United States Department of Agriculture

Research Needs Assessment for the Mass Timber Industry

Proceedings of the 2nd North American Mass Timber Research Needs Workshop

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General Technical Report FPL–GTR–273

September 2019

Abstract

The 2nd Mass Timber Research Needs Assessment was held on November 13–14, 2018, at the USDA Forest Service, Forest Products Laboratory (FPL). The workshop was co-sponsored by FPL, WoodWorks, and the U.S. Endowment for Forestry and Communities. The purpose of the workshop was to gather a diverse group of people with expertise in mass timber, in particular cross-laminated timber, to discuss and prioritize research needed to move the mass timber industry forward in North America. The workshop was attended by more than 100 design professionals, researchers, manufacturers, industry leaders, and government employees. The meeting resulted in a list of 117 research needs. Following the meeting, the list of research needs was prioritized through an online survey. This report presents the prioritized research needs of the mass timber industry in North America. Also included in the appendixes are the formal minutes of the workshop, a list of participants, and the original scribe notes.

Keywords: mass timber, cross-laminated timber, North America, seismic performance, fire performance

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Conversion table

English unit	Conversion factor	SI unit
foot (ft)	3.048×10^{-1}	meter (m)
inch (in.)	2.54×10^{-1}	millimeter (mm)
pound, mass (lb)	4.535924×10^{-1}	kilogram (kg)

September 2019

Zelinka, Samuel L.; Williamson, Tom; Martinson, Karen L.; Ritter, Michael A. 2019. Research needs assessment for the mass timber industry: Proceedings of the 2nd North American mass timber research needs workshop. General Technical Report FPL-GTR-273. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 41 p.

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The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

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Proceedings of the 2nd North American Mass Timber Research Needs Workshop

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Introduction

Mass timber represents a relatively new type of construction in North America (Green and Karsh 2012, Iqbal 2018, Jakes and others 2016, Lehmann 2012, Mohammad and others 2012). Mass timber refers to "massive" engineered wood composites such as glulam, structural composite lumber, nail-laminated timber, and cross-laminated timber (CLT) (Jakes and others 2016). CLT consists of layers of dimension lumber whose laminates are rotated 90° from the previous layer; it can be used as wall or floor assemblies and is delivered to the job site as massive panels with penetrations for connectors and fasteners and fenestrations or mechanical, electrical, and plumbing (MEP) services precut (Mohammad and others 2012). Although many mass timber products have been incorporated into buildings for nearly 100 years, the rise of CLT in North America has allowed advances in wood construction, allowing buildings as tall as 18 stories to be constructed out of wood (Fast and others 2017). Although mass timber holds great promise as a new market for wood materials, research is needed to open new markets for this type of construction.

Currently, there are several research programs focused on delivering research results to help the North American mass timber industry. There is a large amount of research money being invested in mass timber across many different agencies. Therefore, a needs assessment is crucial for establishing the research needs of the mass timber industry. Such a research needs assessment can be performed to evaluate proposals for mass timber research, focus calls for research proposals, and benchmark the current state of knowledge. Three years ago, the U.S. Department of Agriculture, Forest Service, Forest Products Laboratory (FPL) conducted a research needs assessment workshop for mass timber (Williamson and others 2016). However, since that time, the industry has evolved. Some research questions have been answered, and new questions have come to light as the industry has grown. This report represents the current research needs of the mass timber industry in the United States.

Objective and Scope

The objective of this report is to present a comprehensive, prioritized list of the research needed to support the growing mass timber industry in North America. The scope of the needs assessment encompasses all aspects of mass timber utilization. The scope is broad and includes nonbuilding applications for mass timber and not only the engineering properties of mass timber but also the environmental and economic aspects.

Methodology

Workshop

The second mass timber research needs assessment was held in Madison, Wisconsin, USA, at the FPL on November 13–14, 2018. There were 105 attendees at the meeting. Attendees included a mix of industry, trade associations, nongovernmental organizations, academia, and government participants.

The majority of the workshop was divided into seven panel discussions on different areas of mass timber research. Panel topics were

1. Structural Resilience
2. System Design and Construction
3. Fire Performance
4. Durability and Building Physics
5. Materials and Manufacturing Processes
6. Sustainability and Economic Analysis
7. Nonbuilding Applications

For each panel discussion, four to five panel members were seated in the front of the room. Each panelist was given approximately ten minutes to present what he or she felt were relevant research topics within their area. Following this, the panelists were then allowed to comment and build upon the presentations from the other panelists. Then the audience was allowed to interact with the panelists to generate additional ideas.

During the panel discussions, detailed notes were recorded by two scribes for each panel. The notes collected by the scribes are included in Appendix C.

Online Survey

Following the Mass Timber Research Needs Assessment Workshop, the scribes and workshop organizers refined their extemporaneous notes into a list of one sentence “research topics”. These research topics were then compiled into an online survey which was sent to all participants. The order in which the research topics were presented to each participant were randomized. For each research topic, participants were asked to rate the level of the research need from 1, lowest priority, to 5, highest priority.

Prioritized Needs Assessment

The prioritized research needs assessment was created by averaging the scores given by all participants for each research topic. The research topics were then sorted from highest to lowest score to develop the prioritized list of research topics.

Results

The results of the prioritized research topics are included in Tables 1 to 8. Tables 1 through 7 present the research topics from the panel discussions with two rankings. The first ranking is the ranking of that research topic within the panel discussion category. The second ranking is the overall ranking of the research topic. The average score for each research topic is also presented in Table 8 (the overall rankings).

Concluding Remarks

Mass timber represents an exciting potential market for wood products. However, its use in North America is in its infancy. The 2nd Mass Timber Research Needs Assessment Workshop was an opportunity for key industry stakeholders to work together to identify the most critical research needs for the widespread adoption of mass timber and CLT in the United States. The conversations and research topics generated in this workshop have been summarized in this report.

Multiple agencies are funding research on mass timber in North American. Because of this, it is critical to have a comprehensive agreement on the most critical research needs facing the mass timber industry. This report presents a prioritized list of research needs that can be used to evaluate proposals and develop calls for proposals. Furthermore, it can be used as a benchmark of the current state of knowledge of mass timber. It is hoped that in future years, many of the current research needs will have been accomplished and that potential research topics will have evolved.

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Table 1—Structural resilience

Category rank	Overall rank	Research topic
1	1	Complete research on CLT shear wall performance and publish seismic design coefficients.
2	2	Develop building-code-approved prescriptive designs for CLT diaphragms and shear walls.
3	10	Conduct CLT diaphragm research that specifically addresses the effect of aspect ratios.
4	15	Evaluate performance of connections and panels as panels shrink and swell because of moisture exposure.
5	20	Evaluate the effects of openings on the performance of CLT shear walls.
6	21	Evaluate lateral force resisting systems for multistory mass timber open floor plan buildings.
7	28	Research CLT diaphragms with concrete topping over CLT.
8	31	Determine the performance of self-tapping screws under moisture cycling.
9	40	Further evaluate the performance of wood–concrete composite systems from a seismic perspective.
10	42	Conduct research to evaluate different timber–concrete composite connector systems.
11	48	Develop a rocking shear wall CLT design guide.
12	54	Study the deformation capability of connections including strain-rate and extreme loading.
13	57	Study the punching shear effect of two-way slabs.
14	62	Determine the effect of perpendicular-to-grain crushing loads on CLT panels.
15	75	Establish methodology for repairing CLT buildings after a seismic event.
16	82	Conduct research on the effect of notches in glulam that are beyond code limitations.
17	85	Conduct research on hybrid composite panels that address brittle behavior of panels and ductile behavior of connections.
18	87	Conduct holistic testing that looks at a CLT panel from a structural, fire performance, and acoustics perspective.
19	88	Evaluate feasibility of using drilled-in and epoxy rods to reinforce glulam as done in Europe.
20	98	Study the feasibility of seismic retrofit of masonry buildings with CLT.
21	102	Develop displacement-based design for nonlinear static pushover.
22	103	Continue and expand research efforts to study ballistic, forced entry, and blast testing of CLT.
23	105	Determine the windborne debris resistance of CLT.
24	108	Evaluate dowel fasteners under different strain rates.

Table 2—System design and construction

Category rank	Overall rank	Research topic
1	6	Conduct CLT diaphragm research based on needs determined by design professionals.
2	9	Conduct research to develop design methods for point-supported and two-way spanning CLT panels.
3	16	Develop approaches to enhance CLT performance in low seismic regions.
4	22	Conduct vibration testing of CLT–concrete panel systems (e.g., nonstructural topping concrete over panels and structurally connected concrete over CLT).
5	38	Conduct detailed testing on CLT panels to investigate the size/volume effect of CLT in edgewise, flatwise, and shear loadings.
6	43	Improve vibration, acoustic, and connection performance of wood–concrete composite systems.
7	49	Develop design methodologies for the reinforcement of notched glulam beams that will permit their use beyond the National Design Specification and International Building Code limits.
8	58	Determine the cyclic wetting and drying behavior of wood–concrete composite panels.
9	60	Develop approaches to minimize CLT crushing in high loading areas.
10	65	Conduct acoustic testing of 3-ply CLT assemblies.
11	89	Evaluate the torsion–twisting performance of CLT.
12	90	Develop nonscrew attachment options for concrete over timber composite systems.
13	96	Identify strategies to enhance glulam product performance (i.e. use of epoxy rods and fiber reinforcement such as used in Europe).
14	114	Conduct high-strain-rate testing (i.e., blast–ballistic loads) of CLT using a variety of species and connectors.

Table 3—Fire performance

Category rank	Overall rank	Research topic
1	5	Perform 2-h fire testing on a wide variety of connections and mass timber connection configurations.
2	8	Research improvements to the American Wood Council 2018 TR-10, Calculating the Fire Resistance of Wood Members and Assemblies, regarding more efficient testing and design methodology for protection of connections in wood.
3	11	Develop guidance for detailing assembly intersections, assembly fire stop systems, and penetration fire stops for up to 3-h fire ratings.
4	33	Conduct research to evaluate the impact of gaps between CLT and NLT boards on fire performance and calculated fire resistance of these systems.
5	36	Research fire performance of embedded steel in mass timber connections.
6	41	Research viability of using more fire-retardant treatment products in mass timber buildings to reduce the use of gypsum and other fire protective methods.
7	44	Develop intermediate-scale qualification tests for adhesives to verify that the adhesive doesn't lead to delamination and fire regrowth.
8	52	Conduct additional testing of nongypsum board noncombustible protection options to establish their performance when used in mass timber construction.
9	55	Carry out compartment fire testing under office loads and with exposed timber ceilings, and define benchmarks for acceptable performance.
10	56	Research fire performance of timber–concrete composite floors with varying shear connectors and panel connections.
11	59	Test and evaluate more products for protecting penetrations in mass timber construction.
12	61	Conduct more fire resistance testing on timber–concrete and timber–steel hybrid assemblies.
13	63	Develop exterior flame spread standards for Type III, IV-HT, and V construction types in accordance with the International Building Code.
14	66	Identify market gaps and perform scaled-down fire performance testing of mass timber components for more efficient product development.
15	70	Carry out additional compartment fire tests on CLT with adhesives that comply with ANSI PRG 320-18, Standard for Performance Rated Cross-Laminated Timber.
16	78	Explore possible adoption of Canadian code provisions for use in the U.S. regarding the use of 1-1/2 in. noncombustible toppings as prevention for penetration of hot gasses and thermal rise.
17	93	Research and demonstrate the performance of partially constructed mass timber buildings involved in a construction fire.

Table 4—Durability and building physics

Category rank	Overall rank	Research topic
1	3	Determine how duration and severity of wetting affect mass timber products (dimensional change, surface mold, biological deterioration, corrosion of connections, etc.).
2	4	Develop written specification language that incorporates best practices for moisture management during and after construction.
3	17	Develop improved moisture and structural condition assessment methods for mass timber products (e.g., infrared thermography, ground-penetrating radar).
4	19	Develop methods for repair and remediation of mass timber products in the field.
5	23	Characterize the performance of mass timber construction in southern high-moisture climates.
6	24	Establish and validate detailed wood protection methods for mass timber construction.
7	25	Evaluate the effectiveness of protective coatings and membranes at limiting moisture uptake during construction.
8	26	Evaluate the integrity of fasteners and structural connections between mass timber products after moisture cycling.
9	29	Quantify mass timber energy performance and develop specific energy code provisions that account for benefits (e.g., less continuous insulation than similar concrete or steel walls).
10	30	Evaluate acoustic performance of mass timber building assemblies.
11	34	Explore the feasibility and potential benefit of manufacturing exposed layers of CLT with material treated with preservative treatment.
12	35	Develop a database of lessons learned on durability of mass timber buildings.
13	37	Document best practices for construction coordination between designers and contractors regarding mass timber structures.
14	45	Quantify moisture transfer from concrete to CLT in hybrid assemblies and determine its effect on structural performance.
15	47	Develop details for mass timber products on concrete foundations that minimize moisture risk.
16	50	Evaluate the termite resistance and feasibility of pressure-treated glulam and CLT.
17	64	Evaluate the effectiveness of active moisture management strategies during construction (e.g., squeegee and vacuum).
18	67	Develop moisture detection devices incorporated during fabrication.
19	68	Establish characteristic mechanical properties of preservative-treated CLT with oil-type and waterborne preservatives.
20	71	Evaluate the drying time and physical and mechanical effects of submerging mass timber products in water for various periods to simulate exposure to flooding conditions.
21	72	Develop a database of current international research and recent publications.
22	79	Determine best practices for roof and exterior wall design including cladding attachment methods to mass timber that minimize thermal bridging.
23	83	Develop best practices for cleaning exposed wood surfaces after the building is enclosed or following flooding events.
24	86	Evaluate structural behavior of connection systems for preservative-treated CLT.
25	91	Develop updated termite and decay hazard maps of North America.
26	94	Investigate the feasibility of landscape level termite management to protect mass timber construction.
27	97	Develop guidance to address diffusion of water vapor generated in the building interior.
28	99	Characterize the differences in hygrothermal performance between mass timber products such as CLT and NLT and others.
29	107	Quantify pollutant emissions (e.g., volatile organic compounds) from mass timber products.

