SOUTHWEST RESEARCH INSTITUTE®

6220 CULEBRA ROAD 78238-5166 • P.O. DRAWER 28510 78228-0510 • SAN ANTONIO, TEXAS, USA • (210) 684-5111 • WWW.SWRI.ORG

CHEMISTRY AND CHEMICAL ENGINEERING DIVISION

FIRE TECHNOLOGY DEPARTMENT
WWW.FIRE.SWRI.ORG
FAX (210) 522-3377

INTERNATIONAL EXPERT ELICITATION PROCESS TO DEVELOP BUILDING CODE REQUIREMENTS FOR FIRE-SAFE TALL WOOD BUILDINGS

FINAL REPORT
Consisting of 128 Pages

SwRI® Project No. 01.21941.01.001
Period of Performance: February 22, 2016 through December 31, 2016
Report Date: June 30, 2017

Prepared for:

American Wood Council
222 Catoctin Circle SE
Leesburg, VA 20175

Submitted by:

Marc Janssens, Ph.D., FSFPE
Senior Engineer
Center for Nuclear Waste Regulatory Analyses

Approved by:

Karen C. Carpenter, M.S., P.E.
Manager
Fire Resistance Section
Fire Technology Department

TABLE OF CONTENTS

PAGE

1.0 INTRODUCTION 1

2.0 PROJECT TEAM 1

3.0 FIRE SAFETY ISSUES IN TALL WOOD BUILDINGS 1

4.0 TALL WOOD BUILDING SURVEY 2

4.1 Survey Objectives 3

4.2 Selected Buildings 3

4.3 Questionnaire 7

4.4 Comparison of Standard Test Methods 9

4.4.1 Fire Resistance 10
4.4.2 Reaction-to-Fire ("Surface Burning Characteristics" in North America) 13
4.5 Tall Wood Building Survey Results 15

4.5.1 Summary of Survey Results 15
4.5.2 Summary of Additional Information Obtained 17
4.6 Swedish Fire Incident Data Study 18

5.0 NEEDS FOR ADDITIONAL TESTING, MODELING, AND RELATED ACTIVITIES 18

5.1 Needs Identified in the Literature 18

5.2 Compliance with Prescriptive Code Requirements for Fire Resistance 19

5.2.1 Standard Fire Resistance Furnace Testing 19
5.2.2 Simplified Calculation Methods 19
5.2.3 Detailed Structural Fire Modeling 20
5.3 Performance-Based Assessment 20

5.3.1 Custom Fire Testing 20
5.3.2 Simplified Calculation Methods 20
5.3.3 Detailed Fire Modeling 20
5.4 Charring Rate of Mass Timber 21

5.5 Contribution of Exposed Wood 21

5.6 Trade-offs and Equivalence 21

5.7 Detailing 22

6.0 CONCLUSIONS 22

Appendix A—Questionnaire Responses
Appendix B—Guidelines for Fire Safety on EXPAN Construction Sites
Appendix C—References
Appendix D—References Arranged by Topic

LIST OF TABLES

PAGE
Table 1. Fire Protection Requirements for Type IA and IB High-Rise Buildings. 2
Table 2. Selected Buildings. 3
Table 3. Comparison of Reaction-to-Fire Classes of Selected Materials. 14
Table 4. Comparison of Selected Surveyed Buildings and Unsprinklered Type IB Buildings. ... 15
Table 5. Comparison of Selected Surveyed Buildings and Sprinklered Type IB Buildings. 16
Table 6. Comparison of Selected Surveyed Buildings and Type IA Buildings. 16
Table 7. Fraction of Wood Surfaces Left Exposed in Surveyed Buildings. 17
Table 8. Swedish Fire Incident Data for Wood-Frame Apartment Buildings (1994-2014). 18

LIST OF FIGURES

PAGE

Figure 1. Photographs and Architectural Renderings of the Selected Buildings. 4
Figure 2. Questionnaire Table 1: General Information Concerning the Building. 8
Figure 3. Questionnaire Table 2: Information Concerning Fire Resistance. 8
Figure 4. Questionnaire Table 3: Information Concerning Reaction-to-Fire. 9
Figure 5. Questionnaire Table 4: Information Concerning Active Fire Protection and Egress. .. 9
Figure 6. ASTM E119, ISO 834, and UL 1709 Temperature-Time Curves. 11
Figure 7. ASTM E119 Furnace Temperature Probe. 12
Figure 8. Plate Thermometer Schematic. 12

EXECUTIVE SUMMARY

This report describes the results of an expert elicitation project in support of the development of building code requirements for tall wood buildings. The following experts on fire safety of tall wood buildings were involved in the project:

- Prof. Andy Buchanan, University of Canterbury, New Zealand
- Dr. Steve Craft, CHM Fire Consultants, Canada
- Prof. Andrea Frangi, Federal Institute of Technology, Switzerland
- Dr. Birgit Östman, SP Trätek, Sweden

An international survey was conducted to obtain information about the fire protection features of existing or planned tall wood buildings in different parts of the world. A questionnaire was developed to facilitate obtaining the desired information. Responses were received for 13 buildings in 13 countries; 1 building in the U.S., 1 building in Canada, 1 building in Australia, and 10 buildings in different countries in Europe. Three of the buildings were in the planning stages when the survey was conducted. Five of the European buildings, ranging between seven and nine stories in height, are unsprinklered and would not meet IBC Type IB fire resistance requirements. Three of the remaining buildings, ranging between eight and ten stories in height, would not meet IBC Type IB fire protection requirements since they lack pressurized exit stairs. Another three of the remaining buildings, ranging between ten and twelve stories in height, would meet all IBC Type IB fire protection requirements. One of the remaining buildings, fifteen stories in height, would not meet IBC Type IA fire resistance requirements. The final building is 18 stories in height and would meet all IBC type IA fire protection requirements. The reaction-to-fire characteristics of wall and ceiling linings in Europe generally exceed the equivalent IBC Type IA and IB surface burning class requirements.

The questionnaire was supplemented with a list of five questions. From the responses to the questions it was determined that (1) seven of the thirteen projects had additional safety and/or security procedures beyond what is normal on construction sites, (2) in three buildings, two unsprinklered and one sprinklered, all primary structural members and connections are exposed, and (3) the fraction of CLT wall and ceiling surfaces left exposed ranges from 0% in one of the unsprinklered buildings to 100% in one of the sprinklered buildings.

A Swedish study collected and reviewed fire incident data for 10,000 timber-frame apartment buildings over two stories constructed in Sweden over the period of 20 years. The results of the analysis indicate that modern multi-story timber buildings for housing exhibit a lower fire incident rate than the rest of the multi-family housing stock. Future monitoring of fire incident statistics will tell whether this finding can be extended to tall wood buildings.

Based on the results of the survey and a literature review, the following needs were identified:

- More testing to evaluate mass timber fire performance during the cooling phase;
- Improvement of simplified calculation methods and detailed structural fire models to more accurately predict mass timber construction performance during cool down.
- Additional work to better predict gypsum board fall-off and CLT delamination at the glue-line.
- Additional guidance for detailing of mass timber construction.
- Further study of the contribution of wood flooring (if permitted) to the severity of a room fire.
- Further development of time-equivalence methods for application to mass timber construction.
- Research to determine how the amount of exposed wood affects fire severity and spread.
- Analysis of fire statistics to gain a better understanding of the magnitude of the fire problem in tall buildings and to better determine if and how the use of mass timber might affect it.
- Development of a fire risk assessment model to provide a rational basis for trade-offs.

1.0 INTRODUCTION

The American Wood Council (Client), located in Leesburg, Virginia, contracted with Southwest Research Institute's (SwRI's) Fire Technology Department, located in San Antonio, TX, to convene an international group of technical experts on fire safety in tall wood buildings to do the following:

1. Identify issues that need to be addressed to ensure an acceptable level of fire safety in tall wood buildings;
2. Conduct a survey of fire safety requirements for tall wood buildings in the U.S. and foreign countries;
3. Determine if, how, and up to what extent these issues have been addressed in the surveyed buildings and identify gaps in the knowledge; and
4. Develop a list of needed fire testing, modeling, risk assessment and related activities to fill the gaps.

This report describes the results of this project, which was conducted between February 22, 2016 and December 31, 2016.

2.0 PROJECT TEAM

The project team consisted of the following individuals:

- Project Manager: Karen Carpenter, PE
- Principal Investigator: Dr. Marc Janssens, FSFPE
- International Group of Experts
  - Prof. Andy Buchanan, University of Canterbury, New Zealand
  - Dr. Steve Craft, CHM Fire Consultants, Canada
  - Prof. Andrea Frangi, Federal Institute of Technology, Switzerland
  - Dr. Birgit Östman, SP Trätek, Sweden

Although the project was funded by AWC, the project team operated independently without industry direction and review.

