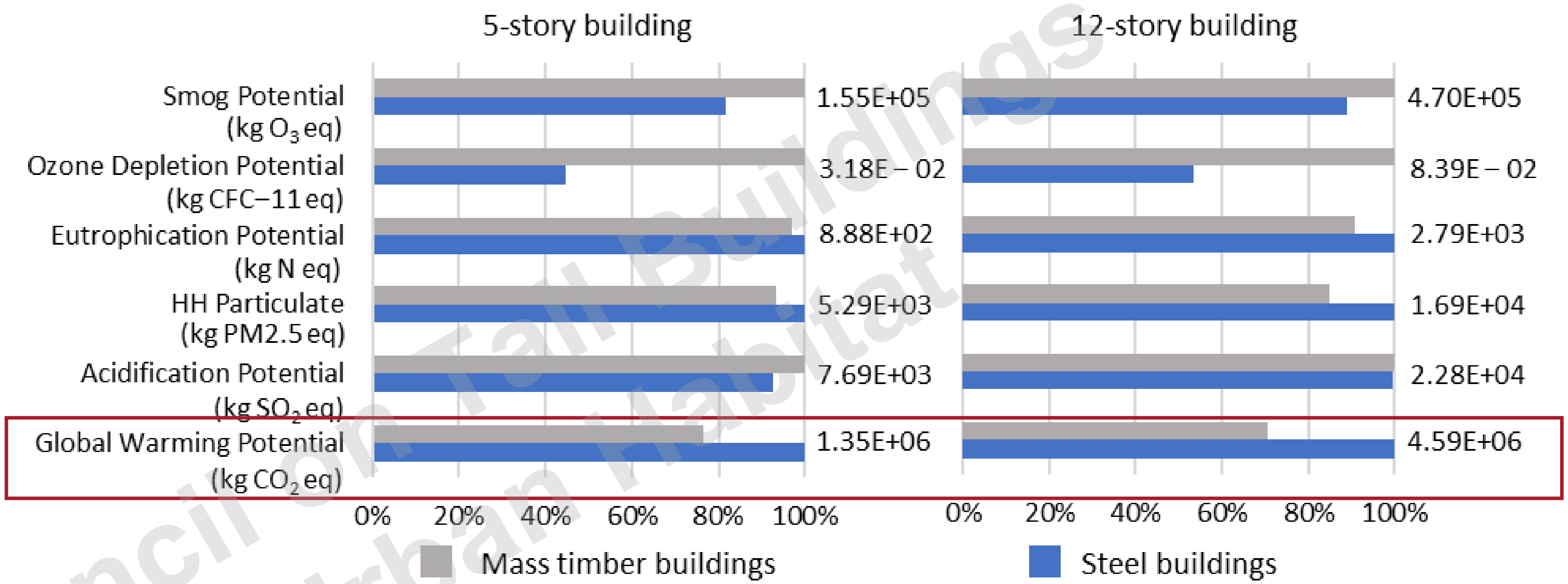


Figure 5: 5-story and 12-story prototype building LCIA results.

Report details further breakdown of environmental impacts between the buildings.[1] Concrete is approximately 50% of steel building GWP, while the steel is approximately 20% of total GWP.

Life-Cycle Impact

Table 3: Normalized GWP (kg CO_2 eq. / m^2) used in MCDA.

Decision Case	Mass Timber	Steel
5-story Buildings	161	211
12-story Buildings	164	233