Table 5—Materials and manufacturing processes

Category rank	Overall rank	Research topic
1	12	Develop nondestructive evaluation techniques to evaluate the structural condition of CLT panels in service.
2	18	Develop nondestructive evaluation techniques that evaluate bond line integrity in CLT panels.
3	39	Develop models to predict properties of CLT that can minimize the need for physical testing of multiple species–grade–adhesive options.
4	51	Quantify the CLT volume size factor such that it can be used for performance-based designs.
5	73	Develop and evaluate ways to optimize mills for usage of available wood resources for mass timber production.
6	76	Develop CLT stress grades that are based on assembled panels rather than the constituent lumber properties.
7	80	Determine the most efficient layups for CLT, similar to the work previously completed for glulam.
8	81	Develop layups and design values for CLT panels that include low value and underutilized wood species.
9	84	Develop and conduct fire tests that evaluate adhesive performance rather than panel performance.
10	95	Develop improved estimates of panel strength in the minor strength direction.
11	100	Determine how to best utilize saw logs to increase CLT laminating stock.
12	101	Evaluate the value-added potential for including insulation layers built into CLT building envelope layers.
13	110	Conduct indoor air quality tests to evaluate off-gassing of CLT panels, not just the adhesives.
14	117	Evaluate the feasibility of utilizing reclaimed lumber in the manufacture of CLT panels.

Table 6—Sustainability and economic analysis

Category rank	Overall rank	Research topic
1	7	Further evaluate cost-effective detailing, such as standardized connections, to improve the cost effectiveness of mass timber buildings.
2	13	Complete research to determine if 8- to 12-story mass timber buildings will be cost effective against competing materials.
3	14	Conduct whole-building life-cycle assessments to compare mass timber buildings with those constructed of steel and concrete.
4	27	Conduct whole building life cycle assessments and building service life studies to better quantify the carbon sequestration and environmental impacts from mass timber buildings.
5	32	Quantify the long-term energy characteristics of mass timber buildings.
6	46	Evaluate methods to use more low-quality wood in mass timber systems to help promote forest health.
7	53	Compare similar buildings using different building materials to determine the operational capacity and energy profiles over a 2- to 3-year period.
8	69	Document the costs of assemblies and cost-effective standard assemblies and details.
9	74	Determine the optimal design for mass timber systems, instead of just a conversion from steel and concrete designs.
10	77	Identify and quantify carbon benefits of different mass timber building products.

Table 7—Nonbuilding applications

Category rank	Overall rank	Research topic
1	92	Investigate CLT dimensional stability, strength, creep, temperature, and ultraviolet radiation effects during long-term exterior exposure such as in bridge applications.
2	104	Develop a strategic plan outlining laboratory testing, analytical modeling, and field evaluations necessary for adopting CLT bridge designs into AASHTO Bridge Design Specifications.
3	106	Develop nondestructive evaluation techniques that can be used to improve inspections of mass timber bridges.
4	111	Conduct feasibility and cost-effectiveness study for utilizing CLT components in other transportation structure applications including noise barrier walls, box culverts, crane mats, and marine facilities.
5	112	Investigate the feasibility of composite CLT systems utilizing concrete or steel components in bridge applications.
6	113	Investigate the fire performance of CLT primary bridge superstructure components using untreated material and material treated with oil-type and waterborne preservative treatments.
7	115	Explore mixed and/or naturally durable species for use in CLT bridge applications.
8	116	Review existing international literature for validity and applicability of mass timber for North American bridge applications.

Table 8—Overall rankings and average scores

Overall rank	Score	Research topic
1	4.24	Complete research on CLT shear wall performance and publish seismic design coefficients.
2	4.10	Develop building code approved prescriptive designs for CLT diaphragms and shear walls.
3	3.88	Determine how duration and severity of wetting affect mass timber products (dimensional change, surface mold, biological deterioration, corrosion of connections, etc.).
4	3.78	Develop written specification language that incorporates best practices for moisture management during and after construction.
5	3.73	Perform 2-h fire testing on a wide variety of connections and mass timber connection configurations.
6	3.67	Conduct CLT diaphragm research based on needs determined by design professionals.
7	3.65	Further evaluate cost-effective detailing, such as standardized connections, to improve the cost effectiveness of mass timber buildings.
8	3.59	Research improvements to the American Wood Council 2018 TR-10, Calculating the Fire Resistance of Wood Members and Assemblies, regarding more efficient testing and design methodology for protection of connections in wood.
9	3.58	Conduct research to develop design methods for point-supported and two-way spanning CLT panels.
10	3.55	Conduct CLT diaphragm research that specifically addresses the effect of aspect ratios.
11	3.51	Develop guidance for detailing assembly intersections, assembly fire stop systems, and penetration fire stops for up to 3-h fire ratings.
12	3.49	Develop nondestructive evaluation techniques to evaluate the structural condition of CLT panels in service.
13	3.48	Complete research to determine if 8- to 12-story mass timber buildings will be cost effective against competing materials.
14	3.47	Conduct whole-building life-cycle assessments to compare mass timber buildings with those constructed of steel and concrete.
15	3.46	Evaluate performance of connections and panels as panels shrink and swell because of moisture exposure.
16	3.45	Develop approaches to enhance CLT performance in low seismic regions.
17	3.45	Develop improved moisture and structural condition assessment methods for mass timber products (e.g., infrared thermography, ground-penetrating radar).
18	3.43	Develop nondestructive evaluation techniques that evaluate bond line integrity in CLT panels.
19	3.40	Develop methods for repair and remediation of mass timber products in the field.
20	3.39	Evaluate the effects of openings on the performance of CLT shear walls.
21	3.39	Evaluate lateral force resisting systems for multistory mass timber open floor plan buildings.
22	3.39	Conduct vibration testing of CLT–concrete panel systems (e.g. nonstructural topping concrete over panels and structurally connected concrete over CLT).
23	3.39	Characterize the performance of mass timber construction in southern high-moisture climates.
24	3.39	Establish and validate detailed wood protection methods for mass timber construction.
25	3.34	Evaluate the effectiveness of protective coatings and membranes at limiting moisture uptake during construction.
26	3.32	Evaluate the integrity of fasteners and structural connections between mass timber products after moisture cycling.
27	3.32	Conduct whole-building life-cycle assessments and building service life studies to better quantify the carbon sequestration and environmental impacts from mass timber buildings.
28	3.31	Research CLT diaphragms with concrete topping over CLT.
29	3.31	Quantify mass timber energy performance and develop specific energy code provisions that account for benefits (e.g., less continuous insulation than similar concrete or steel walls).

Table 8—Overall rankings and average scores—con.

Overall rank	Score	Research topic
30	3.31	Evaluate acoustic performance of mass timber building assemblies.
31	3.30	Determine the performance of self-tapping screws under moisture cycling.
32	3.29	Quantify the long-term energy characteristics of mass timber buildings.
33	3.28	Conduct research to evaluate the impact of gaps between CLT and NLT boards on fire performance and calculated fire resistance of these systems.
34	3.26	Explore the feasibility and potential benefit of manufacturing exposed layers of CLT with material treated with preservative treatment.
35	3.26	Develop a database of lessons learned on durability of mass timber buildings.
36	3.24	Research fire performance of embedded steel in mass timber connections.
37	3.22	Document best practices for construction coordination between designers and contractors regarding mass timber structures.
38	3.20	Conduct detailed testing on CLT panels to investigate the size/volume effect of CLT in edgewise, flatwise, and shear loadings.
39	3.20	Develop models to predict properties of CLT that can minimize the need for physical testing of multiple species–grade–adhesive options.
40	3.19	Further evaluate the performance of wood–concrete composite systems from a seismic perspective.
41	3.19	Research viability of using more fire-retardant treatment products in mass timber buildings to reduce the use of gypsum and other fire protective methods.
42	3.18	Conduct research to evaluate different timber–concrete composite connector systems.
43	3.18	Improve vibration, acoustic, and connection performance of wood–concrete composite systems.
44	3.18	Develop intermediate-scale qualification tests for adhesives to verify that the adhesive doesn’t lead to delamination and fire regrowth.
45	3.18	Quantify moisture transfer from concrete to CLT in hybrid assemblies and determine its effect on structural performance.
46	3.17	Evaluate methods to use more low-quality wood in mass timber systems to help promote forest health.
47	3.16	Develop details for mass timber products on concrete foundations that minimize moisture risk.
48	3.12	Develop a rocking shear wall CLT design guide.
49	3.12	Develop design methodologies for the reinforcement of notched glulam beams that will permit their use beyond the National Design Specification and International Building Code limits.
50	3.12	Evaluate the termite resistance and feasibility of pressure-treated glulam and CLT.
51	3.11	Quantify the CLT volume size factor such that it can be used for performance-based designs.
52	3.10	Conduct additional testing of nongypsum board noncombustible protection options to establish their performance when used in mass timber construction.
53	3.09	Compare similar buildings using different building materials to determine the operational capacity and energy profiles over a 2- to 3-year period.
54	3.06	Study the deformation capability of connections including strain-rate and extreme loading.
55	3.06	Carry out compartment fire testing under office loads and with exposed timber ceilings, and define benchmarks for acceptable performance.
56	3.06	Research fire performance of timber–concrete composite floors with varying shear connectors and panel connections.
57	3.03	Study the punching shear effect of two-way slabs.
58	3.03	Determine the cyclic wetting and drying behavior of wood–concrete composite panels.

Table 8—Overall rankings and average scores—con.

Overall rank	Score	Research topic
59	3.01	Test and evaluate more products for protecting penetrations in mass timber construction.
60	3.00	Develop approaches to minimize CLT crushing in high loading areas.
61	3.00	Conduct more fire resistance testing on timber–concrete and timber–steel hybrid assemblies.
62	2.99	Determine the effect of perpendicular-to-grain crushing loads on CLT panels.
63	2.99	Develop exterior flame spread standards for Type III, IV-HT, and V construction types in accordance with the International Building Code.
64	2.97	Evaluate the effectiveness of active moisture management strategies during construction (e.g., squeegee and vacuum).
65	2.96	Conduct acoustic testing of 3-ply CLT assemblies.
66	2.96	Identify market gaps and perform scaled down fire performance testing of mass timber components for more efficient product development.
67	2.96	Develop moisture detection devices incorporated during fabrication.
68	2.96	Establish characteristic mechanical properties of preservative treated CLT with oil-type and waterborne preservatives.
69	2.96	Document the costs of assemblies and cost-effective standard assemblies and details.
70	2.95	Carry out additional compartment fire tests on CLT with adhesives that comply with ANSI PRG 320-18, Standard for Performance Rated Cross-Laminated Timber.
71	2.92	Evaluate the drying time and physical and mechanical effects of submerging mass timber products in water for various periods to simulate exposure to flooding conditions.
72	2.92	Develop a database of current international research and recent publications.
73	2.92	Develop and evaluate ways to optimize mills for usage of available wood resources for mass timber production.
74	2.92	Determine the optimal design for mass timber systems, instead of just a conversion from steel and concrete designs.
75	2.91	Establish methodology for repairing CLT buildings after a seismic event.
76	2.91	Develop CLT stress grades that are based on assembled panels rather than the constituent lumber properties.
77	2.89	Identify and quantify carbon benefits of different mass timber building products.
78	2.88	Explore possible adoption of Canadian code provisions for use in the U.S. regarding the use of 1-1/2-in. noncombustible toppings as prevention for penetration of hot gasses and thermal rise.
79	2.88	Determine best practices for roof and exterior wall design including cladding attachment methods to mass timber that minimize thermal bridging.
80	2.87	Determine the most efficient layups for CLT, similar to the work previously completed for glulam.
81	2.87	Develop layups and design values for CLT panels that include low value and underutilized wood species.
82	2.85	Conduct research on the effect of notches in glulam that are beyond code limitations.
83	2.85	Develop best practices for cleaning exposed wood surfaces after the building is enclosed or following flooding events.
84	2.85	Develop and conduct fire tests that evaluate adhesive performance rather than panel performance.
85	2.84	Conduct research on hybrid composite panels that address brittle behavior of panels and ductile behavior of connections.
86	2.82	Evaluate structural behavior of connection systems for preservative-treated CLT.
87	2.80	Conduct holistic testing that looks at a CLT panel from a structural, fire performance, and acoustics perspective.
88	2.75	Evaluate feasibility of using drilled-in and epoxy rods to reinforce glulam as done in Europe.

Table 8—Overall rankings and average scores—con.

Overall rank	Score	Research topic
89	2.75	Evaluate the torsion–twisting performance of CLT.
90	2.74	Develop nonscrew attachment options for concrete over timber composite systems.
91	2.72	Develop updated termite and decay hazard maps of North America.
92	2.72	Investigate CLT dimensional stability, strength, creep, temperature, and ultraviolet radiation effects during long-term exterior exposure such as in bridge applications.
93	2.71	Research and demonstrate the performance of partially constructed mass timber buildings involved in a construction fire.
94	2.70	Investigate the feasibility of landscape level termite management to protect mass timber construction.
95	2.70	Develop improved estimates of panel strength in the minor strength direction.
96	2.69	Identify strategies to enhance glulam product performance (i.e., use of epoxy rods and fiber reinforcement such as used in Europe).
97	2.58	Develop guidance to address diffusion of water vapor generated in the building interior.
98	2.57	Study the feasibility of seismic retrofit of masonry buildings with CLT.
99	2.55	Characterize the differences in hygrothermal performance between mass timber products such as CLT and NLT and others.
100	2.55	Determine how to best utilize saw logs to increase CLT laminating stock.
101	2.55	Evaluate the value-added potential for including insulation layers built into CLT building envelope layers.
102	2.53	Develop displacement-based design for nonlinear static pushover.
103	2.52	Continue and expand research efforts to study ballistic, forced entry, and blast testing of CLT.
104	2.51	Develop a strategic plan outlining laboratory testing, analytical modeling, and field evaluations necessary for adopting CLT bridge designs into AASHTO Bridge Design Specifications.
105	2.49	Determine the windborne debris resistance of CLT.
106	2.49	Develop nondestructive evaluation techniques that can be used to improve inspections of mass timber bridges.
107	2.47	Quantify pollutant emissions (e.g., volatile organic compounds) from mass timber products.
108	2.45	Evaluate dowel fasteners under different strain rates.
110[a]	2.44	Conduct indoor air quality tests to evaluate off-gassing of CLT panels, not just the adhesives.
111	2.43	Conduct feasibility and cost-effectiveness study for utilizing CLT components in other transportation structure applications including noise barrier walls, box culverts, crane mats, and marine facilities.
112	2.41	Investigate the feasibility of composite CLT systems utilizing concrete or steel components in bridge applications.
113	2.41	Investigate the fire performance of CLT primary bridge superstructure components using untreated material and material treated with oil-type and waterborne preservative treatments.
114	2.34	Conduct high-strain-rate testing (i.e., blast–ballistic loads) of CLT using a variety of species and connectors.
115	2.29	Explore mixed and/or naturally durable species for use in CLT bridge applications.
116	2.22	Review existing international literature for validity and applicability of mass timber for North American bridge applications.
117	2.10	Evaluate the feasibility of utilizing reclaimed lumber in the manufacture of CLT panels.