3.0 FIRE SAFETY ISSUES IN TALL WOOD BUILDINGS

To identify fire safety issues in tall wood buildings one needs to first determine what constitutes a "fire-safe" building? In the context of performance-based codes, a building could be considered fire-safe if it is equipped with features that in the event of a fire (1) minimize fire-related injuries and prevent undue loss of life for the building occupants, emergency responders, and the public at large; (2) minimize damage to the structure, avoid local structural failure, and prevent total collapse and fire spread to neighboring property; (3) provide for continuity of operation; and (4) limit environmental impact. In case of tall wood buildings (3) and (4) are of secondary importance.

However, except for some esoteric structures in places like Las Vegas, Nevada, fire protection of buildings in the U.S. is based on compliance with prescriptive requirements. These requirements are typically met through a combination of passive and active fire protection measures. Consequently, it seems logical to require that tall wood buildings (1) meet the same passive and active fire protection requirements as tall steel and concrete structures, and (2) include additional fire protection features that are necessary to address fire safety issues unique to tall wood structures.

Depending on the building height, tall steel and concrete buildings in the United States have to meet the passive and active fire protection requirements for Type IA or Type IB construction as defined in the International Building Code (IBC). The primary fire protection requirements for these types of construction are given in Table 1. Type IB construction is limited to 12 or 11 stories, depending on whether the building is equipped with and automatic sprinkler system or not.

Table 1. Fire Protection Requirements for Type IA and IB High-Rise[a] Buildings.

	IBC Type IA		IBC Type IB	
Height (ft.)	Unlimited	420[b]	180[c]	180[d]
Stories	Unlimited	Unlimited	12	12
Total Area ($ft.^2$)	Unlimited	Unlimited	Unlimited	Unlimited
Occupancy Class	All	All	M	B, R
Fire Resistance of Columns (h)	3	3	2	1
Fire Resistance of Walls (h)	3	2	2	1
Fire Resistance of Floors (h)	2	2	2	1
Wall Surface Burning Class (Exits/Rooms)[e]	B or C[f]/C	B or C[f]/C	A or B[f]/C	B or C[f]/C
Ceiling Surface Burning Class (Exits/Rooms)[e]	B or C[f]/C	B or C[f]/C	A or B[f]/C	B or C[f]/C
Sprinklered?	Yes	Yes	Yes	Yes
Smoke Detection and Alarm?	Yes	Yes	Yes	Yes
Maximum Distance between Exit Stairs (ft.)	250	250	250	250
Pressurized Stairs?	Yes	Yes	Yes	Yes

[a] Buildings greater than 75 ft. (note: all buildings greater than 75 ft. need to be sprinklered).

[b] IBC-2015, Clause 403.2.1.1 (1) allows sprinklered Type IA buildings, 420 ft. or less in height, can have a fire resistance rating of Type IB, except columns.

[c] IBC-2015, Table 601 along with Clause 403.2.1.1 (2) allows sprinklered Type IB for Assembly, Educational, Business, Low-hazard Factory, Institutional, Residential, and Low-hazard Storage occupancies to have fire resistance ratings of Type IIA.

[d] Fire resistance requirements in IBC-2015, Table 601 apply only to High-hazard Factory, Mercantile, and High-hazard Storage occupancies. Fire resistance requirements for other occupancies are modified by Clause 403.2.1.1 (2).

[e] Per ASTM E84.

[f] Inferior class applies to R-2 use and occupancy group.

Buchanan identified the following additional issues that need to be considered for wood buildings [1]:

- Fires during construction, which is a particular problem during periods when large quantities of wood may be unprotected;
- Early fire hazard due to the potential for large areas of exposed internal wood surfaces;
- Exterior fire spread, i.e., vertical fire spread via combustible facades or cavities;
- Mechanical performance and fire containment, which may be affected by the contribution of the structural material to the severity of the fire; and
- Cleanup and restoration following burnout.

4.0 TALL WOOD BUILDING SURVEY

An international survey was conducted to obtain information about the fire protection features of existing or planned tall wood buildings in different parts of the world. Most of these features were provided to comply with fire safety regulations.

An informative survey conducted by Östman and Rydholm in 2002, and updated in 2006, provides useful information concerning the national fire regulations as it pertains to wood construction in the countries outside North America where the surveyed buildings are located [2]. Summaries of building regulations and requirements for the fire resistance cross-laminated timber (CLT) construction in Austria, France, Germany, Italy, Sweden, and Switzerland were presented at the Joint Conference of COST Actions FP1402 and FP1404 on CLT held in Stockholm, March 10-11, 2016 [3].

4.1 Survey Objectives

The primary objectives of the survey were as follows:

- Would existing or planned tall wood buildings comply with the prescriptive IBC requirements for noncombustible structures of the same height and area?
- Do these buildings have any fire safety features that go beyond the IBC requirements?
- Were any testing, modeling, or other related activities conducted to justify what would be variances from the prescriptive requirements?
- How were fire safety issues that are specific to wood construction addressed?

4.2 Selected Buildings

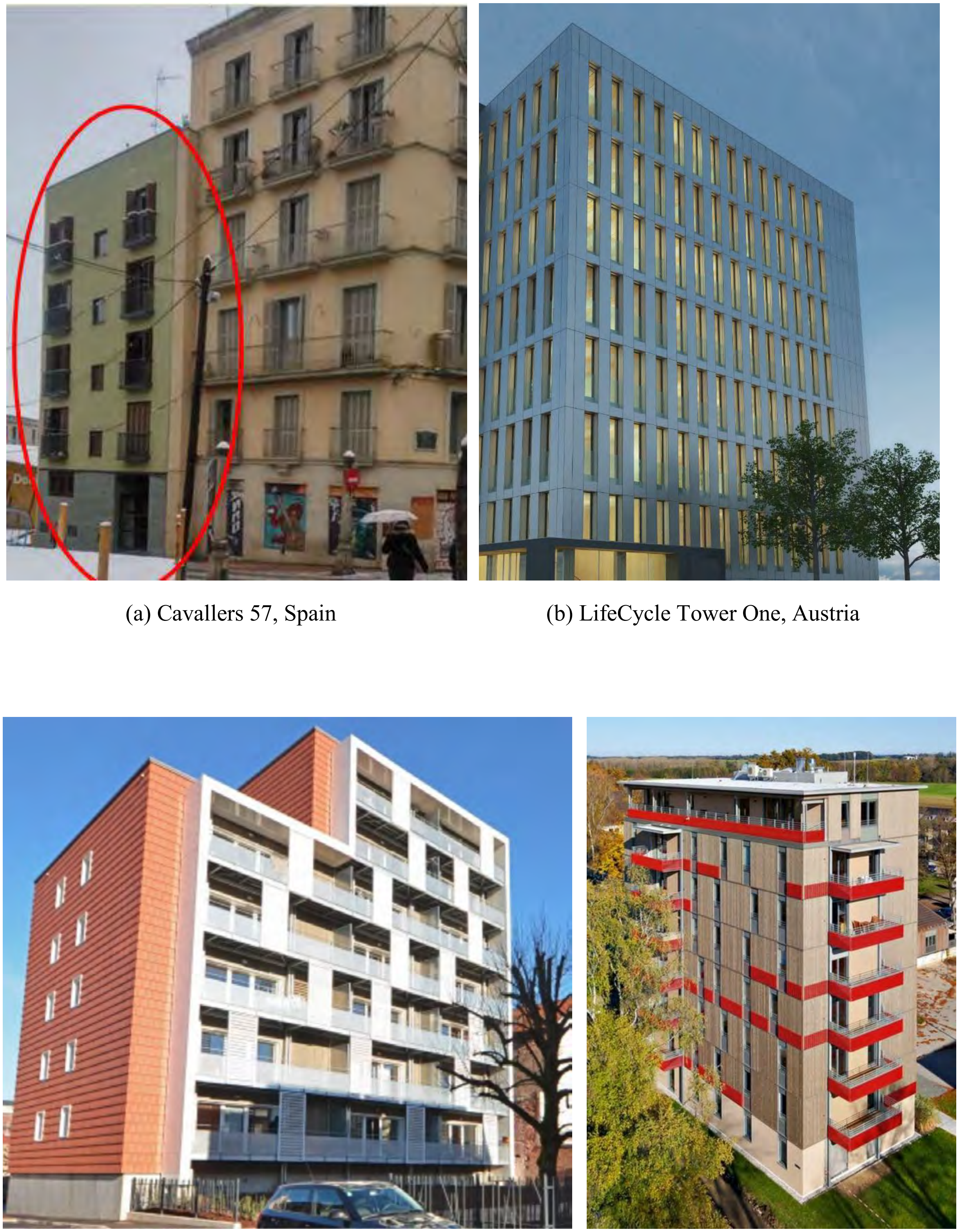
The survey includes one building in each country where tall wood buildings (>6 stories) have been constructed, are being built, or are in the advanced planning stages. If there are several tall wood buildings in a given country, preference was given to the highest building since it is likely to have more comprehensive fire protection. In addition, recent buildings were chosen over older ones as the designer may have incorporated new features or improvements as a result of lessons learned from previous experience.