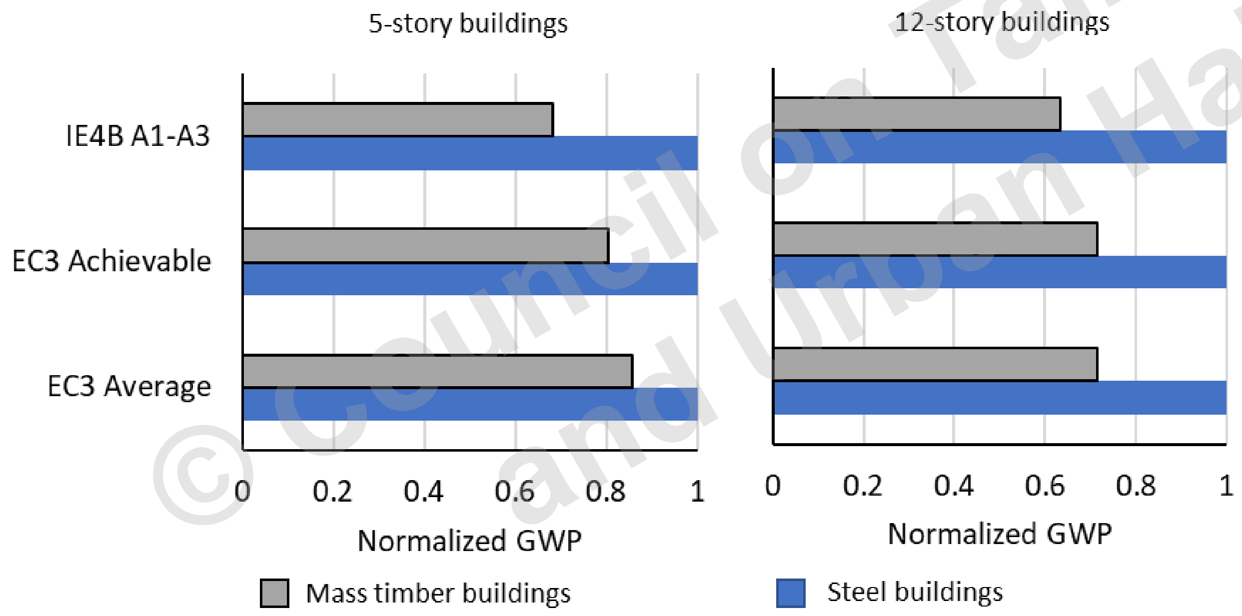


Figure 6: Variability in LCIA results based on software program, EPD, and assumptions. [1]

Construction Costs

- Estimates were calculated with collaboration from industry
- 11 scenarios were examined
- Mass timber is approximately twice as expensive as conventional steel.

Table 3: Average cost estimate ($/ ft^2) used in MCDA.

Decision Case	Mass Timber	Steel
5-story Buildings	$54.07	$27.14
12-story Buildings	$55.77	$31.55

Steel Cost Summary

- Baseline $27.14/SF & $31.55/SF
- Metals Fab $22.72/SF & $25.55/SF
- Hybrid (CLT Floors) $34.26/SF & $38.56/SF

Mass Timber Cost Summary

- Baseline $57.85/SF & $59.55/SF
- Realistic Low $47.07/SF & $48.39/SF
- Realistic High $61.43/SF & $63.71/SF