[a]Number 109 has been deleted from the table because the text for 109 was identical to the text for number 103.

Appendix A—Meeting Minutes Captured at the Second Annual Research Needs Assessment Workshop

The 2nd Mass Timber Research Needs Workshop was held at the USDA Forest Service, Forest Products Laboratory, to provide a technical forum on the topic of mass timber research. The objectives of this Mass Timber Research Needs Workshop, held November 13–14, 2018, were to (1) bring design professionals, researchers, and industry leaders together to examine the state-of-the-art in mass timber construction, with an emphasis on CLT, and (2) identify technical barriers to the broader use of mass timber in engineered structures that need to be addressed through research and ongoing education of design professionals and others. A list of all participants is included in Appendix B.

Keynote Presentations

Key industry leaders provided presentations highlighting the importance of this mass timber workshop. These presentations were as follows.

"Welcome and Mass Timber Research Needs From the FPL Perspective"

Mike Ritter, Assistant Director of FPL

Mike Ritter pointed out that mass timber refers to the incorporation of a variety of engineered wood products including glued-laminated timber, nail-laminated timber, dowel-laminated timber, cross-laminated timber, mass plywood, and structural composite lumber in a wood structure.

He noted that the workshop objectives were to

- Better understand what research is currently in progress for mass timber
- Identify research gaps that must be filled to further advance mass timber structural systems
- Formulate an international network to share research information and compile nonrefereed research in progress summaries

From a Forest Service perspective, the growth in demand for mass timber will help to foster environmental stewardship, social responsibility, and economic development. To fully develop this potential, there must be a sustainable wood supply that can be harvested, transported, and manufactured in a cost-effective manner.

He pointed out that requirements for design and construction of mass timber structures, as well as the availability of forest resources, vary by country and within a country. Both research and technology transfer are critical to overcome barriers that hinder widespread mass timber use. Communicating research activities and identifying research needs and priorities will help us all achieve objectives in a more efficient, cost-effective manner.

"Mass Timber Market Update"

Jennifer Cover, WoodWorks CEO

Jennifer Cover discussed the significant advancements that have been made with respect to using mass timber construction in the United States. She highlighted this on slide 12 of her presentation, which was a map of the United States showing the location of 157 completed mass timber projects.

She then discussed what she felt were the primary and secondary drivers for using mass timber. The primary drivers are construction efficiency and speed, labor constraints, innovation/aesthetic and construction site constraints, and urban infill. Secondary drivers are structural performance, lightweight construction, and carbon reductions.

Although there are many positive reasons for using mass timber, a study by WoodWorks of 75 planned mass timber projects that were not completed identified a number of reasons for not using mass timber. Some of these were project cancelled (29), steel or concrete used (19), wood cost too much (10), code did not allow wood (5), and financing failed (5). She noted that research can help overcome some but not all of these.

In closing, she summarized by stating that input from the participants at this workshop is needed to

- Prioritize research with applicability in mind
- Identify research that helps drive down project cost
- Identify what research will get more structures built
- Determine what is holding this industry back
- Determine what hurdles the proposed research will help us clear in advancing the industry
- Determine the pathway to the solution

"Overview of Completed/Ongoing Mass Timber Research"

Sam Zelinka, Project Leader at FPL

Sam Zelinka presented an overview of completed and ongoing mass timber research emphasizing work since the first Mass Timber Research Workshop. He noted that the THINK WOOD website has an exhaustive summary of this research in their "research library". He also reported that Forestry Innovation Investment Ltd., Vancouver, British Columbia, Canada, has generated a draft Research in Progress Report 2018-19 of Mass Timber and Tall

Wood Building Research in Canada and the United States. This research is broken down into seven subtopics as follows with the number of projects in each area shown in parentheses.

- Seismic, Wind, and Structural Performance (32)
- Cost and Economic Impacts (18)
- Fire Performance (12)
- Durability (9)
- Building Science (7)
- Environmental Impacts (6)
- Manufacturing (5)

He noted that one of the key research studies on seismic performance of CLT is the Federal Emergency Management Agency (FEMA) P-695 project, Quantification of Building Seismic Performance Factors, at Colorado State University. All of the testing has been completed and the project is currently under peer review. Other key lateral load resistance studies include rocking wall research, design of diaphragms, and the use of timber-braced frames.

In the area of fire performance, significant testing of CLT compartments has been completed. This research took high priority because it was needed to address fire concerns raised by the International Code Council (ICC) AdHoc Committee on Tall Wood Buildings. The positive result of this research was key to the committee recommending code changes to the 2021 International Building Code (IBC), which will permit tall wood building up to 18 stories in height.

He also presented highlights of research in the areas of economics, durability, building science moisture monitoring, building science environmental impacts, environmental product declarations, environmental building declarations, and manufacturing.

Panel Discussions

Following these opening presentations, the attendees participated in a series of seven panel discussions addressing key research needs areas. These were the following:

1. Structural Resiliency
2. System Design and Construction
3. Fire Performance
4. Durability and Building Physics
5. Materials and Manufacturing Processes
6. Sustainability and Economic Analysis
7. Nonbuilding Applications

Each of these panel discussions were aimed at (1) addressing what challenges are limiting the use of mass timber forest products; (2) determining what information, methods, guidance, or solutions may be valuable to add to the state of the practice; (3) anticipating the challenges the industry or practice will encounter in the next 3, 5, or 10 years; and (4) determining what future research needs to be addressed to overcome these challenges. A detailed summary of each panel discussion is included in these proceedings, and original detailed scribe notes from each panel session are included in Appendix C.

A closing summary session highlighted the key research needs identified during this workshop.

Panel Sessions Summary

Key market concerns and market drivers together with research needs identified for each panel discussion session are summarized as follows. Postworkshop research needs were also solicited, and these are included in the research needs summary. These are generally presented in the sequence in which they were discussed and are not prioritized.

Panel Discussion 1: Structural Resiliency – Designing to Resist

- Earthquakes
- Wind loads
- Floods
- Terrorism (blast resistance)

Moderator

Scott Breneman, WoodWorks

Panelists

Mark Weaver, Karagozian & Case

Adam Jongeward, DCI Engineers

Eric McDonnell, KPFF

Chris Duvall, Coughlin Porter Lundeen

Hans-Erik Blomgrem, Katerra

FPL Scribes

Rammer, Senalik

General Observations on Market Drivers–Challenges–Opportunities

1. An initial hurdle is the perception among engineers that wood is weak, burns, and is brittle. Need better technology transfer to address these concerns. Graduate curriculum at universities doesn’t address wood, and more of this level of education is needed.
2. Need exists to turn research into design guidelines and ultimately code provisions.
3. There is much research out there, U.S., Europe, Canada, etc., but not many individuals can comb through this

and use it in a successful manner nor will jurisdictions do this or accept it. Need to get these over the finish line by publishing design guides.

4. While prescriptive requirements in the code can be valuable, they can also be considered to be limiting. An alternative to prescriptive code language may be to go back to 1st principles of mechanics values so that engineers who want to think outside the box can go there.
5. Need to be able to move toward more performance designs but engineers need the data. Load deformation curves not just "allowable design values" are needed.
6. Everyday practitioner is bound by the code and there's just not much there. Need to start getting seismic- and fire-tested assemblies in the building code.
7. Need more prescriptive assemblies for acoustics, fire, etc., since there are few prescriptive fire assemblies or acoustic assemblies documented.
8. Information on special inspections is lacking. Engineers are doing these on their own and industry needs to come up with consensus guidance documents to address this since we don't have people trained to perform these special inspections.
9. Better supply chains – have limited tools in tool kit. Catalogs typically include 3-, 5-, and 7-ply panels. The analogy is trying to design an efficient steel building with only three stock steel beam sizes to work with. Need to scale up the configuration options of CLT.
10. Wood framing engineering design is focused on light frame. Need to consider restructuring National Design Specification (NDS) to make it more user friendly. Differentiate light frame and mass timber by separating these in the code or make it two different codes.
11. Think about design from building official perspective. We have to convince the building official that what we are designing is safe. How can we better communicate with building officials, through the code, that this is safe and developed?
12. Communicate cost benefits of using wood in terms of it being a low damage system. Since the bottom line nearly always controls the decision to use mass timber or not, can we capture the economic values of resiliency?
13. Don't have standardized designs, connections, etc., and need more standardized details to advance the industry. For example, engineers no longer design shear connections in steel beams as this has been standardized. Need more of this for mass timber.
14. Wood is generally designed fairly conservatively with values based on 5th percentiles. When dealing with blast or other high-intensity loads, need is to deal with 50th percentile values. Published data are 5th percentile and although the tests do have the 50th percentile data, it's difficult to find those data.
15. Also, vertical systems for low seismic, low wind regions need simple solutions to start for simple problems.

Research Needs Identified

1. Nothing in the code right now that would allow an engineer to prescriptively design a CLT diaphragm or shear wall. Limits pool of projects that can go through alternative means and methods request process and pool of engineers who can do it. Also varies with jurisdictions so it's a wildcard that needs to be resolved through research.
2. Diaphragm research needed to address the fact that there is nothing in the code for CLT diaphragm aspect ratios forcing designers to stick to aspect ratios for wood structural panel diaphragms.
3. Research needed on diaphragms with concrete toppings.
4. Construction durability and quality control. We can design mass timber buildings but what loss of stiffness is there when the wood swells and shrinks, and does this affect capacity and performance of connections? Need research to address these concerns.
5. Research is needed to push the mass timber systems forward for housing or small-scale systems, not necessarily in terms of building size (actually looking at small projects) but what is needed most for infrastructure? Some suggesting brute force method, $R = 2$ or plywood-covered CLT shear walls, but these need to be addressed through research for code adoption.
6. Need a design guide for CLT rocking shear walls based on research and field testing.
7. Holistic testing needed to look at the bigger picture. Take an assembly through structural, fire, and acoustics — not just one of these in any given test.
8. Wood is a brittle material but connections can be made ductile. Need to look at development of hybrid panels to address this.
9. Need more research on hybrid systems (timber–concrete composites) for blast resistance.
10. Need more research on timber–concrete composite connectors. Relates to seismic since concrete topping is often assumed as the diaphragm.
11. Ballistic, forced entry, and blast — wood in and of itself can't resist all of these. Develop a system that can do all of these.
12. Buildings for the U.S. Department of State (DOS) have to meet blast as well as ballistic, forced entry,

and progressive collapse requirements. Various blast and ballistic testing on CLT panels has already been performed. Research that builds on these efforts to develop a cost-effective panel capable of meeting DOS's requirements (which are over and above Department of Defense requirements) would be timely.

13. For performance-based approaches (e.g., to resist seismic or blast loads), which have gained acceptance and will probably only become more important in the future, it is important to be able to quantify the expected (50th percentile) strength of a material. Traditionally, timber construction has relied on 5th percentile values for design. This approach is appropriate considering that a single point of failure can potentially compromise a joist or glulam beam. However, for CLT panels that have plies in two directions, it can be argued and has been observed through testing that the presence of cross plies seems to lead to a lower coefficient of variation, particularly for real-life panel widths (not 1-ft wide strips). Testing programs to definitively document this fact for stress paths of importance (flatwise bending in the major and minor strength directions, in-plane shear, etc.) will enable explicit documentation of 50th percentile values. The presence of such values will enable mass timber to compete in performance-based designs, an area where steel and concrete hold sway.
14. For connections, not much strain rate data or testing exist to back this up. Getting to these 50th percentile values is something we need to continue to build up. Not only for panels but also for connections. Getting to actual capacity of connections will need testing under both dynamic and static limit states.
15. Research on connections for modular CLT structures in extreme loading events is lacking.
16. Deformation compatibility of connections – lacking this, but need to have more information as we go taller. There is much information about this in steel and other materials.
17. Research needed on dowel-type fasteners under different strain rates to determine actual capacities. Connections are perhaps the most over-designed things in blast design.
18. What effect does size or volume have on design values. There is a definite size factor for CLT but this is not addressed in PRG 320. From the panel perspective, there is a significant difference between a 7 ply and a 3 ply. The MOR differs between the 7 and the 3 ply. Need testing to document this.
19. Need research to understand how long self-tapping screws perform under moisture exposure and cycling.
20. Shear walls – need published seismic design coefficients from the CSU FEMA P695 study or other research.
21. Can we get away from the seismic response coefficient altogether? Can timber take the step and show the other materials that fundamental approach in code isn't the best way forward? Come up with a displacement-based design approach, nonlinear static pushover.
22. Openings in CLT shear walls, in plane stress concentrations. Is an opening in the shear wall significant or not? Function of opening size. Design guidance on this could apply to shear walls or diaphragms.
23. Low seismic applications – wind-controlled structures should have an easier pathway but the first look is always to go to the high seismic approach. Need clarity on how to design low seismic risk mass timber buildings.
24. Seismic retrofit of existing masonry buildings with CLT. There are opportunities of doing localized fixes. If already an American Society of Civil Engineers (ASCE) 41 design, now you have a new system you are introducing. There is much potential opportunity. ASCE 41 says you have to know the exact deformation characteristics to know load share, thus more data on panels and connections are needed.
25. What do you do after a major seismic event? Repairing CLT building. How much does that cost? How soon can you occupy? More info on this is needed. Base code requirement is life safety but nothing about being able to repair–restore structure. Ten-story shake table test will help with this.
26. Need more research on low-ductility shear walls and braced frames.
27. Timber-braced frames. In the code, there is a provision for cantilever columns and that's it. Need to have more info on this in code. Possibly combine with steel-braced frames in ASCE 7.
28. Braced frames for wood? Buckling restraint braced frames? Issue here is how to deal with the large forces at the beam-to-column connections. There is information in the Canadian code on braced frames. Can this be leveraged for the U.S. without further research?
29. Expected in-plane properties of CLT panels – some manufacturers don't even list allowable properties let alone expected values. As more performance designs are done, need exists to have the actual capacities based on testing.
30. Adhesives — there is nothing in the code that covers drilled-in and epoxy rods in glulam as used in Europe. Need to rely on global recommendations but these vary significantly. North American research is needed to advance this technology.