The list of surveyed buildings is provided in Table 2. Three of the thirteen buildings are planned or under construction (shaded rows in Table 1). Photographs of the existing buildings and architectural renderings of the remaining buildings are shown in Figure 1.

Table 2. Selected Buildings.

Country	City	Project Name	Stories*	Year
Spain	Lleida	Cavallers 57	7/6	2014
Austria	Dornbirn	LifeCycle Tower One	8/8	2012
France	St. Dié-des-Vosges	Toit Vosgien	8/8	2013
Germany	Bad Aibling	Holz 8	8/8	2011
Italy	Milan	Cenni di Cambiamento	9/9	2013
Sweden	Växjö	Limnologen	8/7	2009
Finland	Kuokkala	Puukuokka	8/8	2014
Australia	Melbourne	Forté	10/9	2012
Switzerland	Risch-Rotkreuz	Suurstoffi	10/9	2018
UK	Hackney, London	The Cube Building	10/10	2015
USA	Portland, OR	Framework	12/12	2018
Norway	Bergen	Treet	15/14	2015
Canada	Vancouver, BC	UBC Brock Commons Phase 1	18/17	2017

*Total Stories/Timber Stories



(a) Cavallers 57, Spain (b) LifeCycle Tower One, Austria

(c) Toit Vosgien, France (d) Holz 8, Germany

Figure 1. Photographs and Architectural Renderings of the Selected Buildings.

(e) Cenni di Cambiamenti, Italy

(f) Limnologen, Sweden

(g) Puukuokka, Finland

Figure 1. Photographs and Architectural Renderings of the Selected Buildings (continued).

(h) Forté, Australia

(i) Suurstoffi, Switzerland

(j) Cube, United Kingdom

(k) Framework, United States

Figure 1. Photographs and Architectural Renderings of the Selected Buildings (continued).

(l) Treet, Norway (m) UBC Brock Commons Phase 1, Canada

Figure 1. Photographs and Architectural Renderings of the Selected Buildings (continued).

4.3 Questionnaire

A questionnaire was developed to facilitate obtaining the desired information. The questionnaire consisted of four tables and a list of five questions. The tables are reproduced in Figures 2 through 5 below. The questionnaire was in S.I. units since all surveyed buildings, except one, are located in countries that use the metric system. The tables were designed to collect the necessary information to ascertain whether the building would comply with IBC requirements for tall noncombustible buildings of Type IA or Type IB construction, and determine if and up to what extent calculation methods were used in lieu of testing to demonstrate compliance with fire safety regulations and requirements.

The tables were supplemented with the following five questions:

1. Describe any measures taken to prevent fires during building construction.
2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.
3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)
4. Are the timber connections exposed or protected? If the connections are protected, explain how.
5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

Building name:	
Street address:	
Completion date (or expected completion date):	
Building height above grade (m):	
Total number of stories:	
Number of timber stories:	
Total floor area, all stories (m^2):	
Maximum floor area per story (m^2):	
Use and occupancy:	☐ Apartments (floors: ___________) ☐ Offices (floors: ___________) ☐ Hotel rooms (floors: ___________) ☐ Shops (floors: ___________)
Structural members resisting vertical loads:	
Structural members resisting horizontal loads:	
Code compliance:	☐ Meets prescriptive requirements ☐ Prescriptive requirements with variances ☐ Meets performance-based requirements
Additional construction details:	

Figure 2. Questionnaire Table 1: General Information Concerning the Building.

Test standard used to obtain fire resistance rating:	
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☐ No ☐ Yes Reference(s):
Fire resistance rating of primary structural frame:	
Fire resistance rating of exterior loadbearing walls:	
Fire resistance rating of interior loadbearing walls:	
Fire resistance rating of exterior non-bearing walls:	
Fire resistance rating of interior non-bearing walls:	
Fire resistance rating of floor construction and associated secondary members:	
Fire resistance rating of roof construction and associated secondary members:	

Figure 3. Questionnaire Table 2: Information Concerning Fire Resistance.

Reaction-to-fire test standard to qualify wall coverings:	
Class required for wall coverings in interior exit stairs:	
Class required for wall coverings in exit corridors:	
Class required for wall coverings in rooms:	
Reaction-to-fire test standard to qualify ceiling linings:	
Class required for ceiling linings in interior exit stairs:	
Class required for ceiling linings in exit corridors:	
Class required for ceiling linings in rooms:	
Reaction-to-fire test standard to qualify floor coverings:	
Class required for floor coverings in interior exit stairs:	
Class required for floor coverings in exit corridors:	
Class required for floor coverings in rooms:	
Fire test standard(s) to qualify exterior claddings:	
Classification of the exterior cladding(s) used:	
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☐ No ☐ Yes Reference(s):

Figure 4. Questionnaire Table 3: Information Concerning Reaction-to-Fire.

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☐ No ☐ Yes Standard:
Is the building required to be sprinklered?	☐ No ☐ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	
Does adding sprinklers allow for an increase in the height and/or area of the building?	☐ No ☐ Yes (height, area, or both)
Is the building equipped with smoke detectors?	☐ No ☐ Yes
Is the building equipped with a fire alarm system?	☐ No ☐ Yes
Does the building have an emergency voice system?	☐ No ☐ Yes
Number of exit stairs:	
Maximum distance between exit stairs (m):	
Are exit stairs pressurized (smoke-free)?	☐ No ☐ Yes

Figure 5. Questionnaire Table 4: Information Concerning Active Fire Protection and Egress.

4.4 Comparison of Standard Test Methods

To compare the passive fire protection requirements between different countries, it is helpful to briefly review the fire test methods and classification systems that are used where the surveyed buildings are located. Fire resistance of structural elements and assemblies is discussed first. This is followed by an overview of test methods and classification systems to control the reaction-to-fire of interior finish materials. The term “reaction-to-fire” is not very common in North America, and terms such as “non-combustibility” and “surface burning” are used instead.

4.4.1 Fire Resistance

The primary fire resistance test standards that are used in the countries where the surveyed buildings are located are listed below:

- North America
    - United States: ASTM E119
    - Canada: ULC S101
- Other countries
    - Europe: EN-1363 Part 1
    - Australia: AS/NZS 1530-4

The European and Australian fire resistance tests standards are based on ISO 834. Conceptually, these test methods are all very similar. Wall and floor/ceiling assemblies, roof structures, doors, windows, etc., are mounted in a vertical or horizontal frame. The frame is placed against an open wall furnace or on top of an open ceiling furnace, and is exposed to a standard fire. Structural members such as beams and columns are (partially) immersed in the furnace environment.

Fires can spread from the fire compartment to a neighboring compartment if the heat transfer results in a temperature rise that is high enough to ignite common combustibles on the side not exposed to the fire, or if cracks develop that allow the passage of flames and hot gases. End-point criteria for separating non-load-bearing assemblies in fire resistance furnace tests are therefore based on heat transmission (I) and integrity (E). Heat transmission is measured with a number of thermocouples attached to and distributed over the unexposed side of the test specimen. The end-point criteria for heat transmission are exceeded when the temperature rise of the thermocouples, either on average or individually, reaches a specified limit. The average and single point temperature rise limits are 250 °F (139 °C) and 325°F (181 °C) in the North American fire resistance test standards, and nearly the same (140 °C and 180 °C, respectively) in the tests that are used in other parts of the world. The integrity of an assembly is maintained as long as there is no passage of flames and gases hot enough to ignite cotton waste on the unexposed side. Fires can also spread when load-bearing assemblies or structural members cease to support the load. Fire resistance furnace tests on load-bearing assemblies and structural members therefore also determine whether the test specimen is capable of supporting the applied load for a specified duration (R). The time when the first applicable end-point is reached in an ASTM E119 or ULC S101 test determines the fire resistance rating of the assembly or structural element and is reported to the nearest minute. Outside North America, the ratings are reported for each applicable end point, i.e., R, E, and I, respectively.

The fire resistance test standards used in North America prescribe a supplementary hose stream test procedure to evaluate the ability of the construction to resist disintegration under adverse conditions. The hose stream test is either performed after termination of the furnace test, or on a duplicate specimen that has been exposed to the standard fire for half the duration of the desired fire resistance classification. A hose stream test is not required for columns, floor/ceiling assemblies, and roof structures; wall assemblies with a fire resistance rating of less than 1 h; and 20-min rated door assemblies. The hose stream requirement is unique to North America.

The fire resistance of a building element is a function of the severity of the fire. To provide a uniform basis for measuring the fire resistance in the laboratory, a number of standard fires have been defined. These standard fires are expressed in the form of a furnace temperature-time curve. Figure 6 shows the standard temperature-time curves for tests conducted according to ASTM E119 and ISO 834. The former is identical to that specified in ULC S101, while the latter is the same as the curve specified in the European and Australian fire resistance test standards. These curves are representative of a compartment fire involving typical building contents. The third temperature-time curve shown in Figure 6 is specified in the UL 1709 standard. This curve initially rises at a faster rate and is representative of a liquid hydrocarbon fuel fire. The UL 1709 curve will be referred to later.