WSM Results: Pulling it together

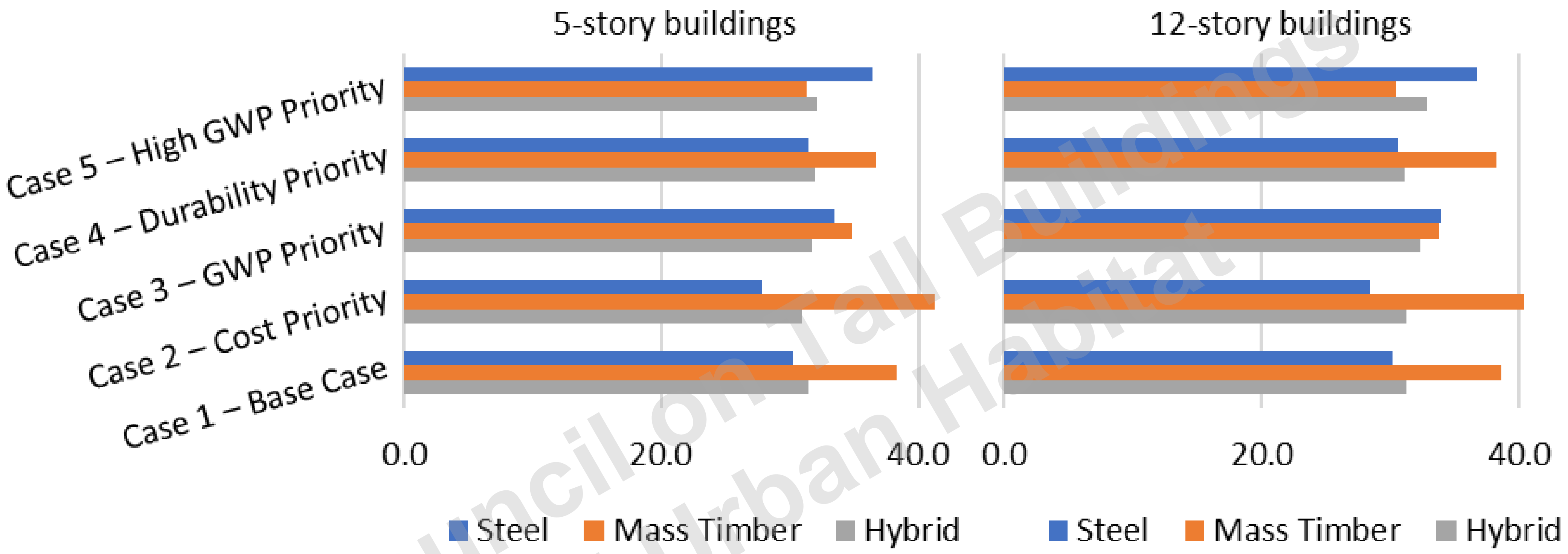


Figure 6: 5-story and 12-story prototype building WSM results.[1] Low-score is most preferred.

- The hybrid building was a simplistic combination of CLT floors + steel lateral and gravity framing. LCIA and cost analysis was conducted for the hybrid case; seismic resiliency was taken as identical to the BRBF building.

Conclusions

- Code-designed BRBF's have excellent seismic resiliency, even when compared to PBD systems.
- Steel buildings are far cheaper to design and construct than all-wood mass timber buildings.
- While steel buildings have higher GWP, only 20% of the total emissions are coming from steel components. 50% is the concrete (floors & foundation).
- <u>Hybrid steel-timber buildings are a good option across the full range of decision maker priorities.</u>

Figure 7: 12-story prototype building as a hybrid steel-timber building.

Future Research Questions

- Structural configuration bay study for minimizing cost and carbon using steel-timber hybrid. (Ongoing).
- Investigating various sizes & heights of steel-timber hybrid buildings for peak efficiency in low-embodied carbon buildings.
- Investigating the 2nd-order effects of timber floors, i.e. less seismic mass, smaller foundations.
- Investigating practical solutions to concrete-less floor diaphragms using mass timber and steel composites.

Figure 7: 12-story prototype building as a hybrid steel-timber building.

Thank You

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Thank you to AISC and Ironworkers District Council of the PNW.

References

[1] Phillips, A. R., Ahmad, F., and Allan, K. (2021). Multiple-Criteria Evaluation of Steel and Mass Timber Construction using Two Prototype Buildings in Seattle, WA. Final Report AISC, Chicago, IL.

[2] Wilson, A., Motter, C., Phillips, A. R., and Dolan, J. D. (2020). "Seismic response of post-tensioned cross-laminated timber rocking wall buildings," *ASCE Journal of Structural Engineering*. 146(7).

[3] Wilson, A., Phillips, A. R., Motter, C., Lee, J.Y., and Dolan, J. D. (2021). "Seismic Loss Analysis of Buildings with Post-Tensioned Cross-Laminated Timber Walls," *Earthquake Spectra*. 37(1): 324-345.

[4] Athena Sustainable Materials Institute. (2019). Athena Impact Estimator for Buildings, User Manual and Transparency Document, V5. Ottawa, Ontario, Canada.