31. Notching in glulam beams — for example, notch limited to 1/10 the beam depth or 3 in. Reinforcing, engineered design solutions possible to support exceeding these limits, but research is needed to support this approach. Jurisdictions don't understand the reason for the prescriptive limitations so they don't bend on allowances beyond them.
32. Perpendicular to grain crushing load — based on old data that were subjectively allowed. New data needed for mass timber.
33. Need more research data on two-way slabs, punching shear. Brock Commons did testing, rolling shear issue one layer up from bottom, shear failure between panels.
34. High-performance lateral force resisting systems for multistory mass timber building with large open floor plans. Open floor mass timber buildings are popular for commercial and mixed-use applications. They utilize glulam beam–column grids to support gravity load and typically do not have enough structural walls in the floor plan to carry lateral loads in high seismic regions.
35. Research is needed on windborne debris resistance of CLT in high wind zones such as hurricanes and tornados.
36. Combining vertical wood systems with nonwood lateral systems. Requires actual stiffness properties for wood so designers know how the load is shared, and these data are lacking.

Panel Discussion 2: System Design and Construction

- Connections
- Component design
- Serviceability (vibration, acoustics, displacement)
- Standardized design tools

Moderator

Ricky McLain, WoodWorks

Panelists

Greg Kingsley, KL&A, Engineers & Builders

Graham Montgomery, Britt Peters and Associates

Jeff Morrow, Lendlease

Phil Line, American Wood Council (AWC)

FPL Scribes

Brashaw, Wang

General Observations on Market Drivers–Challenges–Opportunities

1. Although new code provisions will permit up to 18 stories for mass timber construction, 6 to 12 stories may be the sweet spot and more emphasis is needed on expanding this market.
2. Challenge is working around the code limitations because designing outside the code is really difficult.
3. Getting architects and engineers to try using new materials such as CLT is important, and breaking new ground is always a learning curve for all the stakeholders.
4. Standardized details are needed similar to what is available to designers for other construction materials.
5. Tall wood – conservatism in the new proposals IV-C, 85' 9 stories? Keep improving codes as people start using new Type IV provisions. Persistence to keep codifying and cleaning up code limitations.
6. For developers, it is all about cost or perceived cost that hinders mass timber buildings.
7. Cost: wood volume really counts. Better design information needed so we can we optimize design and lower costs.
8. U.S. CLT Handbook is almost too conservative (acoustics in particular).
9. Draft proposals needed for Special Design Provisions for Wind & Seismic (SDPWS) 2021 to add CLT diaphragms and shear walls.
10. Any AWC standard change proposal: Where is the data? What can you test that can be standardized?
11. CLT generally used in one-way action and in bearing walls. Handled in standards but room to get more efficiency in system.
12. Timber braces for lateral design would be useful.
13. Cost driver: lack of experience by contractors to efficiently erect large mass timber panels.
14. Why people don't use mass timber? “risk”.
15. Codes and standards are trailing items.
16. Industry standards needed for self-tapping screws. Recognition of higher capacity fastener models to fully use available strength.
17. Composites need to be simple in the field.

Research Needs Identified

1. Component design. We have a lot of information for glulam but not much information available on CLT or other mass timber products. Research needed in this area.
2. Need more research on composites: Wood to wood (e.g. CLT over glulam beam) or concrete to wood (panel or beam). Need concrete for acoustics, so need to understand how to best use it for structural.

3. Vibration testing of topping concrete over panels with friction-only connection (e.g., nonstructural topping concrete) needed. And structurally connected concrete over timber testing also needed.
4. More acoustics testing needed.
5. Acoustics. Need acoustically tested 3-ply assemblies.
6. For composite wood–concrete over glulam beam, can a more optimized glulam be developed and produced? This may require testing.
7. Connections limit design such as with concealed connectors. May need to up-size a beam to get these to work. Research needed to be less conservative in connection requirements.
8. Connections of CLT panels exposed to blast loads undergo large deformations and transfer high-intensity, short-duration force demands. As "failure" modes generally involve wood crushing or steel yielding, these connections can be designed relatively easily to be extremely ductile and energy absorbing. However, at the present time, there is relatively limited test data documenting the response of timber connections (and even less for CLT connections) exposed to strain rates associated with blast loads. As such, a relatively conservative approach to obtaining design values must be used when designing connections for blast loads. High strain rate testing on different species of wood and dowel-type fasteners at a material and fastener level, respectively, will allow for higher connection design values and more economical designs.
9. Every span table is driven by vibrations. Sometimes to gain a couple of inches of span, this can really impact economics. Need more research on how to minimize the effect of vibrations.
10. Design methods for point-supported and two-way spanning CLT panels needed. Also punching shear needs to be further evaluated.
11. CLT diaphragm research. If we agree this is needed, what does the research need to test? Don't let researchers define what to test but involve design professionals.
12. A lot of use of proprietary screws but difficult to standardize. "Nail is the right thing to test" but research needed.
13. CLT in low seismic regions (Seismic Design Category B for example) is a barrier. Need more testing for performance of CLT in low seismic regions.
14. Need data on strength and reinforcement of CLT crushing (e.g., platform framing, under toe of CLT shear wall).
15. Size or volume effects of CLT in edgewise and flatwise bending and shear need to be studied.
16. Tension perpendicular to the surface of the CLT. What is panel capacity of a screw in tension in only one lam?
17. Design of epoxy rods in glulam, CLT, solid sawn lumber. Commonly used in Europe but no North American research available.
18. Design of reinforcement of notched beams beyond the NDS limit. Research needed to address this.
19. Nonscrew concrete over timber composite options? Screws cost a lot. Shear keys, adhesives, and more need to be evaluated. Use research to get creative, make it fast and easy to do.
20. Determine the cyclic wetting–drying behavior on composite panels.
21. No information available on torsion–twisting of CLT.

Panel Discussion 3: Fire Performance

- Code considerations
- Component performance
- System performance
- Connections

Moderator

Scott Breneman, WoodWorks

Panelists

David Barber, Arup

Jason Smart, AWC

Steve Craft, CHM Fire Consultants

Carl Baldassarra, Wiss Janney Elstner Associates

FPL Scribes

Bourne, Yedinak

General Observations on Market Drivers–Challenges–Opportunities

1. Education needed – of building officials in particular. Get them inside these buildings, such a difference from showing them pictures. They are the big barriers, even code-compliant buildings now can still be a nightmare to get through approval.
2. There is a feeling that testing is the only solution – in many cases, it's not. Analysis, engineering, and education will quite often solve the issues. Some of this is that the building codes are based around testing and many follow this trend. The mass timber industry has slightly butted heads with the rest of the construction sector since it has taken a slightly different approach.

3. If there is a significant fire in a mass timber building, it could be a huge issue for all of us.
4. Need to be realistic with global approach to fire safety design in mass timber. Some areas don't use sprinklers – they rely on the fire department getting there to suppress the fire.
5. Compartment tests with office fire loads and exposed timber ceilings. Inform future projects that want more exposed than the current proposals.
6. Special inspection (SI) training would be helpful – 2021 IBC requires SI for new Type IV construction types. For fire protection of members and, more importantly, fire protection of connections.
7. More guidance needed on detailing at assembly intersections. Assembly fire stop systems, penetration fire stops, for up to 2- or 3-h fire rating.
8. Developing guidance for post fire rehabilitation of mass timber structures – might provide an opportunity to show advantages of mass timber compared with other structure types.
9. Smartlam has a presentation on how to rehabilitate exposed ceiling panels for test 2 of the tall wood building (TWB) ad hoc committee compartment testing.
10. Clarification of fire requirements for protection of connections in all construction types.
11. Fire protection of connections in TR 10 – further clarification and getting this into the standard needed.
12. TWB code proposals are largely based on what has been tested. Building officials are by nature conservative so tests will win out over calculations.
13. There is nothing in UL directory for fire protection of connections for steel and concrete, but there is still a need for a designer to be able to place standard, tested details on their drawings to satisfy building officials.
14. Fire tests done for TWB AHC largely neglecting the use of automatic fire sprinkler protection. Should be able to leverage this to see if we can go beyond TWB proposals (for items like percentage exposed timber) when you do start to look at use of sprinklers.
15. More standardization of updated Type IV construction details needed.
16. Commentary to Type IV says that it needs to be rated for 1 h. Therefore, by extension, supporting members and connections needs to be 1-h rated.
17. Can we get the information on what was used for connections in the fire tests, specifically for compartment tests? Something as simple as a screw holding drywall in the char zone can be questioned – how does it perform?
18. Extend calculated fire resistance method up to 3 h as needed by new Type IV-A.
19. Refine calculated fire resistance method for nail-laminated timber (NLT) to more accurate method than the 1/3 side char approach in the NDS.
20. Prescriptive recognition of continuous topping over mass timber panels that satisfy E119 integrity requirements is needed.
21. Update NDS char calculations for CLT based on new adhesive requirements per PRG 320 2018.
22. Not a technical basis for how tall you can go – still need to be flexible for allowing future changes but recognize that testing will probably be necessary to do so.
23. Need clarification of fire requirements for protection of connections in all construction types.

Research Needs Identified

1. Information in the code now is based on fire tests done with CLT that used adhesives that caused delamination. Should/could we do new tests now that we know what we know on this topic, that with new adhesives we can do better.
2. 2-h fire-rated connections – usually needing to increase member size to fit connection while still providing fire protection of connection. This isn't efficient, too much timber volume, driving costs too high. Need more 2-h testing, particularly for connections.
3. Construction fires – need research on how mass timber buildings perform during construction if a fire starts. Do a demonstration of how hard it is to get a mass timber building on fire during construction. These are usually very clean sites with small fuel loads.
4. Need to carry out compartment fire tests on CLT with PRG 320-18 adhesives (no delamination under fire). Then there is a very convincing argument to allow for future code changes to allow for the timber to be exposed in high-rise buildings, which is what the market is demanding.
5. The literature suggests that the fire loads are comparable, although fire loads for office buildings are higher than loads for residential occupancies. Additional compartment fire tests under office loads and with exposed timber ceilings are needed to have mass timber better recognized. One of the issues with these tests is that there is no "benchmark" as to what constitutes acceptable performance. Is it heat release rate, maximum burn-through of CLT, maximum temperatures, etc.? These need to be discussed and agreed upon before more expensive test series are developed.

6. Penetrations, fire caulk, protection of these can kill a project because of added cost. Ability to have more tested products and solutions to lower cost will remove barriers.
7. There are a number of small projects – such as connections fire testing or fire engineering analysis – that could be done to push this forward. Product solutions are important. Find the gaps, do a bunch of small projects to test and get more solutions on the market.
8. Develop intermediate-scale qualification tests of adhesives to verify that it doesn't lead to delamination and fire regrowth.
9. Additional testing to establish performance of other noncombustible protection types (mineral wool board, others) placed on mass timber (other meaning other than gypsum board).
10. More guidance needed on detailing at assembly intersections. Assembly fire stop systems, penetration fire stops, for up to 2- or 3-h fire rating. Need to determine what research might be needed.
11. More fire resistance testing on timber concrete and timber steel hybrid assemblies.
12. Development of an exterior flame spread standard, this would be for Type III, IV-HT, and V. New Type IV provisions don't allow any combustibles on the exterior side of the exterior wall.
13. Performance of general timber connections in fire. Need research to determine how embedded steel propagates conduction and transfers heat throughout a section.
14. Need to study the performance of timber–concrete composite floors in fire with varying shear connectors and panel connections.
15. Can we reduce the number of gypsum protection layers on tall wood timber by using fire-retardant treated (FRT) mass timber – either topically or pressure impregnated? Can we look to use more FRT wood interior partitions in these tall wood buildings instead of light gauge steel? Research needed to support this.
16. Canadian code recognizes that 1-1/2-in. noncombustible topping prevents hot gases and thermal rise. Can we do this in the U.S.? Is research needed?
17. Testing and design method for protection of connections in wood. Can more efficient methods than 2018 TR-10 be developed and justified?
18. Quantify impact of gaps between boards in CLT and NLT on fire performance. Determine the impact on calculated fire resistance?

Panel Discussion 4: Durability and Building Physics

- Hygrothermal performance
- Biotic attack resistance
- Protective coatings
- Preservative treatment
- Energy efficiency
- Indoor environmental quality

Moderator

Ricky McLain, WoodWorks

Panelists

Jonathan Heppner, LEVER Architecture

Robert LePage, RDH Building Science

Joe Mayo, Mahlum

Dallin Brooks, Western Wood Preservers Institute

Ron Anthony, Anthony and Associates

FPL Scribes

Glass, Kirker

General Observations on Market Drivers–Challenges–Opportunities

1. Construction moisture strategies…don't scale to tall buildings.
2. What is the effectiveness of a passive approach to moisture management?
3. How effective is active moisture management during construction (squeegees and shop vacs).
4. Solutions: Keep it dry. Active and passive moisture management needed during construction.
5. How wet can the panels get before closing in?
6. Validation of wood resistance treatment methods. In what scenarios do which methods work?
7. Reduce costs after turnover. Call-backs, warranties, litigation.
8. Need databases of what we know. Lessons learned.
9. Concrete industry is keeping database about mass timber.
10. Uncertainty of questions from developer. Questions are hard to answer.
11. Wish list of cool things that could exist
    a. Pre-fab moisture detection
    b. Pre-fab finish–weathering layers.
    c. UV coatings and different fasteners in different products exposed to weather–UV

12. Coordination. Less coordinated project is the most complicated with the most problems. Most projects have water exposure during construction. Document best practices and lessons learned for coordination.
13. Working on better coordination and communication up front can reap big dividends.
14. Clearly delineating scope, etc., needed to help with project coordination.
15. Research on termites exists, but need to bring it together to determine if further research is needed.
16. Need work to update termite maps.
17. Create situations with landscaping. Don't place planters next to building with sprinklers and mulch. Basic best practices are out there.
18. Need to establish best practices for cleaning exposed wood surfaces after the building is enclosed.
19. If there is long-term exposure in hidden situations over time, then that can cause damage.