Based on Figure 6 one would conclude that ISO 834 is slightly more severe than ASTM E119. However, the severity of the test is not only a function of the temperature-time curve but also depends on how the furnace temperature is measured. The ASTM E119 furnace temperature probe consists of 14, 16 or 18-ga Type K thermocouple wires in a porcelain insulator, located inside an Inconel pipe (see Figure 7). The time constant of the thermocouple assembly is between 5.0 and 7.2 min.

The ISO 834-based test standard prescribes the use of plate thermometers to control the furnace temperature-time curve. A schematic of the plate thermometer is shown in Figure 8. Plate thermometers respond significantly faster than the shielded thermocouples specified in ASTM E119 (response time less than one minute). The net result is that ASTM E119 is more severe than ISO 834, in particular during the first 10 minutes of a test [4]. Consequently, the North American fire resistance test standards are actually slightly more severe than the ISO 834-based standards during the first 10 minutes of the test. Based on the consistency of charring rate data for wood obtained in different parts of the world, the differences between the temperature sensors that are used to control the furnace appears to compensate for the variation in the temperature-time curve.

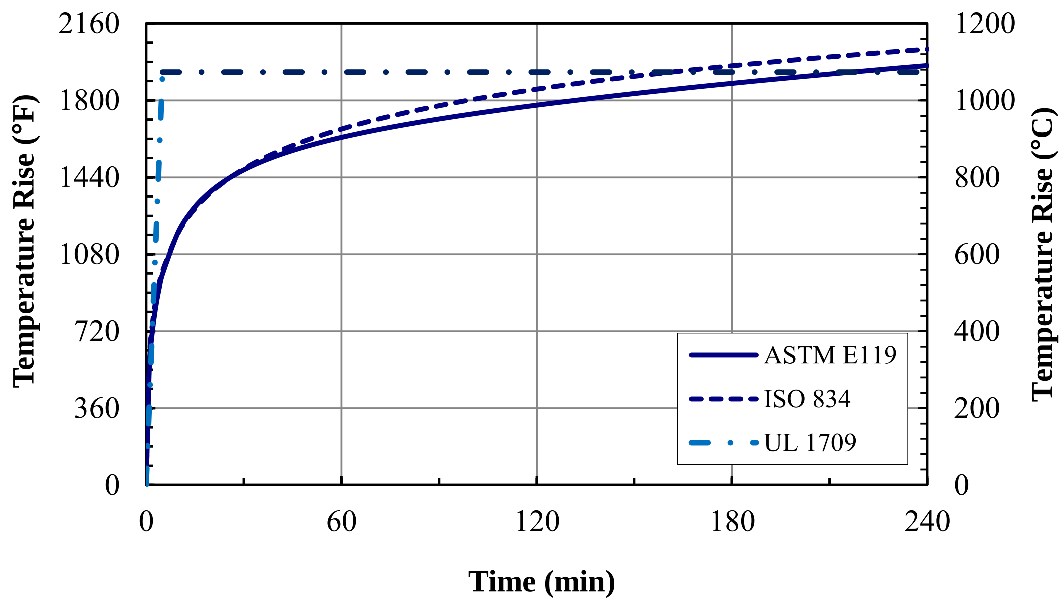


Figure 6. ASTM E119, ISO 834, and UL 1709 Temperature-Time Curves.

Figure 7. ASTM E119 Furnace Temperature Probe.

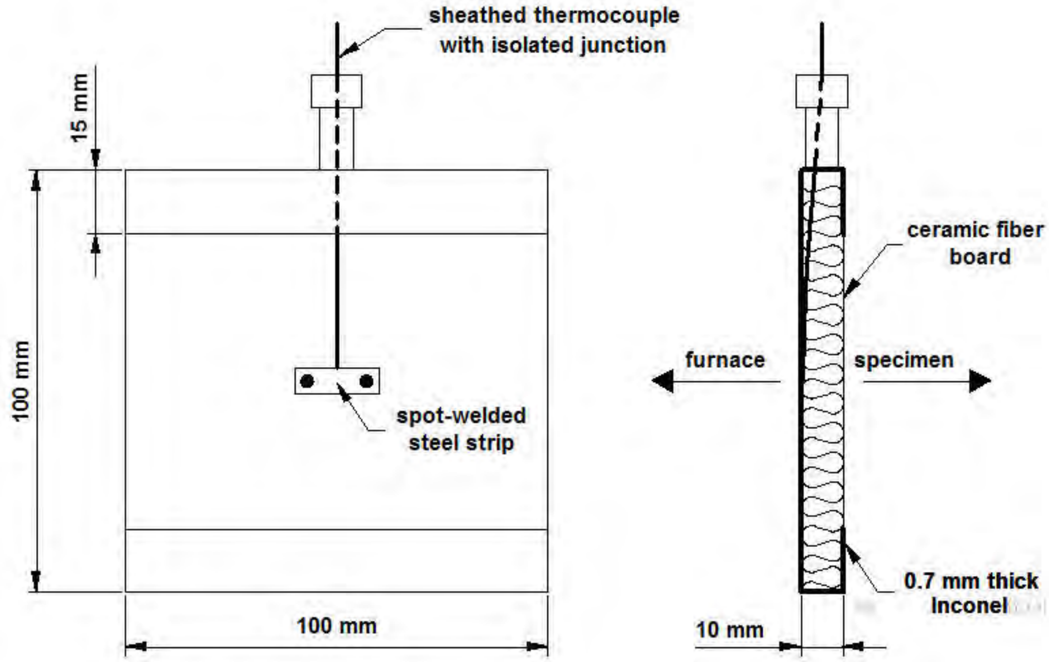


Figure 8. Plate Thermometer Schematic.

It can be concluded that fire resistance ratings obtained in various parts of the world are essentially equivalent. It should be noted that the additional hose stream requirement in North America generally does not present a problem for assemblies used in tall wood buildings, and, therefore, does not make it more difficult for mass timber walls and ceilings to obtain a specified fire resistance rating in North America compared to other parts of the world.

4.4.2 Reaction-to-Fire ("Surface Burning Characteristics" in North America)

North America

The Steiner tunnel test is the primary test method for evaluating the surface burning characteristics of interior finish materials in the United States. The method is described in ASTM E84. The apparatus, consists of a tunnel-like enclosure measuring 25 × 1½ × 1 ft. The test specimen is 24-ft long and 20-in. wide and is mounted in the ceiling position. It is exposed at one end, designated as the burner end, to a 79-kW gas burner. There is a forced draft through the tunnel from the burner end with an average initial air velocity of 240 ft./min. The measurements consist of flame spread over the surface and smoke obscuration in the exhaust duct of the tunnel test apparatus. Test duration is 10 min.

A flame spread index (FSI) is calculated on the basis of the area under the curve of flame tip location versus time. The FSI is 0 for an inert board, and is normalized to approximately 100 for red oak flooring. A smoke developed index (SDI) is calculated on the basis of the area under the light obscuration vs. time curve normalized to the area for red oak flooring, which by definition has an SDI of 100.

The classification of interior finish materials in the U.S. model building codes is based on the FSI and SDI. There are three classes: Class A for products with FSI ≤ 25, Class B for products with 25 < FSI ≤ 75, and Class C for products with 75 < FSI ≤ 200. In all cases the SDI must be 450 or less. Class A products are generally permitted in enclosed vertical exits. Class B products can be used in exit access corridors and Class C products are allowed in other rooms and areas.

The National Building Code of Canada refers to a variation of the Steiner tunnel test described in ULC S102. The differences in the test apparatus result in a lower flame spread index for Class C materials. To account for this, the upper FSI limit for Class C is reduced to 150.

Europe

The Single Burning Item (SBI) test is the primary test method for evaluating the reaction-to-fire of wall linings and ceiling materials in Europe. The test method is described in European standard EN 13823. Two specimens of the material to be tested are positioned in a specimen holder frame at a 90° angle to form an open corner section. Both specimens are 60 in. high. One specimen is 40 in. wide, and is referred to as the long wing. The other specimen is 20 in. wide and is referred to as the short wing. During a test, the specimen is exposed for 20 min to the flame of a triangular diffusion propane gas burner operating at 30 kW. The products of combustion are collected in a hood, and are extracted through an exhaust duct. Instrumentation is provided in the duct to measure temperature, velocity, gas composition (oxygen, carbon dioxide and carbon monoxide concentrations) and light obscuration. The velocity and gas composition data are used to determine heat release rate on the basis of the oxygen consumption technique. Smoke production rate is determined based on the measured flow rate and light obscuration in the duct. During the test observations are made of lateral flame spread over the specimen surface and the presence of flaming droplets or particles.