Research Needs Identified

1. Need to determine how wet mass timber products can be for how long, safely, with minimal risk of dimensional change problems, surface mold, biological deterioration, corrosion of connections, etc.
2. Need to evaluate the drying capability of mass timber products – effectiveness of passive vs. active moisture mitigation.
3. Need to evaluate the effectiveness of protective coatings at limiting moisture uptake. Polyurethane sealants are not completely effective.
4. Need to determine the differences in hygrothermal performance between mass timber products, CLT vs. NLT vs. others, to identify different moisture management strategies.
5. Need improved moisture and structural condition assessment methods for mass timber products (e.g., infrared thermography, ground-penetrating radar).
6. Research needed on how to determine moisture penetration in mass timber systems.
7. Need research to establish best practices of moisture management during and after construction. This should lead to written specification language that incorporates best practices for managing moisture during construction.
8. Need research on the long-term effects of moisture on building aging. What are service life expectations for mass timber? How are these impacted by exposure to moisture?
9. Base of wall behavior – what happens where the CLT is on the concrete foundation. Need to modernize best practices for detail at foundations and incorporate in codes and industry recommendations.
10. Need to study moisture transfer from concrete to CLT in hybrid assemblies and determine its effect on building performance – not just structurally but also on mold, mildew, and decay.
11. Energy – how to codify mass timber wall for energy is important. Need to address solid mass timber walls behavior and standards in the energy codes. Less continuous insulation than similar concrete or steel walls. Quantifying this through research is important to convince designers to use mass timber.
12. Need research to determine best practices for roof and exterior wall design including cladding attachment methods to mass timber that minimize thermal bridging.
13. What is the termite resistance of pressure-treated glulam and CLT? Need validation of wood resistance treatment methods. In what scenarios do which methods work?
14. Research is needed to better understand the performance of mass timber construction in southern high moisture climates. Although CLT has started making inroads in building construction in the U.S. Northwest and Northeast, it is almost nonexistent in the South. Often, builders weld angle iron to metal I-beam uprights and start the CLT layers removed from the ground to minimize biological effects. Although this might seem like a solution, there is no guarantee that termites or other wood-destroying insects and biologicals will not attack CLT constructed structures in the southern climate. That said, the absolute worst thing that we could do as an industry would be to construct mass timber buildings in the South and have them exhibit issues, which would tarnish the CLT story and discourage its use in the South for years to come.
15. ANSI/APA PRG-320-2018 does a great job in generating the strength values from various constructions of CLT and making it a commodity product that many manufacturers can produce. However, until the durability issues in the South are clearly understood and addressed, lenders and builders will tend to shy away from CLT structures. There needs to be corroborating research done at universities to give the building industry confidence that CLT structures built in the South will perform and last, free from structural issues during the life of the structure.
16. Development of durable CLT rationale: Just like other wood products, CLT is susceptible to termite and fungi attacks. However, detailed protection methods are not discussed in the PRG 320-2018 standard. Wood

protection methods need to be researched to a broader extent.

17. Explore making the bottom layers of CLT structures declared industrial products, making the use of CCA a production possibility.
18. Need to evaluate the impact of pressing pressure during manufacturing on creep of CLT.
19. Need to establish characteristic mechanical properties of preservative-treated CLT.
20. Understanding structural behavior of connection systems for treated CLT panels is needed. This should include developing a computer tool for simulating and predicting structural behavior of self-tapping screw connections for structural engineers.
21. Need guidelines on how to assess buildings and develop methods for the repairs if decay or mold is detected in mass timber.
22. Need research on the integrity of structural connections between mass timber products after moisture cycling.
23. Further research on acoustics is needed.
24. Indoor air quality is an issue with glued wood products. CLT handbook didn't cover formaldehyde emissions and volatile organic compounds (VOCs), and this needs to be quantified via available information or additional testing.
25. Need research to address vapor diffusion of internally created vapors.

Panel Discussion 5: Materials and Manufacturing Processes

- Material species and grade
- Component layup requirements
- Manufacturing quality control and monitoring
- Adhesives
- In-place assessment and maintenance

Moderator

Scott Breneman, WoodWorks

Panelists

Todd Beyreuther, Katerra

Ian McDonald, Oregon State University

Mark Clark, Hexion

BJ Yeh, APA

FPL Scribes

Senalik, Farber, Brashaw

General Observations on Market Drivers–Challenges–Opportunities

1. North American manufacturers often compare themselves to the strong benchmark of Europe, but our reality is not the same as theirs. Our mills are being pushed into better practices for sorting, cut patterns, and drying by retail outlets at the low end of the distribution chain.
2. Finding the return on investment based on enhanced technology is necessary and possible, for example having in-house kilns for drying lam stock. Studies are needed to show manufacturers how they can control this in-house where they will have greater control on lam stock moisture and associated cost.
3. Create link between forest health and use of wood in building – this is missing. Many areas want to use mass timber but once they see it is not manufactured in their area, they lose the connection to the forest health since it's a benefit they won't see locally.
4. Manufacturing skills shortage. As you move from a commodity product such as solid sawn to CLT, there is a greater opportunity for utilizing digital design skills, BIM CAD/CAM. But those are skill sets not normally associated with the timber industry. So there is a need for these skills. How does the industry develop these?
5. Need to be able to tell the story of mass timber better. Don't wait for publication to happen two years after researcher has done the work – disseminate it now, build on the momentum.
6. Standardized connectors needed, and having them in the codes is necessary.
7. More testing is needed, but need to have a formulated plan. Don't just go out and do more testing for the sake of doing more testing.
8. Goal of adhesive manufacturers is to supply to industry a product that performs as good or better than the wood itself.
9. Adhesive research is well understood. It has been going on for 80 years. It may not be well understood by engineers and architects, but there is adequate information on bonding available to support the advancement of the mass timber industry.
10. Although some adhesives say they are formaldehyde free, they may have used formaldehyde previously in the manufacturing process and this needs to be addressed in claims.
11. Volume of adhesive between lam layers – are we giving opportunity for termite infestation in this line?
12. Adhesives that allow décor, skins, application to wood but then removable later may be desirable for some

applications. Pressure-sensitive adhesives are on the market but very different than structural adhesive.

13. PRG 320 looking to incorporate product-specific structural composite lumber (SCL) layups to expand manufacturing and supply chain. Expected in the 2019 version. May require testing to ensure compliance with PRG 320.
14. PRG 320 standard started with 60-person consensus standard committee and has evolved into the benchmark standard for the industry. But some feel it has too many limitations.

Research Needs Identified

1. Development of supply chain for CLT lam stock needs to grow. Industry is not making the best use of saw logs. What research is needed to address this?
2. Study ways to optimize mills for mass timber – don't start with 2 bys and then make it work for mass timber. Start with milling use that is customized for mass timber, thus increasing efficiency and yield.
3. Need better evaluation of stress rating of panels – where industry becomes uncompetitive using CLT is looking at capacity of individual lumber vs. how it is used in CLT. May be getting too much reduction in capacity. Example – CLT panels seem to be stronger than getting credit for, so this needs further study.
4. Need to better value-engineer the panels – this has already been done for glulam. It is well known that glulam is largely controlled by tension lams, and glulam layups have been modified accordingly to make them most efficient. What research is needed to do the same with CLT?
5. Can different (higher) wood properties around perimeter of CLT panel be incorporated to improve performance? Research needed to develop this technology.
6. Low-value wood, under-utilized species, and reclaimed wood all need to be considered for CLT. Example – we can't take some salvaged hardwood, glue it up, and then stamp it per PRG 320. If we really want to make PRG 320 as flexible as possible, how can we modify the standard to allow greater wood possibilities? A value of 0.35 was set as minimum specific gravity of lumber in PRG 320 to provide a baseline minimum consistent with lumber grades in the NDS. SG = 0.35 covers 99% of structural wood species.
7. Reclaimed timber – some cities are putting landfill bans on wood. Conduct research to demonstrate how these timbers can be incorporated in a mass timber building instead of burning or sending to landfills.
8. Always need to have design values for the lams or wood elements that are going into a CLT panel. True for solid sawn, true for SCL. That lam/element needs to have gone through ASTM testing in order to have design values to use in a model to predict the results. Then testing is needed to validate the prediction. So, how about developing a mathematical model to determine the properties of CLT? This model could be based on the density of boards, or it could be a very complicated model.
9. The current PRG 320 standard negates the use of a volume size factor for CLT panels. Presumably, this approach is followed to err on the side of conservatism. However, testing performed to this point has indicated that there appears to be a volume size factor. In lieu of testing that quantified this effect, a recently completed Protective Design Center technical report attempted to generate a size factor based on available information. This size factor needs to be validated by additional testing. A CLT size factor is also necessary to properly use performance-based design approaches.
10. PRG 320 will be updated in the near future to specify a tolerance for the narrow edge gap between boards in the same layer. Once this is done, it is important that a research effort be initiated to develop better expressions to quantify panel strengths in the minor strength direction. At the present time, the outboard ply in compression is ignored when computing the minor strength direction capacities.
11. Mass timber industry is still at the evolving stage. Opportunity to value-add with insulation layers built in the envelope layers. Increase prefabrication and value of mass timber. Initial cost for CLT is higher, but savings on construction costs can offset it. More research and development is needed.
12. The PRG 320 large-scale fire test is to test adhesives at a particular temperature. That test doesn't stress the adhesive enough. Small clears give you data about the adhesives. We need to start with small clear samples and test until the adhesive fails to better understand how/why adhesive fails.
13. Small-scale fire testing of an adhesive bond under load is needed. Need a better high-temperature adhesive test that doesn't require a 5- by 16-ft panel.
14. Indoor air quality. All structural adhesives used for CLT that are PRG 320-18 approved are Green Guard certified and do not emit formaldehyde. There are more VOCs from the wood than from the adhesives. However, it is recognized that more testing may be needed to demonstrate this and the results need to be communicated to the end users.
15. Quality control – what happens when things don't go as planned and there are "suspect" bond lines in a CLT panel. If a panel with "suspect" quality has been

installed, are there guidelines for nondestructive testing (NDT) of these panels to determine if they have met the industry standards? Change in PRG 320 added to permit use of core shear test (1-in. diameter) to address adhesive glue bond issue. Not quite nondestructive but close. NDT methods need to be developed through research to verify that adequate bond lines have been achieved. This technology could be used as an in-line manufacturing test such as those used for plywood and oriented strandboard (OSB) and for field evaluations.

16. NDT of mass timber panels could be important to spot defects resulting from moisture, termites, etc. K&C recently completed a Small Business Innovative Research (SBIR) Phase I effort that devised and demonstrated feasibility of a noninvasive and NDT methodology capable of measuring concrete material properties, including relevant spatial and statistical information associated.

Panel Discussion 6: Sustainability and Economic Analysis

- Life-cycle analysis (LCA)
- Life-cycle cost analysis (LCCA)
- Forest health benefits
- Environmental building declarations
- Carbon sequestration impacts
- Material and building system economics

Moderator

Ricky McLain, WoodWorks

Panelists

Jennifer Cover, WoodWorks

Maureen Putnam, CORRIM

Cindy West, USDA Forest Service

Michael Gorgan, U.S. Endowment for Forestry and Communities

FPL Scribes

Bergman, Gu

General Observations on Market Drivers–Challenges–Opportunities

1. Promote increased revenue potential of mass timber buildings because of shorter time to occupy and decreased time to rent.
2. Defending sustainable use of wood for the public and industries is important. Thus, we need to generate fact sheets to proactively defend the wood used in mass timber buildings.
3. Quality of data needed for building LCAs is important. Need to keep LCA data up to date for use in environmental product declarations (EPDs), etc.
4. LCA should include regeneration, and the forest products industry should be an advocate for the work to generate LCA studies.
5. Operational energy of the CLT mass timber buildings are critical for LCA analysis.
6. Telling the carbon mitigation and long-term carbon storage stories is important.
7. Better documentation of carbon savings needed, accounting for in forest and extended to wood products. We need sustainability metrics and measures showing carbon benefits.
8. Using carbon currency for integrating climate change and cost could benefit mass timber construction.
9. Forest carbon management: need to utilize wood efficiently in mass timber building systems.
10. Need better documenting and communication regarding carbon impact.
11. Dynamic carbon capture is also important for carbon benefits with mass timber buildings and to advocate wood use by collaborating with universities. Educating college students or even high school and elementary school children is a great way to advocate.
12. Define economic values of the whole mass timber building for private owners and establish carbon credits. These would provide building owners incentives for the market, sell or exchange.
13. Need standards or policies made on how to calculate the carbon sequestrated and the credibility to buy the mass timber buildings.
14. Fact sheet on reforestation or regeneration is important for building architects to promote wood use in their building designs.
15. Increasing forest health is major goal. Big companies are currently investing in forest lands to achieve their sustainability goals.
16. Forest — best use of space for carbon storage.
17. How do we improve sustainability of the current mass timber manufacturing systems?
18. Sustainability story should be told in an effective way.
19. Need to understand how to connect or communicate with millennials regarding the issues facing mass timber construction.
20. Changing climate trend caused extreme wildfires, provided significant challenges for the forest products

community. What impact does using mass timber have on mitigating impact of future wildfires.

21. Advocating and support needed for FPL and USDA State and Private Forestry programs related to mass timber construction.
22. Better storytellers of the positive impact of healthy forest management needed.
23. What about putting everything under a larger umbrella? Put the story into context of bioeconomy.
24. Education needed on how we are not losing forest area, state by state.

Research Needs Identified

1. If we want to meet acoustic and vibration requirements, what is the cost? What research is needed?
2. Feasibility study with cost effectiveness for 6- to 8-story building has been done. Need research studies showing that 8 to 12 stories will be cost effective compared with competing materials.
3. Information needed on costs of assemblies, cost-effective standard assemblies and details.
4. Cost-effective detailing is important, such as cost saving analysis for standardizing the connections and moving quicker to achieve cost-effective solutions. This needs further study.
5. Information needed on installation costs including cost-effective detailing. Example would be the required time/cost for installing bucket hanger vs. knife plate.
6. Need better structural grid spacing analysis. Research is needed to determine the optimal design for mass timber systems, instead of just a conversion from steel and concrete designs.
7. CORRIM did two building LCAs several years ago, one in Atlanta and one in Minnesota. Now is the time to do more whole-building LCAs comparing mass timber buildings with steel and concrete.
8. Whole-building LCA and building service life studies are needed to help understand carbon sequestration and environmental impacts from mass timber buildings.
9. Need LCA and EPD for each sustainability measure, but also need the ability to explain this to different stake holders or users.
10. Need exists to identify and quantify carbon benefits of different products.
11. Comparing similar buildings from different materials is needed, looking at the operational capacity and energy profiles with 2 to 3 years of data.
12. Need to quantify long-term energy characteristics of mass timber buildings.
13. Use of more low-quality wood in mass timber systems needs further study to help promote forest health.

Panel Discussion 7: Nonbuilding Applications

- Highway bridges
- Pedestrian bridges
- Sound walls
- Crane mats and other nonstructural applications

Moderator

Scott Breneman, WoodWorks

Panelists

Matt Smith, Laminated Concepts, Inc.

Travis Hosteng, Iowa State University

Jim Henjum, SmartLam, Inc.