The European reaction-to-fire classification system for construction products is described in European Standard EN 13501-1. Classification of construction products except floor coverings in Euroclasses A2, B, C, and D is primarily based on the fire growth rating (FIGRA), total heat released over the first 10 min of the test, and lateral flame spread across the long wing specimen measured in the SBI. The FIGRA is equal to the maximum value of (heat release rate)/(elapsed time). Euroclass A2 materials are of limited combustibility and have to meet additional requirements based on performance in tests conducted according to EN ISO 1182 (non-combustibility test) or EN ISO 1716 (oxygen bomb calorimeter). Euroclass B, C and D materials have to meet additional requirements based on performance in tests performed according to EN ISO 11925-2 (small open flame test).

Australia

Requirements for the reaction-to-fire of interior finish materials in the Building Code of Australia (BCA) are based on performance in the AS ISO 9705 room corner test. The AS ISO 9705 test apparatus consists of a room measuring approximately 12-ft deep by 8-ft wide by 8-ft high, with a single v open doorway measuring approximately 32 in. wide by 80 in. high in the front wall. In the standard configuration the interior surfaces of all walls (except the front wall) and the ceiling are covered with the material being evaluated. The material is exposed to a propane burner ignition source located on the floor in one of the rear corners of the room opposite the doorway.

At the start of a test, the propane gas burner is ignited and the material is exposed to a 100-kW flame. After 10 min of exposure to 100 kW, the gas flow to the burner is increased to a heat release rate of 300 kW and maintained at that level for an additional 10 min.

The products of combustion emerging through the doorway are collected in a hood and extracted through an exhaust duct by a fan. The primary measurements are heat release rate and smoke production rate in the exhaust duct, and heat flux to the floor in the room. The test is generally terminated shortly after flashover. The BCA classifies interior finish materials into four groups based on the assumption that flashover occurs when the heat release rate measured in the exhaust duct reaches 1 MW:

- Group 1: No flashover in 20 min (300 kW fire)
- Group 2: Flashover 10-20 min (300 kW fire)
- Group 3: Flashover 2-10 min (100 kW fire)
- Group 4: Flashover 0-2 min (100 kW fire)

Group 1 materials can be used anywhere in the building. Group 2 materials are not allowed in fire exits. Group 3 materials can be used in many areas, in particular if the building is sprinklered. Group 4 materials are not permitted.

Comparison of Reaction-to-Fire and Surface Burning Classes of Selected Materials

Table 2 compares the reaction-to-fire and surface burning classes for selected interior finish materials that are specified in the building codes and regulations of the countries where the surveyed buildings are located.

Table 3. Comparison of Reaction-to-Fire Classes of Selected Materials.

Material	North America	Europe	Australia
Gypsum Board	NC[a]	A2 or B[c]	Group 1
FR-treated Wood	A	B	Group 2
Untreated Wood	B or C[b]	D	Group 3

[a] Gypsum board is considered noncombustible in the U.S. model building codes.
[b] Softwoods are Class B. With a few exceptions, other wood products are Class C.
[c] Gypsum board with thin paper is Class A2, and with thick paper is Class B.

4.5 Tall Wood Building Survey Results

4.5.1 Summary of Survey Results

Selected survey results are presented in the next three tables. The surveyed buildings are organized in three groups; unsprinklered buildings with less than 12 stories, sprinklered buildings 12 stories or less, and sprinklered buildings with more than 12 stories. The fire protection features of these buildings are compared for unsprinklered IBC Type IB buildings, sprinklered Type IB buildings, and IA buildings, respectively. Buildings features that exceed the IBC requirements are highlighted in green, while those that do not meet the requirements for the corresponding IBC type are in red.

Table 4. Comparison of Selected Surveyed Buildings and Unsprinklered Type IB Buildings.

	IBC Type IB Unsprinklered	Cavallers 57 Spain	LifeCycle Tower One	Toit Vosgien France	Holz 8 Germany	Cenni di Cambiamento
Height (ft)	75	61	**89**	**79**	**82**	**89**
Stories[a]	11/None	8/8	8/8	8/8	8/8	9/9
Use and Occupancy	B, R	1B+5R-2	B	R-2	2B+6R-2	R-2
Total Floor Area (ft^2)	Unlimited	10118	24972	29138	18740	100684
Fire Resistance of Columns (hr)	2	**1[d]**	**1.5**	**1[d]**	**1.5[d]**	**1[d]**
Fire Resistance of Floors (hr)	2	**1[d]**	**1.5**	**1[d]**	**1.5[d]**	**1[d]**
Wall Surface Burning (Exits/Rooms)	US A or B[b]/C	EUR B/**C**	EUR **A**/D	EUR **A**/D	EUR **A1/A2**	EUR **A2/A2**
Ceiling Surface Burning (Exits/Rooms)	US A or B[b]/C	EUR B/**C**	EUR **A**/D	EUR **A**/D	EUR **A1/A2**	EUR **A2/A2**
Sprinklered?	No	No	No	No	No	No
Smoke Detection and Alarm?	Yes	**No**	**No**	Yes	Yes	**No**
Number of Exit Stairs	≥2	**1**	**1**	**1**	**1**	**1**
Max. Distance between Exit Stairs (ft)	200	-	-	-	-	-
Pressurized Stairs?	Yes[c]	No	**No**	Yes	**No**	**No**

[a] # of stories/# of timber stories
[b] Class C applies to R-2 occupancies
[c] Exit stairways serving floors above 75 ft. shall be "smokeproof"
[d] Established through combination of testing and calculation (Eurocode 5)

Table 5. Comparison of Selected Surveyed Buildings and Sprinklered Type IB Buildings.

	IBC Type IB Sprinklered	Limnologen Sweden	Pukuokka Finland	Forté Australia	Suurstoffi Switzerland	The Cube UK	Framework USA
Height (ft)	180	79	79	102	118	98	144
Stories[a]	12	8/7	8/8	10/9	10/9	10/10	12/12
Use and Occupancy	B, R	R-2	R-2	1M+9R-2	B	R-2	7B+5R-2
Total Floor Area (ft^2)	Unlimited	37243	66916	25941	164257	NR[i]	NR[i]
Fire Resistance of Columns (hr)	1[b]	**1.5**	1[e]	**1.5**	1[e]	**1.5**[e]	**2**
Fire Resistance of Floors (hr)	1[b]	1	1[e]	**1.5**	1[e]	**1.5**[e]	**2**
Wall Surface Burning (Exits/Rooms)	US B or C[c]/C	EUR **B/C**	EUR **A2**/D	AUS G1	EUR **A2**/D	NR[i]	US B/C
Ceiling Surface Burning (Exits/Rooms)	US B or C[c]/C	EUR **B/B**	EUR **A2**/D	AUS G1[g]	EUR **A2**/D	NR[i]	US B/C
Sprinklered?	Yes	Yes	Yes	Yes	Yes[h]	Yes	Yes
Smoke Detection and Alarm?	Yes	Yes	Yes	Yes	Yes	NR[i]	Yes
Number of Exit Stairs	≥2	2	1+1[f]	1	2	NR[i]	2
Max. Distance between Exit Stairs (ft)	250	33	-	-	92	NR[i]	43
Pressurized Stairs?	Yes[d]	**No**	**No**	**No**	Yes	NR[i]	Yes

[a] # of stories/# of timber stories
[b] 2 h for Mercantile occupancies
[c] Inferior class applies to R-2 use and occupancy group
[d] Exit stairways serving floors above 75 ft. shall be "smokeproof"
[e] (Partly) established through calculation (Eurocode 5)
[f] Exit stairs and additional egress path (rescue from balcony)
[g] One side of one wall in each apartment can be G3 (wood)
[h] Sprinklers can be used to reduce fire resistance by 0.5 hr
[i] Not reported

Table 6. Comparison of Selected Surveyed Buildings and Type IA Buildings.

	IBC Type IA	Treet Norway	UBC Canada
Height (ft)	420	173	174
Stories[a]	Unlimited	15/14	18/17
Use and Occupancy	All	R-2	R-2
Total Floor Area (ft^2)	Unlimited	62754	162697
Fire Resistance of Columns (hr)	3	**1.5**[c]	2[d]
Fire Resistance of Floors (hr)	2	**1**	2
Wall Surface Burning (Exits/Rooms)	US B or C[b]/C	EUR B/D	ULC A/C
Ceiling Surface Burning (Exits/Rooms)	US B or C[b]/C	EUR B/D	ULC A/C
Sprinklered?	Yes	Yes	Yes
Smoke Detection and Alarm?	Yes	Yes	Yes
Number of Exit Stairs	≥2	2	2
Max. Distance between Exit Stairs (ft)	250	33	82
Pressurized Stairs?	Yes	Yes	Yes

[a] # of stories/# of timber stories
[b] Inferior class applies to R-2 use and occupancy group
[c] (Partly) established through calculation (Eurocode 5 or similar)
[d] Primary framing members fully encapsulated in 3-4 layers 5/8 in. Type X GB

The following observations can be made based on the results of the survey:

- None of the unsprinklered buildings meet the IBC Type IB fire safety requirements.
- Two sprinklered buildings (Limnologen and Puukuokka) do not meet the Type IB requirements only because the exit stairs are not smoke-proof.
- One sprinklered building (Treet) does not meet Type IA requirements because the fire resistance rating of the loadbearing frame, walls, and floors is inadequate.
- The reaction-to-fire characteristics of walls and floors in the European buildings generally exceed the equivalent IBC surface burning requirements.
- Structural fire protection of most European buildings is demonstrated through calculation with little or no testing.

4.5.2 Summary of Additional Information Obtained

The information that was obtained as a result of the responses to the additional questions can be summarized as follows:

- The presence of large amounts of unprotected mass timber at tall wood building construction sites poses increased risk for large fires. Seven of the thirteen projects had additional safety and/or security procedures beyond what is normal on construction sites. Guidelines for fire safety at mass timber construction sites in New Zealand can be found in Appendix B. Guidelines for construction sites in the UK are discussed in Hopkin et al.[5]
- In two projects CLT panels were lined with gypsum board prior to or during building construction; Holz 8 and UBC.
- All primary structural members and connections are exposed in 3 buildings: LifeCycle Tower One, Toit Vosgien, and Suurstoffi; only the latter is sprinklered.
- The fraction of wall and ceiling surfaces left exposed varied widely from 0% in Cenni di Cambiamento, almost 0% in Limnologen and UBC, to 100% in Suurstoffi. Additional details are provided in Table 7.

Table 7. Fraction of Wood Surfaces Left Exposed in Surveyed Buildings.

Country	Project Name	Exposed Wood
Spain	Cavallers 57	The ceiling of the bedrooms and dining rooms
Austria	LifeCycle Tower One	All primary framing members (glulam posts and beams)
France	Toit Vosgien	About 2/3 of wood surfaces, incl. framing members and most connections
Germany	Holz 8	CLT in the living rooms, and wood laminate flooring in all flats and offices
Italy	Cenni di Cambiamento	Nothing left exposed
Sweden	Limnologen	Negligible
Finland	Puukuokka	Laminated floors, ceiling surfaces, window frames (based on pictures)
Australia	Forté	One side of one wall in each apartment
Switzerland	Suurstoffi	Primary glulam framing members; floor, wall and ceiling surfaces
UK	The Cube Building	Facade and balconies, laminated wood floors inside (based on pictures)
USA	Framework	Offices: ~40% of underside of floor and beams, ~80% of columns .Apartments: ~30% of underside of floor, ~20% of beams and columns
Norway	Treet	CLT panels, glulam beams and columns (coated with fire protective paint)
Canada	UBC Brock Commons	Nothing left exposed, except walls in top floor lounge.

4.6 Swedish Fire Incident Data Study

Although at this time it is not possible to evaluate the effect of the use of mass timber on fire statistics in tall buildings due to the lack of incident data, a recent study conducted in Sweden may provide some insight [6]. The study collected and reviewed fire incident data for 10,000 timber-frame apartment buildings over two stories constructed in Sweden over the period between 1994, when the building code became performance-based, and 2014. The results of the analysis are summarized in Table 8. The first row gives the total number of fire incidents for all apartment buildings with more than 2 stories, and the number of incidents broken down according to the extent of fire damage. The values in the second row are equal to those in the first row apportioned based on the number of wood-frame apartment buildings. The actual values in the third row are based on the fire incident statistics. Table 8 indicates that modern multi-story timber buildings for housing exhibit a lower fire incident rate than the rest of the multi-family housing stock. Only one fire was reported for which the wood framing was a contributing factor to fire spread. The building was a student dormitory, which had code violations that were not caught during the initial inspection and had to be demolished.

Table 8. Swedish Fire Incident Data for Wood-Frame Apartment Buildings (1994-2014).

	# of Fire Incidents	Extent of Fire Damage					
		Ignition Source	Room of Origin	Appartment	Building	Other Building(s)	Unknown
Total for all apartments with more than 2 stories	48949	32386	11160	3865	1347	84	107
Expected for wood-frame apartments with more than 2 stories	73	48	17	6	2	0.1	0.2
Actual for wood-frame apartments with more than 2 stories	22	12	7	1	2	0	0

5.0 NEEDS FOR ADDITIONAL TESTING, MODELING, AND RELATED ACTIVITIES

This section contains an extensive number of citations of references that are included in the bibliography in Appendix C. Appendix D is a list of the same references arranged by topic.

5.1 Needs Identified in the Literature

Over the past few decades several papers and reports have been published that provide a detailed discussion of the fire safety challenges of tall wood buildings [1, 7-15]. To meet the challenges many of those publication identified specific needs for research, testing, and other activities. For example, a recent white paper on fire resistance of timber buildings [14] reviewed relevant work and compiled the following prioritized list of needs:

1. Agreement on relevant design fires (parametric fires) to be used for the structural fire performance of buildings – these should be the same for all structural materials.
2. Determine the contribution of massive timber elements (e.g. CLT) to fire severity for non-standard fire exposure.

3. Determine charring rates as a function of fire exposure (design fires) – does not need large scale facilities.
4. Determine conditions for self-extinguishment of charred wood, and tests to compare the relative performance of different species and products.
5. Determine the performance of timber elements with non-combustible construction, including the fall-off times of protective boards for non-standard fire exposure.
6. Determine the performance of different types of connections for non-standard fire exposure.
7. Determine the relevant fire exposure conditions for different types of fire stops in voids in timber structures.
8. Determine the influence of wooden façade claddings on the exterior fire spread of multi-story buildings with flames coming out from a broken window after flashover in an apartment.
9. Determine the influence of passive (e.g. non-combustible claddings) and active (e.g. sprinkler) fire protection on the items above.

Although these needs are certainly relevant, some may be of lower or higher priority based on how they support the introduction of tall wood buildings in the IBC. Moreover, other issues not specifically related to fire resistance may have to be addressed also. The following sections aim at developing a revised list of needed fire testing, modeling, risk assessment and related activities to fill the gaps in our knowledge to address fire safety challenges in tall wood buildings.

5.2 Compliance with Prescriptive Code Requirements for Fire Resistance

Prescriptive fire resistance code requirements can be met through furnace testing, simplified calculation methods or detailed structural fire modeling.

5.2.1 Standard Fire Resistance Furnace Testing

An impressive amount of standard fire resistance furnace test results have been published in the literature. This includes data for mass timber (CLT, glulam, LVL, etc.) members[16-45], connections[46-63], and protective membranes[64-82]. Several publications address gypsum board fall-off[67, 70, 75-77, 83-85], which is an important aspect of its performance and ability to protect the underlying mass timber structure. Although there will always be a need for standard fire resistance testing to evaluate new materials and techniques or address project-specific concerns, the existing database of fire resistance test results has been used to develop simplified calculation methods that will greatly alleviate this need. One issue that may require more attention is the performance of massive timber members during the cooling phase in a fire, as standard fire resistance tests do not include it and available test data is very limited[37, 44, 45].

5.2.2 Simplified Calculation Methods

Simplified methods to calculate the fire resistance of mass timber members, unprotected as well as protected, are based on an estimate of the residual load-bearing cross section as a function of time. This section is (usually, but not always conservatively) determined based on an assumed charring rate, which may be constant or vary with time, and zero strength layer. The development and validation of reduced cross-section methods are documented in detail in the literature[22, 24, 28, 29, 34, 40, 42, 86-100]. Simplified methods for connections either consist of design rules derived from experimental data, or rely on providing adequate protection to the fasteners. Although simplified calculation methods are well established, adjustments may be needed for new materials and construction techniques, or to address applications outside the validation range of the method. Needs pertaining to charring rate estimates and the effect of a protective membrane are discussed in section 5.4. Guidance for detailing of mass timber construction has received relatively little attention[101, 102] and could also be improved.

5.2.3 Detailed Structural Fire Modeling

Detailed structural fire models can be used as an alternative to simplified calculation methods to evaluate the performance of unprotected or protected mass timber structures under standard fire conditions[34, 45, 56, 57, 69, 103-113]. These models calculate the heat transfer through and thermal degradation of the protective membrane, if present, and the massive timber elements and connections. Some also evaluate the mechanical performance of the structure. The primary input data for the models consist of the thermos-physical and mechanical properties of the constituent materials. These properties are relatively well known, but strictly speaking only valid for standard fire exposure[81, 84, 103, 114-131]. However, there is a need for additional work to better model changes in the geometry, e.g., due to gypsum board and char layer fall-off.