Mikhail Gershfeld, Cal Poly at Pomona

FPL Scribe

Wacker

General Observations on Market Drivers–Challenges–Opportunities

1. Need for more education on the use of timber structural materials for practicing design professionals and at the university level to address the pervasive misperceptions about wood structures throughout society in general.
2. Timber research and development for bridges is typically government funded, and funding sources are cyclical in nature. Other competing materials are industry funded, which is stable. Amount of money spent on wood research and development is much smaller compared with other industries such as steel and concrete. They're going to outperform us on further implementation – this requires research, and research requires money. How do we generate this funding?
3. In bridges, weight of the structure often represents 90% of the loading. Mass timber is very good in terms of strength to weight ratio. Promote its use for bridges for this reason.
4. Butted end joints between conventional deck panels could be minimized with the use of CLT for bridge decks.
5. CLT bridges (untreated) have been utilized for off-highway applications in Montana such as temporary and portable logging/harvesting bridges.
6. Department of Natural Resources and Conservation specification in Montana included CLT in timber sales. Logger had option of using CLT bridges for stream crossings in lieu of culverts, which were disruptive. This application needs further study to expand to other states.

7. Success with the use of CLT stream bridges during timber lot sales: 10- by 40-ft panel, 20-ft span with 9-ply over small streams.
8. Crane access rigging mat market has downsized; difficult for CLT to compete in the market now.
9. One-million-pound movable oil driller. Normally need to over-excavate, place aggregate, pour concrete to allow machine to walk across a field. Industry has looked at multiple CLT panel combinations to greatly minimize soil disturbance. Very much a soils design exercise that needs further study.
10. Manufacturers have looked at CLT for balconies, wrapped in weather protection but have had issues with the CLT moving and cracking the weather protection wrapping. What encapsulation alternatives exist?

Research Needs Identified

1. Most past efforts on highway bridge structures have focused on using glulam, but very little knowledge of CLT in these applications exists. Using CLT for bridge decks could be a significant market opportunity, but supporting research is needed.
2. Meeting code approvals – the American Association of State Highway and Transportation Officials (AASHTO) has good criteria for glulam and SCL used in bridges – would CLT fall into this category? May need to do full-scale testing to evaluate moving loads on bridge deck panels.
3. Need to do fatigue testing for connections in bridges with CLT decking.
4. Need to investigate the use of concrete and/or steel materials for developing composite behavior with timber (CLT) components.
5. Moisture protection is the chief concern for bridges and other exposed applications. What happens when mass timber panels reach high moisture content? Oil-type preservatives preferred by code and engineers for bridges. Research needed to determine what types of treatments will be best on these large mass timber panels. Would need to work with CLT manufacturers on optimum panel size for treatment recognizing that the panels need to fit in commercial pressurization cylinders.
6. CLT is currently certified for dry-use condition only under PRG 320. If it is exposed to the elements, we need to know the impact of moisture on creep, strength reductions, long-term durability, cupping, panel deformations, etc. This will require significant research and development.
7. Best moisture management (drainage, protection, etc.) for mass timber systems needs to be evaluated.
8. Availability of wider CLT deck panels highly beneficial for bridge decks – every time you have a panel joint, there is a potential for a crack to develop in the wearing surface topping. A wider panel results in fewer topping cracks, which means better durability. What structural issues need to be evaluated for wide bridge deck panels?
9. There may be opportunities for CLT in box culvert applications. CLT may be competitive with concrete alternatives, but research is needed to develop designs.
10. Longevity/durability of CLT adhesives during moisture exposure needs to be confirmed, either by research or evaluating existing documentation.
11. Sound walls represent an opportunity instead of precast concrete or masonry but no test information available.
12. Would also like to see use of mixed species and alternate CLT grades studied (something that is decay resistant), such as for Alaska yellow-cedar. Have this for glulam now but not for CLT.
13. Remedial treatments need to be studied – how to fix mass timber panels when decay has occurred.
14. Nondestructive evaluation (NDE) – develop the use of NDE to provide better maintenance and minimize repairs, increasing longevity. Also to be used for inspection and evaluation of "suspect" panels.
15. Need exists to further investigate fire testing of mass timber bridges and other exposed structures in light of recent wild fires.
16. Evaluate shoring design using CLT as temporary shoring for concrete buildings.

Closing Session: Participant Prioritization of Research Needs

Moderators

Jennifer Cover, WoodWorks

Mike Ritter, FPL

Panel 1: Structural Resilience

1. CLT diaphragms – need code recognition, capacities, aspect ratios, deflection (tests should have a goal of standardization opportunities)
2. Standardized connections needed
3. CLT shear wall solutions for low seismic areas (what R value to use)

Panel 2: System Design and Construction

1. Wood to wood and concrete to wood composite system performance (acoustics, vibration, connections)

2. Two-way spanning performance (point supported/ punching shear)
3. Testing and design aspects (CLT size/volume effect, notched beams, CLT compression perpendicular to grain, tension connection connector capacity)

Panel 3: Fire Performance

1. Tested, standardized assemblies
2. Intermediate-scale tests to verify adhesive performance
3. Extended resistance for more 2- and 3-h systems

Panel 4: Durability and Building Physics

1. What level of wetness is sufficiently safe, construction and in service, long-term impacts?
2. Best practices for moisture management during construction
3. Treatment methods of mass timber for termites and manufacturing of CLT from treated wood
4. Best practices for coordination of mass timber building construction

Panel 5: Materials and Manufacturing Processes

1. Nondestructive testing of panels in the plant and in the field
2. Medium-scale fire testing of panels under load with new adhesives
3. Expanded options and optimization of lam stock for custom CLT, value-engineer mass timber as we have done for glulam
4. Supply chain development to increase available options for lumber

Panel 6: Sustainability and Economic Analysis

1. Cost comparisons – wood vs. steel/concrete
2. LCA studies – wood vs. steel/concrete

Panel 7: Nonbuilding Applications

1. What treatments can/should be used and how does this impact structural performance?
2. Bridges – understand long-term moisture effects

Appendix B—List of Participants

First Name	Last Name	Company
Sevda	Alanya-Rosenbaum	USDA Forest Service
Mohammad Omar	Amini	CSU/FPL
Geoff	Angle	Norbord, Inc.
Ron	Anthony	Anthony & Associates, Inc.
David	Babson	Office of the Chief Scientist, USDA
Carl	Baldassarra	Wiss Janney Elstner Associates
David	Barber	Arup
Andre	Barbosa	Oregon State University
Amelia	Baxter	Whole Trees Structures
Nathan	Bechle	USDA FS FPL
Rick	Bergman	USDA FS FPL
Todd	Beyreuther	Katerra
Todd	Black	DR Johnson Wood Innovations
Hans-Erik	Blomgren	Katerra
Brian	Brashaw	USDA Forest Service
Scott	Breneman	WoodWorks – Wood Products Council
Andrew	Brigham	Simpson Strong-Tie
Dallin	Brooks	Western Wood Preservers Institute
Mark	Clark	Hexion, Inc.
Jennifer	Cover	WoodWorks – Wood Products Council
Steven	Craft	CHM Fire Consultants
Paul	Crovella	SUNY ESF
Dan	Current	Henkel Adhesives
Qingli	Dai	Michigan Technological University
Alfredo	Dias	University of Coimbra
Mark	Dietenberger	USDA FS FPL
Chris	Duvall	Coughlin Porter Lundeen
Omar	Espinoza	University of Minnesota
Kimberley	Furlong	University of Arkansas, Fay Jones School of Architecture and Design
Robert	Gerard	Katerra
Mikhail	Gershfeld	California State Polytechnic University, Pomona
Sam	Glass	USDA FS FPL
Jake	Godwin	International Beams
Michael	Goergen	U.S. Endowment for Forestry and Communities
Hongmei	Gu	USDA FS FPL
Rakesh	Gupta	Oregon State University
John	Haluska	Norbord, Inc.
Wes	Hanson	USDA
Michaela	Harms	PFS TECO
Troy	Hawkins	Argonne National Laboratory
Jim	Henjum	Smartlam

First Name	Last Name	Company
Jonathan	Heppner	LEVER Architecture
Benjamin	Herzog	Advanced Structures and Composites Center, University of Maine
Travis	Hosteng	Iowa State University Wood Center
Runze	Huang	ExLattice
Levi	Huffman	DR Johnson Wood Innovations
Diana	Hun	Oak Ridge National Laboratory
Melissa	Jenkins	USDA Forest Service
Hanwan	Jiang	University of Wisconsin–Platteville
Adam	Jongeward	DCI Engineers
Greg	Kingsley	KL&A, Engineers & Builders
Grant	Kirker	USDA FS FPL
Richard	Kristie	Wiss Janney Elstner Associates
Steven	Kuan	FPInnovations
Pat	Layton	WU + D Institute Clemson University
Robert	Lepage	RDH Building Science
Hui	Li	Washington State University
Shaobo	Liang	North Carolina State University
Hyungsuk	Lim	Mississippi State University
Thomas	Lim	Mississippi State University, Department of Sustainable Bioproducts
Philip	Line	American Wood Council
Marco	Lo Ricco	University of Wisconsin–Milwaukee
Yunxiang	Ma	Michigan Technological University
Iain	Macdonald	Oregon State University – TallWood Design Institute
Peter	MacKeith	University of Arkansas, Fay Jones School of Architecture and Design
Mark	Mankowski	USDA FS FPL
Steve	Marshall	USDA Forest Service
Joseph	Mayo	Mahlum
Dwight	McDonald	USDA FS FPL
Eric	McDonnell	KPFF
Ricky	McLain	WoodWorks – Wood Products Council
Tahar	Messadi	University of Arkansas
Graham	Montgomery	Britt Peters and Associates
Jeff	Morrow	Lendlease
Williams	Munoz Toro	Nordic
Cameron	Murray	University of Arkansas
Kenneth	Ogorzalek	KPFF
Katie	Ohno	USDA FS FPL
Ronald	Ott	Oak Ridge National Laboratory
Weichiang	Pang	Clemson University
Chris	Pantelides	University of Utah
Vishal	Patil	Ashland
Shiling	Pei	Colorado School of Mines
Josh	Powers	Katerra

First Name	Last Name	Company
Maureen	Puettmann	CORRIM
Douglas	Rammer	USDA FS FPL
Michael	Ritter	USDA FS FPL
Mark	Rudnicki	Michigan Technological University
Kamalakanta	Sahoo	USDA FS FPL
Ann	Sarnecki	USDA FS FPL
Dan	Seale	Mississippi State University, Department of Sustainable Bioproducts
Christopher	Senalik	USDA FS FPL
Judith	Sheine	University of Oregon – TallWood Design Institute
Jason	Smart	American Wood Council
Matthew	Smith	Laminated Concepts, Inc.
Joseph	Su	National Research Council Canada
Xiping	Wang	USDA FS FPL
Mark	Weaver	Karagozian & Case
Cynthia	West	Office of Sustainability and Climate–NFS–FS–USDA
Tom	Williamson	Timber Engineering, LLC
Yuan	Yao	North Carolina State University
Borjen	Yeh	APA – The Engineered Wood Association
Sam	Zelinka	USDA FS FPL
Yaqiu	Zhao	Ashland

Appendix C—Scribe Notes from Panel Discussions

Panel Discussion 1: Structural Resiliency – Designing to Resist

- Earthquakes
- Wind loads
- Floods
- Terrorism (blast resistance)

Moderator

Scott Breneman

Panelists

Mark Weaver – Blast/terrorism

Adam Jongeward – Seismic upgrades, transitioned to mass timber

Ed McDonnell – Mass timber 16 completed CLT projects

Chris Duvall – Started with mass timber 2006 Mass Timber World Symposium Timber/concrete composites, fastener testing, 2012 broader projects

Hans-Erik Blomgrem – 20 years commercial building construction, started looking at mass timber 10 years ago

FPL Scribes

Rammer, Senalik

Discussion

Mark Weaver:

- More need for engineers to deal with multiple hazards in the future. Blast or ballistic threats.
- Perception among engineers is that wood is weak, brittle, and burnable. The connections can be made ductile. Usually have a blast, ballistic, and forced entry requirement. Need to make panels that address all of those.
- Education is an issue. Do not need to take a wood course to graduate from most programs.
- Wood designed conservatively. Designed for 5th percentile. When dealing with blasts, which are high intensity and short duration, want to deal with 50th percentile. Out-of-plane bending or in-plane bending. Need 50th percentile for panel and connections. Sometimes dealing with data that is 80 years old for connection strength and dynamic loading behavior. How is the panel really going to behave?
- People are interested in incorporating wood into structures such as embassies, but there is no way forward. CLT composites are helpful toward that.
- Expand on 50th percentile. Published data based upon 5th percentile. Trying to track down the 50th percentile data is difficult. Out-of-plane bending is proprietary from manufacturing. Should mine the data that we already have.
- What models are being used to solve the problems? In practice, you should go to higher level of detail. Single degree of freedom models rule the world currently in blast testing. Low-fidelity models. Maybe a few multiple degrees of freedom models.
- Question from relative availability of data of wood under extreme load. Reinforced concrete has been tested since WWII.

Adam Jongeward:

- Nothing currently allowed in codes for seismic R-factor for mass timber. So have to use other means and methods, which limits its use by engineers and designers. Diaphrams P695 now out. Rocking CLT walls currently in works. Shear wall systems with ductile hold down system. Knowledge of deformation compatibility of those connections is lacking right now for mass timber. Brace frame systems. Promote low damage solutions. Deformation behavior of gravity connections under seismic or lateral load (wind). Feels there is enough information out there to start making guides.
- Expected properties of in-plane panels. Sometimes don't even have allowable shear properties let alone expected.
- Nothing in the U.S. code to describe how to epoxy drill in rods into panels. Lots of global research on that.
- Construction durability and quality control. What is going to happen when that wood swells and shrinks?
- Prescriptive requirement in code is hindrance. Need to move away from prescriptive value to properties so that engineers who want to be innovative are not limited. The current IBC has one nail and one spacing. What is the purpose of that code provision? Can we achieve that in multiple ways?
- Notching in beams is limiting to 1/6 depth. Maybe have methods to reinforce notched beams rather than only permit 1/6 depth.
- Perpendicular to grain crushing load. No codified data.
- Can only cantilever 35 ft. Why can't we actually calculate the deflection?
- Less prescriptive requirements.
- Give us the material data and let us design our own models.