5.3 Performance-Based Assessment

Compliance with performance-based code requirements and justification for a variance from prescriptive code requirements often requires the evaluation of a mass timber structure in real fires, i.e., under natural (or non-standard) thermal exposure conditions. As with standard fire exposure, this can be accomplished through testing,

5.3.1 Custom Fire Testing

Although custom furnace tests with natural fire exposure have been conducted[41, 45, 73, 132], natural fire tests in a compartment are far more common[45, 79, 133-147]. In compartment fire tests the structure is generally not subjected to load, and the primary purpose of these tests is to assess the contribution of exposed mass timber to the severity of the fire. The focus is hereby on wall and ceiling surfaces. Only one set of room fire tests was found in which the performance of floor assemblies exposed to a fire from above was evaluated[148]. The contribution of wood flooring to the severity of a room fire is a potential topic for further study.

5.3.2 Simplified Calculation Methods

Simplified calculation methods can be used for natural fires by adjusting the charring rate to account for the modified thermal exposure conditions. Another simplified approach involves the use of time-equivalence methods to linking performance in a real fire to that in the standard fire. The equivalent time is based on (1) equal areas under the temperature-time curve[149], or (2) equal temperatures at a critical part of the structure[150-152], or (3) equivalent normalized heat load[153]. Time-equivalence methods are well established for steel and concrete structures, but present some challenges when applied to mass timber structures[154-159].

5.3.3 Detailed Fire Modeling

Structural fire models that are used to evaluate the performance of unprotected or protected mass timber structures under standard fire exposures can also be used for real fires. However, if the thermos-physical and mechanical properties are expressed as a function of temperature, as for example in Eurocode 5, adjustments to the input data are needed to model the cooling phase[45, 120]. This is because the thermal degradation process is not reversible. Moreover, the material properties in Eurocode 5 were developed based on data for the standard fire, and adjustments are needed to model performance of mass timber structures under natural fire exposure. Finally, the boundary conditions for the model need to be modified so that they are consistent with the thermal exposure conditions in the compartment fire. The latter can be estimated from closed-form compartment fire temperature equations or from zone or field compartment fire model calculations.

5.4 Charring Rate of Mass Timber

The charring rate of wood in general and more recently that of mass timber in particular, unprotected or protected, has been studied extensively[16, 20, 21, 160-176]. The charring rate of wood can generally be predicted with sufficient accuracy for engineering calculations, and the effect of material properties and environmental factors is well known. However, the charring rate is very sensitive to abrupt changes in the thermal exposure of uncharred wood, e.g., due to gypsum board and char fall-off or delamination of CLT. Although gypsum board and char fall-off, and delamination of CLT are now well understood, more work may be needed to accurately model these phenomena as new types of gypsum board and mass timber adhesives are being developed and used. A related question is how the number and size of gaps between boards affect the fire resistance of CLT panels and the charring rate used in simplified design calculations.

5.5 Contribution of Exposed Wood

Architects prefer to leave wood surfaces exposed for esthetic reasons, while fire protection engineers want to protect them with gypsum board to control the fire growth and decay. Consequently it is important to understand how the amount of exposed wood may affect fire safety. Involvement of large wood surfaces is likely to increase the severity of the fire, i.e., gas temperature (if the fire is not ventilation-controlled) and fire duration. This was observed in room fire tests conducted with different amounts of exposed CLT[136, 138, 140, 141, 144-147]. If the fire is ventilation controlled, more fuel makes it more likely to spread to adjacent rooms. The excess pyrolyzate may also result in a larger flame emerging from a window, which may accelerate flame spread over the façade and facilitate fire spread to adjacent structures. Although much research has been done on fire testing of exterior walls and modeling of façade fires[177-188] and fire spread to exposed structures[185, 189-192], the effect of using more exposed wood is not entirely clear.

5.6 Trade-offs and Equivalence

The IBC allows an extra story or a reduction of the fire resistance requirements by one hour in Type IB buildings that are sprinklered. This type of trade-off can be justified on the basis of a risk assessment[193]. The same approach could be used to justify the use of mass timber in tall buildings. Fire risk assessment models have been developed and used to evaluate the impact of the type of construction, use of sprinklers, proximity of the fire department, etc.[185, 194-202] However, there are no fire risk assessment models readily available to evaluate the effect of using mass timber in tall buildings on life safety of building occupants and first responders, and on property losses. Fire safety analysis experience from the nuclear industry could be used to develop such a risk assessment model. The probabilistic risk assessment models used in nuclear power plants are based on a Bayesian approach[203]. To support the development of such a model a detailed analysis is needed of the fire incident statistics for tall buildings and pertinent occupancies.

5.7 Detailing

Additional guidance is needed for detailing of mass timber construction. For example, detailing the installation of fire-rated doors or fire dampers in solid wood walls presents some challenges. While fire resistance testing of penetration firestop systems installed in mass timber walls and floors is relatively straightforward, it is hard to justify testing a set of doors in a solid wood wall just to verify the attachment. Another example is the treatment of small combustible concealed spaces. Is a 25-mm gap acceptable, or can it be 50 mm before insulation is needed to fill the gap and prevent fire propagation in the space?

6.0 CONCLUSIONS

The expert elicitation process described in this report identified the following needs and resulted in the following recommendations:

- More testing is needed to evaluate the performance of mass timber elements during the cooling phase of a fire;
- Simplified calculation methods and detailed structural fire models should be enhanced to more accurately account for mass timber construction performance during the cooling phase;
- Additional work is required to more reliably predict and better account for gypsum board fall-off and delamination at the glue-line;
- Additional guidance is needed for detailing of mass timber construction;
- The contribution of wood flooring to the severity of a room fire requires further study;
- Further development is needed of time-equivalence methods so that they can be applied to mass timber construction;
- More work is needed to determine how the amount of exposed wood affects the severity of the fire in the room of origin, and the fire spread to adjacent rooms, over the façade, and to other structures;
- It is proposed to perform an analysis of fire incident statistics to gain a better understanding of the magnitude of the fire problem in tall buildings and to better determine how the use of mass timber might affect it; and
- It is suggested to develop a fire risk assessment model (or adapt an existing model) to provide a rational basis for trade-offs and equivalence.

APPENDIX A

QUESTIONNAIRE RESPONSES

(CONSISTING OF 66 PAGES)

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	Cavallers 57
Street address:	Carrer cavallers 57 Lleida 25002-Spain-
Completion date (or expected completion date):	2014
Building height above grade (m):	18,50 m.
Total number of stories:	7
Number of timber stories:	6
Total floor area, all stories (m^2):	940 m2
Maximum floor area per story (m^2):	140,89 m2
Use and occupancy:	x Apartments (floors: 6) ☒ Offices (floors: 1) ☐ Hotel rooms (floors:) ☐ Shops (floors:)
Structural members resisting vertical loads:	CLT(contralaminated Timber) vertical walls acting as diafragmas al together with the central elevator tower.
Structural members resisting horizontal loads:	CLT(Contralaminated Timber) floors linked to the walls with framed steel squares and screws between them. There's a metallic beam linking the vertical elevator tower to all the floors.
Code compliance:	x Meets prescriptive requirements ☐ Prescriptive requirements with variances ☐ Meets performance-based requirements
Additional construction details:	

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	EN 1995-1-2
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	xNo ☐Yes Reference(s):
Fire resistance rating of primary structural frame:	R 60
Fire resistance rating of exterior loadbearing walls:	REI 60
Fire resistance rating of interior loadbearing walls:	REI 60
Fire resistance rating of exterior non-bearing walls:	EI 60
Fire resistance rating of interior non-bearing walls:	EI 60
Fire resistance rating of floor construction and associated secondary members:	EI 60
Fire resistance rating of roof construction and associated secondary members:	EI 60

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	
Class required for wall coverings in interior exit stairs:	B-s1,d0
Class required for wall coverings in exit corridors:	B-s1,d0
Class required for wall coverings in rooms:	C-s2,d0
Reaction-to-fire test standard to qualify ceiling linings:	
Class required for ceiling linings in interior exit stairs:	B-s1,d0
Class required for ceiling linings in exit corridors:	B-s1,d0
Class required for ceiling linings in rooms:	C-s2,d0
Reaction-to-fire test standard to qualify floor coverings:	
Class required for floor coverings in interior exit stairs:	C_{FL}-s1
Class required for floor coverings in exit corridors:	C_{FL}-s1
Class required for floor coverings in rooms:	E_{FL}
Fire test standard(s) to qualify exterior claddings:	DB-SI (Código técnico)
Classification of the exterior cladding(s)used:	SATE system (mortar over isolations plaques)
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	xNo ☐Yes Reference(s):

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	xNo ☐Yes Standard:
Is the building required to be sprinklered?	xNo ☐Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	
Does adding sprinklers allow for an increase in the height and/or area of the building?	xNo ☐Yes (height, area, or both)
Is the building equipped with smoke detectors?	xNo ☐Yes
Is the building equipped with a fire alarm system?	xNo ☐Yes
Does the building have an emergency voice system?	xNo ☐Yes
Number of exit stairs:	1
Minimum distance between exit stairs (m):	-----
Are exit stairs pressurized (smoke-free)?	xNo ☐Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

No special measures of protection during constructions process.

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

No tests were done.