Chris Duvall:

- Everyday practitioner is bound by building code. For mass timber, there is not a lot there. Need to get tested assemblies into building code. Have not seen enough data to put vertical CLT walls into building. Waiting on P695. Until it is in the building codes, you won't see it in use.
- The number 1 priority to see right now is diaphragms. Office building projects cannot get past building limitations in many jurisdictions.
- Focus on diaphragms. Get it out right away so it can start to be used.
- Timber/concrete composite for seismic areas. Connections are European. Nothing domestic with information. You can dig around and find it.
- One thing that will help mass timber is use by structural engineers.
- Needs to get into NDS. All for loosening restrictions, but first it needs to get into the code.
- Need more tested assemblies. Standard practicing structural engineers cannot propose an assembly unless they have the whole package of information.

Hans-Erik Blomgrem:

- How does CLT behave in low seismic zones?
- CLT in wind load zones probably easier path for CLT use.
- Deal is made or broken on efficiency of connections.
- Engineer of record doesn't necessarily know they can use test data because the load or assumptions may be different.
- Wood world is centered around light frame industry.
- Engineers need to be serviced with good codes and standards.
- NDS needs to be rephrased for use. Differentiate between light framing and mass timber. Commentary is not available free. You can pay for it online, but it is needed. Need to rip apart the code and restructure it.
- Innovative work is usually based on $300 million projects. The project they are dealing with is $20 million, and you can't afford one-off ideas.

Scott Breneman:

- Need something acceptable in low seismic zones. There are many low seismic areas but not many high seismic areas.

Audience:

What challenges have not been addressed by the panel already?

1. In the code right now there is a cantilever column timber frame and that is about it. Would like to see steel frames combined with timber. Besides CLT walls, limited in brace frames.
2. Opening in CLT walls for shear walls. Opening in shear panels. Without doing finite element analysis models. In a wind region, you could have a whole wall replaced with glass or have windows cut. Would like to see it added to the code.
3. Brace frames for wind. Strain brace frames for wind, seismic, and blast. Biggest challenge: what is going on in the beam and frame connections?
4. Fire engineer has sympathy for code officials. We have a responsibility to convince the design officials what we're doing is safe. Also, there needs to be special inspection programs and training for the design officials. The NDS has to facilitate this.
5. The focus on the projects seems to be the cost. Is there a way to quantify the "low damage" aspect of wood into the cost. Are we leveraging enough the low damage aspect of wood? U.S. Resiliency Council rates buildings on resiliency (like LEEDS). Developer-driven projects. Advancement has been more regulatory than voluntary.
6. Special inspections are lacking. Opportunities for research but also opportunities for consensus documents. Also, we don't have people trained to perform these special inspections.
7. Can solve for seismic, but haven't designed for vibration and acoustic.
8. Combining vertical wood systems with nonwood lateral systems. Requires actual stiffness properties for wood so they know how the load is shared.
9. One reason progress has been limited is because of the lack of standardized design systems.

Questions:

1. Stiffness compatibility is one issue in retrofitting masonry buildings. ASCE 41 pier and spandrel system has applicability outside of masonry. You need the exact deflection data in order to install it.
2. Mark Clark of Hexion adhesive manufacturer. Seems that the crux of many problems involves force transfer issues. Not about the generic CLT panels. Seismic and blast and to a lesser extent wind, is the transfer of loads between panels, intrapanel connections, and connections.
3. Punching shear and two way
4. Research perspective – if you had a half million dollars and could spend it on one project, what would you do? What do you feel needs primacy? Diaphragms with different timber concrete composites with different fasteners. Dowel-type connectors and connections under different strain rates. Vertical systems for low seismic/low wind – start simple then add complexity. With that

amount of money, develop a 2- to 3-story shear wall in California.

5. Evaluate for high wind loads and windborne debris for community centers and schools.
6. Connections are the last things to be funded in blast testing. We don't have an understanding of how wood responds at higher strain rates such as an impact.
7. Is there anything for CLT in the 2 to 10 story? Are there some subjects that can be pushed forward to make that possible? We are focused on seismic and wind, but with smaller buildings, you can have a brute force approach. Low ductility with an R of 2 would probably be okay, but if you had a code provision that specified this, it would be easier.
8. What do you do after this mass timber building has gone through an event? If there is damage to the wood structure, how would you repair it? It is a dirty secret on the west coast, but the design is for life safety and no consideration is for repair of building. It is a societal issue to decide upon what is the acceptable level of performance. Develop seismic systems meaning either low damage or easily repaired to a pre-event state. Also have to be careful because if you hold yourself to a standard higher than the others (life safety) then you can price yourself out of the discussion.
9. Should we replace R? That would be changing the fundamental approach. We may agree, but changing to a performance-based design is a major change. Equivalent lateral force methodology that is displacement based may be better. You can spend 10 years developing R factors or you can develop a new system. It would be a big bite to break off, but the concept is enjoyable.

Off-subject topics:

1. Two-way spanning CLT.
2. How do long, self-tapping screws perform under moisture?
3. Full-scale panel testing according to P32018. Manufacturers updating their testing to conform with P32018. Fire testing. You are going to need to go out and buy a panel that meets that requirement. The code official doesn't know if a fire adhesive change affects the fire performance of the panel. Colossal waste of money. The adhesive is virtually the same. The standard was made to improve the fire performance. The panel should just be P32018 compliant. Education issue.
4. ICC tall wood proposals up to 18 stories. It requires new P32018 provisions. It is an immediate issue. Seattle specifically said they need the fire testing as part of that acceptance. The fire testing refers to appendix P32018. A panel would not perform worse than it would in the PS32017.
5. What effect does size or volume have on design values? There is a definite size factor for CLT. From the panel perspective. If you have a 7 ply vs. a 3 ply, there is a significance difference. The MOR is not the same in the 7 ply as it is in the 3 ply.
6. Moisture control during construction. Mold growth.

Additional suggestion from Ling Pei: High-performance lateral force resisting systems for multistory mass timber building with large open floor plans. Open floor mass timber buildings are popular for commercial and mixed-use applications. They utilize glulam beam/column grids to support gravity load and typically do not have enough structural walls in the floor plan to carry lateral loads in high seismic regions.

Panel Discussion 2: System Design and Construction

Moderator

Ricky McLain

Panelists

Greg Kingsley

Graham Montgomery

Jeff Morrow

Phil Line

FPL Scribes

Brashaw, Wang

Areas

- Connections
- Component design
- Serviceability (vibration, acoustics, displacement)
- Standardized design tools

Discussion

Greg Kingsley:

- Perceived cost; fire; how to manage cost, risk
- Wood volume used drives the cost
- Design tables, driven by vibration, deep understanding will help, span table
- Acoustics test: design floor assemblies, 5 ply and 7 ply
- Point-supported panels, residential, hybrid
- Better to design building as wood, not from steel and wood
- Moisture management, how moisture affects connections, provide better information for engineers
- Cost benefit

- Water management during construction, risk to long-term effect, reliability
- Education: lack of experience in construction

Graham Montgomery:

- With CLT, one-way fashion
- Component design, component connection, meet system efficiency, move to that direction
- Composite system design: better vibrational test, CLT–concrete, connections (screws)
- Acoustics: need more information, factors affect acoustics
- Vibration of composite system, CLT, glulam layout, tension zone, compression, very technical thing, need to look into
- Composites: glue not researched, a lot of questions, how much variability?
- In terms of efficiency of composites: connections limit design, conservatism across the industry, reasonable statistical level
- Braced system: very conservative, not necessary
- Moisture problems, related to details
- Tall wood initiatives: selling to developers, again a lot of conservatism, feasibility may change in the future

Jeff Morrow:

- Code process, huge race, cost (6-12 stories)
- Current code constraints through construction, work around the code (online voting for building code)
- How to navigate around the design guidelines and code
- Training on how to use CLT, learning curves for all
- Too much relying on CLT handbook, too conservative, make it better (flexible)
- Share lessons learned

Phil Line:

- Risk, lack of familiarity with wood
- What's done on those successful projects? What led to the success?
- Code and standard: weakest solution
- Priority research: identify specific areas, such as CLT diaphragm; a lot of questions can be standardized, can be implemented into standards; lack of system level testing. need to test something, need data
- A lot of use of propriety screws, difficult to standardize
- Echo: limitation, low seismic region, R-factor? A barrier

Audience:

Comments and thoughts; prioritize research needs:

Diaphragm is a priority now. What specifics?

- Example: use commodity products (existing materials, standards, codes existing), 16 page documents
- Recommendation: test with materials covered by standard and code

Composite system:

Achieve cost savings:

- Tall-wall building project, doing something with composites, something stronger, in terms of research project, better glulam beam, get wood volume down through efficiency
- CLT, glulam beam connections: how to standardize screws

Small detailed items:

- Strengthen special zones, such as reinforcement in local crushing zones, tension zones
- Size/volume effect on CLT panel on bending
- Use rod in glulam beam: nothing standardized
- Notched beam
- A need to design for increasing strength in fire, acceptable strength in fire
- Composite connection options: no screw connections? Are there other ways? Too much cost for screws; something simple and fast; structural adhesives? can be used in glulam, but not in CLT; need more tests

Panel Discussion 3: Fire Protection

Moderator

Scott Breneman

Panelists

David Barber, Arup

Jason Smart, AWC

Steve Craft, CHM Fire Consultants

Carl Baldassarra, Wiss Janney Elstner Associates

FPL Scribes

Bourne, Yedinak

Discussion

Steve Craft:

Code change proposal doesn't capture height, occupancy, beams, columns, ceilings; compartment testing from past found CLT delaminates causing fire regrowth:

- New adhesives do not have the same response so new tests are needed (these tests may allow for more exposed wood)
- Alternative solutions for taller wood buildings (e.g., coverings such as chip board)

2-h exposed connection is expensive:

- Member sizes end up overly large to accommodate this regulation
- Looking at 2- to 3-h connection response helps with larger building planning

How mass timber construction sites perform during fire (demonstration)

David Barber:

Demonstration of exposed CLT fire tests to educate building officials and fire protection officials

More detailing of penetration, joints, and connections because these are driving up price

- Test more products to expand toolbox of options to lower price

Testing is expensive and not always needed

- Educate code officials to accept more prescriptive solutions (specific components mentioned: connection work, glulam, and columns)

One bad fire will kill mass timber industry, no solution proposed

Jason Smart:

Code consideration

- Special inspection training for
  (1) type 4 a, b, and c type construction
  (2) fire protection of members and connectors
- Develop intermediate-scale adhesive test to screen for delamination

Component design

- Performance testing for noncombustible protection other than gypsum board (e.g., mineral wood board)

System performance

- Develop more guidelines for detailing and penetration fire stops up to 3-h ratings
- More testing on hybrid concrete, wood, steel structures
- Postfire rehabilitation guidance, both specific and general
- Development of exterior flame spread (description or method)?

Connections

- Clarification of connection codes as well as performance

Carl Baldassarra:

Expressed an interest in more flexible code for larger and different projects

Suggestion that delamination of CLT was resolved (PRG 320)

- Special need for tested and listed connection details

Automatic sprinklers could be used to offset fire performance

- Exposed wood and connections

Audience:

Fire retardants – look into this or other treatments that could help

Lots of room for interpretation when moving between Type III and IV building code, including connections

- This needs clarification
- More fire tests on connections

Main topics:

More standardized connection and penetration details for 2- to 3-h ratings

- Spend time clarifying this for Type III and IV projects

More compartment fire tests with adhesives that do not delaminate

- Wood exposure specific questions

Education of building offices, fire protection, officials, and designers around mass timber performance

- Focus in on connections and detailing

More connections and penetrations available in toolbox for use

- Includes testing

How construction sites using mass timber perform during a fire

Further clarity on code and restrictions relating to large buildings, including the flexibility around those interpretations

- Move away from testing every combination and look for solutions where calculations could augment these questions (somewhat controversial topic in session)

Intermediate-scale qualification test of adhesives with regards to delamination

Testing to include noncombustible components

- Other materials
- Retardants
- Hybrid building
- Sprinklers

Postfire rehabilitation guidance (specific and general)

Exterior flame spread behavior – system performance

Panel Discussion 4: Durability and Building Physics

Moderator

Ricky McLain

Panelists

Jonathan Heppner

Robert LePage

Joe Mayo

Dallin Brooks

Ron Anthony

FPL Scribes

Glass, Kirker

Discussion

Research needs:

- How wet do mass timber products get during construction?
- How wet can mass timber products be for how long, safely? (with minimal risk of dimensional change problems, biological deterioration, corrosion of connections, etc.)
- Effectiveness of protective coatings at limiting moisture uptake (polyurethane sealants are not completely effective)
- Drying capability of mass timber products (passive vs. active moisture mitigation)
- Pollutant emissions from mass timber products (indoor air quality)
- Updated termite and decay hazard maps of North America
- Termite resistance of pressure-treated glulam and CLT
- Improved moisture and structural condition assessment methods for mass timber products (e.g., infrared thermography, ground-penetrating radar)
- Moisture detection devices incorporated during fabrication
- Methods for repair of mass timber products in the field
- Integrity of structural connections between mass timber products after moisture cycling
- Acoustic performance of mass timber buildings
- Moisture transfer from concrete to CLT in hybrid assemblies
- Mold and mildew control in mass timber
- Landscape-level termite management

Technology transfer needs:

- Best practices for managing moisture during construction (passive and active methods)
- Best practices for specifying mass timber for a given installation
- Written specifications that incorporate best practices for managing moisture during construction
- Best practices for cleaning exposed wood surfaces after the building is enclosed
- Best practices for mass timber products in proximity to the building foundation
- Best practices for roof and exterior wall design including cladding attachment methods
- Database of lessons learned
- Standard details for architects to address owner/developer misconceptions (when project consultants are not in the room)
- Best practices for protection against termites and fungal decay
- Best practices for coordination between design professionals, general contractors, and trades
- Specific energy code provisions for mass timber systems

Panel Discussion 5: Materials and Manufacturing Processes

Moderator

Scott Breneman

Panelists

Todd Beyreuther – Academic research at Washington State University (went from practice to R&D and now is with CLT producer Katerra, based in Spokane, Washington)

Ian MacDonald – Executive Director for Tallwood Design Institute, based in Corvallis, Oregon (part of the agreement between Univ. of Oregon and Oregon State University)

Mark Clark – Adhesive supplier (Hexion) for wood industry (PRG 320 committee member)

BJ Yeh – PRG 320 secretariat and APA – The Engineered Wood Association (QA/QC)

FPL Scribes

Farber, Senalik, Brashaw

Discussion

Panelist comments:

Todd Beyreuther: Need to take the baseline parameters that are critical. Development of lam-stock. Heavily dominated by dimension lumber. Intention of the lumber is different than lam-stock. Linear elements put into a composite material. Shift from a storyline of increasing lumber stocks to getting back to saw log. Still talking about sawing in rectangles. Potentially advancing technology at mill.

Ian MacDonald: Currently focusing on adding lumber layers. There is value in laminating other layers on inside and outside like insulation. Testing data are still laminated. Need to ramp up those efforts. Alan Czinger (USNR, Woodland, Washington, USA) made a presentation at Mass Timber Conference – Optimize the mill for producing mass timber. You can have random widths as long as you have a way of getting to the final panel. 6% or 7% increase in mill production by taking into account what they will be using in mass timber. There is desire to make CLT out of different wood species. How do you get the fiber from the forest to the mill and then to the production facility to make the CLT? Landfill bans on clean wood. Burning should be the last option. Standardized connectors are a huge issue. Part of the problem is communication of the ideas in a manner that can be obtained. As you move from commodity products (lumber) to CLT, there is a lack of skills such as computer numerical control (CNC) and computer programming. Those are not skills that the wood industry has needed.

Mark Clark: Goal of adhesive manufacturers is that the adhesive strength should exceed wood strength. A manufacturer of CLT should be able to build to wood properties and have the adhesive exceed those so the CLT manufacturer does not have to worry about that. We may need a literature review for adhesives. The more wood you put in the way, the less you know about the adhesive. The PRG large-scale test is to test adhesive at a particular temperature. That test doesn't stress the adhesive enough. Small clears give you data about the adhesives. Indoor air quality – PRG17 certified adhesives all have Green Guard certification. They do not off-gas formaldehyde. The wood off-gasses more. There is a misconception about VOC and formaldehyde. A newborn baby emits more formaldehyde than the adhesives. They are all synthetic polymers. They all come from simple feedstock. To say one is green and another is not is a disservice to the manufacturers. The panel test for off-gassing works for CLT panels. We have to get our minds around the story that there are things that we evolved around that are not harming us. Small-scale fire testing of an adhesive bond under load is needed. Need a better high-temperature adhesive test that doesn't require a 5- by 16-ft panel. There needs to be a set of values readily available for screws and other standard fasteners.

BJ Yeh: When we developed PRG 320, requirements were that species should have a specific gravity of 0.35 or higher. Use 0.35 for design. That covers 99.9% of the production out there. It tells you what grades of lumber you can put in a panel. You can change the grade and thicknesses. Suspect some innovation will occur to make CLT more cost competitive. The reality is that when a particular CLT is specified, the PRG 320 has ways of predicting the values. PRG 320 is looking at using structural composite lumber. There is concern about the char rate.

Need demonstration to show formaldehyde emission of CLT. When we get back to sawn lam-stock and look at individual properties that are relevant. When we become competitive with CLT is when we take the reducing factors that affect CLT values. There is a lot of research in North America. The value engineer that designs the panels.

Questions:

Use low-value wood. Is there a research need to use low-value wood? For the Forest Service, utilizing low-value wood is a major concern. We can put it in CLT, but how does it work with respect to PRG 320? How do you certify the value? Liability is taken into consideration. Need to have a design value for the numbers. The design values are taken very seriously. There is another step involved in the use of these materials. Air quality in Vancouver was the worst in the world because of forest fires. You can start having the conversation that this type of worth may be good for forest health.

Brian Brashaw: Comment in regards to NDE. NDE is used widely for lumber – visual grading and machine stress rating. There is also in-line work being done in composite panel plants. It seems logical to develop new strategies for both QA/QC during CLT manufacturing and in service, once the building is completed.

Rusty Dramm: Sawmill and process control are important considerations for manufacturing. What is the correct moisture content? How do you make the CLT at different moisture levels?

There are good and bad things happening in the lumber industry. With the growth of distribution to home centers, the effect is putting the lower end distribution to the pro-builders. Return on investment for capital projects has short paybacks. We are looking at a method to detect the glue bond. CLT edge joint is not glued. Current PRG 320 shows glue bond is durable. What about having higher density around the outside of the CLT and lower interior density?

Adhesive question: Can you put a sacrificial layer that can be removed? Are there some new advances in the adhesive world that give you the option of doing décor or skins? Answer from Mark Clark: Adhesive manufacturers don't really want a way to undo the bonds.

Structural integrity must be defined by PRG 320. That includes mechanical or bond integrity. Are you leaving pathways for water, and do you have liability in that case?

NDT to determine bond integrity. We can do it. You can look at stiffness between bond and wood, but that is not what we want to know. We want to know if we have the chemical bond between glue and wood. Bond line that did not get pressure in time will look fine.

Are there plans to define properties of wood going in the same direction? PRG 320 has a specification of the tolerance. The cross-ply contribution.

Brashaw whiteboard notes:

Key priority topics summary

1. System research/implementation approach
2. Supply chain development to increase available options for lumber
3. Additional layups testing for expanded options of grade lumber that will be done through PRG 320 "custom"
4. Digital skill development
5. Improved communication products and approach for mass timber, i.e., trade and/or scientific journals
6. Drying efficiency for 12% stock
7. Value-engineered layups/testing of CLT
8. Adhesive testing – fire testing under load, formaldehyde testing of panels
9. NDE for panels in plan (QC) and in service with emphasis on identifying poor bond, unbonded, high quality

General white board notes:

Issue/challenge:

Todd Beyreuther:

- Development of lam stock/supply chain
- CLT stock specification opportunities to support final product (CLT, NLT, etc.)

Iain MacDonald:

- Layers beyond just lumber to support prefabrication
- Performance data, specs, creative
- Thoughtful approach on lumber species supply
- Optimized lumber supply and production (random width)
- Species
- Non 2-by dimension
- Underutilized species (reclaimed lumber)
- Business case economic assessments of supply chain
- Nonstandardized connectors (previous sessions)
- Standardized connectors
- Get the word out sooner in media that can be more closely used
- CAD and digital skill development and access

Mark Clark:

- Adhesion not so well understood by code folks
- Standards developed and in place already for structural adhesives
- Air quality performance for CLT based on adhesive is good as all three have green guard approvals.
- More formaldehyde in wood than in lumber
- Greenwashing concerns always brought forward on chem
- Formaldehyde testing of panels, species effects
- Fire testing under load
- Connector standard testing moving forward

BJ Yeh:

- Adding additional lumber materials for CLT (species/grade)
- Add testing options for "custom" path via PRG 320-18
- Testing gaps
- Wane
- SCL
- Reduction factors that have a huge impact
- Refinement of grade to performance "value-engineered" defect
- PRG 320 limitations need to get to "value"
- Need to get for some species, must have design value on lumber certified
- Can model be based on design values for species that are commercial?
- For some other (reclaimed lumber), need design properties
- NDE panels and methods for assessment (in plant and in service)
- Reliable method to assess glue bond using NDE
- Moisture content drying efficiency for 12% equilibrium moisture content and process control for long-term performance and needs assessment
- Europe has lots of lumber custom grades
- What can U.S. sawmills do to improve technology and sawing, grading, and efficiency

- Return on investment on a kiln is much faster than some may think
- PRG core shear 1 in. diameter allowed
- Adhesive innovation to change-outs, repairs, skins
- Skinny 3 ply for decorative applications, appearance
- NDE for bond integrity (Presence of ok. Do we have a good bond?)
- Spacing tolerance on same direction – in PRG 320

Panel Discussion 6: Sustainability and Economic Analysis

- Life-cycle analysis (LCA)
- Life-cycle cost analysis (LCCA)
- Forest health benefits
- Environmental building declarations
- Carbon sequestration impacts
- Material and building system economics

Moderator

Ricky McLain

Panelists

Jennifer Cover

Maureen Putnam

Cindy West

Michael Gorgan

FPL Scribes

Bergman, Gu

Discussion

Research needs, challenges, and opportunities from the panel experts:

Jennifer Cover:

- Economic analysis importance, comparison cost analysis, to add cost perspective to designs
- Feasibility study with cost effectiveness for 6- to 8-story buildings has been done and approved; need research studies showing for instance "8-12 stories will be cost effective" would be helpful
- Assembly cost or cost of installation needs to be obtained
- Cost-effective detailing is important, such as cost saving analysis for standardizing the connections
- If we want to meet acoustic and vibration requirements, what is the cost?
- CLT mass timber buildings tend to stay longer than concrete and steel buildings, but not quantified, and what are the cost benefits for this?

Maureen Putnam:

- Defending sustainable use of wood from the public and industries is important, thus need to general fact sheets for publishing to proactively defend wood use in mass timber buildings
- CORRIM did two building LCAs several years ago — one in Atlanta, one in Minnesota, time to do more whole-building LCAs with the new CLT mass timber buildings going up now
- Quality of data for the building LCAs
- Whole-building LCA and building service life will help understand carbon sequestration and impacts from CLT mass timber buildings
- Telling the carbon mitigation and long-term carbon storage stories is important

Cindy West:

- Changing climate trend caused extreme fires, provides significant challenge
- Opportunity: using carbon currency for integrating climate change and cost
- Challenges: increasing forest health
- Opportunity: big companies are currently investing in forest lands to achieve their sustainability goals
- Forest carbon management: need to utilize wood efficiently in mass timber building systems
- We need sustainability metrics and measures showing carbon benefits
- Need LCA and EPD for such sustainability measures, but also need the ability to explain this to different stake holders or users
- How do we improve sustainability of the current manufacturing systems?
- How do we socialize this idea, which is highly technical, connect them to the work we are doing
- How to connect or communicate with millennials regarding the issues

Michael Gorgan:

- Forest: best use of space for carbon storage
- If value isn't there, it is hard to maintain the forest in healthy conditions or keeping it as forest might not be viable option for the landowner
- Sustainability story should be told in an effective way

- Mass timber tells this story better than any other wood product
- Forest products industry should advocate the work by LCA
- LCA should include regeneration
- Forest is a carbon sequestration technology
- What about putting everything under a larger umbrella — bioeconomy
- Identify and quantify carbon benefits of different products
- Whole-building LCA: there are private carbon markets right now; companies have carbon neutrality targets they try to meet by buying external carbon credits
- Comparing similar buildings from different materials, looking at the operational capacity, energy profiles with 2 to 3 years of data; carbon use in an operational building

From the audience:

- Dynamic carbon capture is also important for carbon benefits with the mass timber buildings and to advocate for wood use in this, collaborating with universities, educating college students or even grade school students is a way to advocate
- Bioeconomy should be put into this mass timber building context
- Define economic values of whole mass timber buildings for private owners, establish carbon credits, these would provide building owners for market sell or exchange
- Need standards or policies made on how to calculate the carbon sequestrated and the credibility to buy the mass timber buildings
- Operational energy of the CLT mass timber buildings are critical for LCA analysis
- Fact sheet on reforestation or regeneration is important for building architects to promote wood use in building designs

Panel Discussion 7: Nonbuilding Applications

- Highway bridges
- Pedestrian bridges
- Sound walls
- Crane mats
- Other nonstructural applications

Moderator

Scott Breneman

Panelists

Matt Smith, Laminated Concepts, Inc.

Travis Hosteng, Iowa State University

Jim Henjum, SmartLam, Inc.

Mikhail Gershfeld, Cal Poly at Pomona

FPL Scribe

Wacker

Discussion

Matt Smith, top issues:

- First step probably a decking application for bridges
- Oil-type preservation preferred by code and engineers
- Moisture management (drainage, protection, swelling, shrinking, warping)
- Requirement for treatment by AASHTO so expect moisture content to exceed 18%
- There is a panel size issue with regard to the size of treatment cylinders, so treatment prior to gluing is most desirable
- AASHTO code recognition for CLT – perhaps the existing verbage for structural composite lumber is applicable to CLT as well?
- Full-size testing may be required to further develop CLT for bridge applications

Travis Hosteng, top issues:

- Comparative research dollars for concrete and steel bridges are staggering compared with those available for timber bridge applications
- We already have the capability to track moisture contents in timber bridge structures and are actively doing so at a demonstration smart bridge project in Buchanan County, Iowa (woodcenter.org)
- Butted end joints between deck panels could be minimized with the use of CLT for bridge decks

Jim Henjum, top issues:

- CLT bridges (untreated) have been utilized for off-highway applications in Montana: temporary and portable logging/harvesting bridges
- Moisture issues as they relate to creep behavior and strength behavior
- Other CLT applications may involve monuments, kiosks, and/or noise barriers
- There are tough marketing challenges associated with crane mats for the oil industry
- Additional research testing should involve the following topics:

- long-term moisture exposure
- effects of UV light and heat
- development of durable encapsulation techniques
- accelerated aging of bridge-sized components
- using mixed species in CLT panels, including the use of naturally durable tree species
- verification that CLT adhesives are waterproof and durable for bridge applications

Mikhail Gershfeld, top issues:

- Recently toured the CLT (i.e., XLAM) plants across Europe
- Long tradition of constructing bridges from wood in European countries
- Euro timber bridges make an architectural statement as well
- Investigate the use of concrete and/or steel materials for developing composite behavior with timber (CLT) components
- Take advantage of the comparative lightweight (high strength/weight ratio) for timber and CLT components
- Validate other related tests or works previously performed elsewhere
- Need for more education on the use of timber structural materials
  - practicing design engineers
  - to address the pervasive misperceptions about wood structures throughout society in general
  - some of this work has commenced as a joint effort between AWC/ASCE to develop guidance materials for college-level engineering courses to improve knowledge about wood as a structural material

Audience participation commences here:

- There may be opportunities for CLT in box-culvert applications and it may be competitive with concrete alternatives
- Power or transmission poles?
- (Matt Smith) The high level of designing for durability in Europe with regard to untreated bridges can be reviewed for applicability
- (Mikhail Gershfeld) Wind tower or wind turbines in Europe
- (Travis Hosteng) Need to better educate on timber structural design at earlier stages; if possible, change the college curriculums
- Timber research dollars are largely connected to Forest Service budgets and tied to land-grant colleges and universities
- Timber bridge funding availability and funding sources are cyclical or circular in nature
- What specifically would be required to attain AASHTO code recognition for CLT products: testing protocols and/or analysis methods?
- (Mikhail Gershfeld) Timber bridge designer must engage with an architect earlier in the overall process
- Further investigate fire testing for timber bridges
  - the use of oil-type vs. waterborne preservatives
  - untreated covered bridge applications
  - techniques for hardening against fire damage
- Need for more remedial treatments
- Increased use of NDE techniques can help to improve inspections of timber bridges