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

The interior walls of the elevator are protected with a 15 mm gypsum board special for fire protection in order to achieve the EI-60. All the vertical walls, achieve the EI-60 protection adding a supplementary thickness of wood in CLT walls, with a 15 mm gypsum board as finishing.

4. Are the timber connections exposed or protected? If the connections are protected, explain how.

The timber connections between the walls and the floors are all at the lower parts of the walls, so they are protected with the floor finishings as the radiant floor isolation and the acustic isolations.

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

The ceiling of the sleeping and dining rooms are left with the wood exposed and they are finished with the called "domestic finishing", but with no special protection for the fire.

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	LifeCycle Tower One (LCT ONE)
Street address:	Färbergasse 17b
Completion date (or expected completion date):	Nov 2012
Building height above grade (m):	27
Total number of stories:	8
Number of timber stories:	8
Total floor area, all stories (m^2):	2320
Maximum floor area per story (m^2):	290
Use and occupancy:	☐ Apartments ☒ Offices ☐ Hotel rooms ☐ Shops
Structural members resisting vertical loads:	Glulam columns, concrete core walls
Structural members resisting horizontal loads:	Hybrid slab diaphragm, concrete core
Code compliance:	☐ Meets prescriptive requirements ☐ Prescriptive requirements with variances ☒ Meets performance-based requirements
Additional construction details:	Hybrid slab = glulam beams + concrete deck

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	EN 1365-2
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☒ No ☐ Yes
Fire resistance rating of primary structural frame:	REI90/EI90
Fire resistance rating of exterior loadbearing walls:	Concrete core walls: REI90
Fire resistance rating of interior loadbearing walls:	Concrete core walls: REI90
Fire resistance rating of exterior non-bearing walls:	No fire resistance
Fire resistance rating of interior non-bearing walls:	Up to EI90 if required
Fire resistance rating of floor construction and associated secondary members:	Hybrid slab: REI90 (REI120 classification is also available)
Fire resistance rating of roof construction and associated secondary members:	Hybrid Slab: REI90 (REI120 classification is also available)

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	No wall coverings
Class required for wall coverings in interior exit stairs:	A
Class required for wall coverings in exit corridors:	B
Class required for wall coverings in rooms:	D
Reaction-to-fire test standard to qualify ceiling linings:	No ceiling linings
Class required for ceiling linings in interior exit stairs:	A
Class required for ceiling linings in exit corridors:	B
Class required for ceiling linings in rooms:	D
Reaction-to-fire test standard to qualify floor coverings:	No floor coverings
Class required for floor coverings in interior exit stairs:	A
Class required for floor coverings in exit corridors:	C
Class required for floor coverings in rooms:	D
Fire test standard(s) to qualify exterior claddings:	ÖNORM B 3806
Classification of the exterior cladding(s) used:	A
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☒ No ☐ Yes

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☒ No ☐ Yes
Is the building required to be sprinklered?	☒ No ☐ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	Not applicable
Does adding sprinklers allow for an increase in the height and/or area of the building?	☐ No ☒ Yes
Is the building equipped with smoke detectors?	☒ No ☐ Yes
Is the building equipped with a fire alarm system?	☐ No ☒ Yes
Does the building have an emergency voice system?	☒ No ☐ Yes
Number of exit stairs:	1
Minimum distance between exit stairs (m):	Not applicable
Are exit stairs pressurized (smoke-free)?	☒ No ☐ Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.
   >> One portable fire extinguisher on every floor
   >> Recorded instruction of site staff
   >> Non-smoking site
   >> Site patrolled by security (2x a night)
   >> Clean and tidy site conditions

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.
   >> Hybrid slab tested according to EN 1365-2 on particular request of the AHJ

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)
   >> Primary framing members left exposed

4. Are the timber connections exposed or protected? If the connections are protected, explain how.
   >> Timber connections exposed resp. embedded in grouting

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?
   >> All glulam posts and beams left exposed
   >> All glulam posts and beams not protected

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	Toit Vosgien, residence Jules Ferry
Street address:	1 voie Jules Ferry, 88100 Saint-Diê-des-Vosges, France
Completion date (or expected completion date):	12/2013
Building height above grade (m):	24m
Total number of stories:	8
Number of timber stories:	8
Total floor area, all stories (m^2):	2707m²
Maximum floor area per story (m^2):	315 m²
Use and occupancy:	x Apartments (floors: all) ☐ Offices (floors: ______) ☐ Hotel rooms (floors: ______) ☐ Shops (floors: ______)
Structural members resisting vertical loads:	Cross laminated timber panels and glulam laminated wood poles
Structural members resisting horizontal loads:	Cross laminated timber panels and glulam laminated wood beams
Code compliance:	☐ Meets prescriptive requirements ☐ Prescriptive requirements with variances ☐ Meets performance-based requirements
Additional construction details:	

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☐ No X Yes Reference(s):
Fire resistance rating of primary structural frame:	R 60
Fire resistance rating of exterior loadbearing walls:	REI 60
Fire resistance rating of interior loadbearing walls:	REI 60
Fire resistance rating of exterior non-bearing walls:	Non-existent
Fire resistance rating of interior non-bearing walls:	No fire resistance
Fire resistance rating of floor construction and associated secondary members:	REI 60
Fire resistance rating of roof construction and associated secondary members:	No fire resistance requested, REI 60 existent

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	
Class required for wall coverings in interior exit stairs:	Non-existent
Class required for wall coverings in exit corridors:	Non-existent
Class required for wall coverings in rooms:	No requirement
Reaction-to-fire test standard to qualify ceiling linings:	
Class required for ceiling linings in interior exit stairs:	Non-existent
Class required for ceiling linings in exit corridors:	Non-existent
Class required for ceiling linings in rooms:	No requirement
Reaction-to-fire test standard to qualify floor coverings:	
Class required for floor coverings in interior exit stairs:	Non-existent
Class required for floor coverings in exit corridors:	Non-existent
Class required for floor coverings in rooms:	No requirement
Fire test standard(s) to qualify exterior claddings:	
Classification of the exterior cladding(s) used:	
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☐ No x Yes Reference(s): -Visible wood cladding (larch) on the façades where there are balconies (north and south) -It also used straw balls as insulation for all the building. It is not visible and it is protected with a non-flammable sheet

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	x No ☐ Yes Standard:
Is the building required to be sprinklered?	x No ☐ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	
Does adding sprinklers allow for an increase in the height and/or area of the building?	x No ☐ Yes (height, area, or both)
Is the building equipped with smoke detectors?	☐ No x Yes
Is the building equipped with a fire alarm system?	x No ☐ Yes
Does the building have an emergency voice system?	x No ☐ Yes
Number of exit stairs:	1
Minimum distance between exit stairs (m):	8m
Are exit stairs pressurized (smoke-free)?	☐ No x Yes (exterior stairs)

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

No special measure : construction carefully controlled as usual and prefabrication

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

None test have been realized

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

The primary framing members are left exposed

4. Are the timber connections exposed or protected? If the connections are protected, explain how.

The timber connections are left exposed except in the technical room where they are protected with wood boards

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

Approximately 2/3 of wood surfaces are left exposed. The unexposed surfaces are covered (but not fire-protected) by gypsum boards

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	Holz 8
Street address:	Dietrich-Bonhoeffer-Straße14 83043 Bad Aibling
Completion date (or expected completion date):	2011
Building height above grade (m):	Ca. 25m (21.7 m upper floor level)
Total number of stories:	8
Number of timber stories:	8
Total floor area, all stories (m^2):	1741 m^2
Maximum floor area per story (m^2):	ca. 225 m^2
Use and occupancy:	☒ Apartments (floors: 3-8) ☒ Offices (floors: 1, 2) ☐ Hotel rooms (floors: __________) ☐ Shops (floors: __________)
Structural members resisting vertical loads:	Floors: CLT; Walls: CLT and timber frame elements (wall cavities filled with solid timber studs → solid wood wall element) with external thermal insulation
Structural members resisting horizontal loads:	Concrete stairwell core and CLT elements
Code compliance:	☐ Meets prescriptive requirements ☒ Prescriptive requirements with variances ☐ Meets performance-based requirements
Additional construction details:	Concrete stairwell core, solid wood and CLT construction for the external and internal walls, CLT floors

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	EN 13501-2, EN 1363, EN 1365
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☐ No ☒ Yes (calculating and testing) Reference(s): EN 1995-1-2
Fire resistance rating of primary structural frame:	REI 90 + $K_2$60, alternative solution accepted by fire expert (prescriptive code requires non combustible materials)
Fire resistance rating of exterior loadbearing walls:	REI 90 + $K_2$60 alternative solution accepted by fire expert (prescriptive code requires non combustible materials)
Fire resistance rating of interior loadbearing walls:	REI 90 + $K_2$60 alternative solution accepted by fire expert (prescriptive code requires non combustible materials)
Fire resistance rating of exterior non-bearing walls:	-
Fire resistance rating of interior non-bearing walls:	EI 90 + $K_2$60
Fire resistance rating of floor construction and associated secondary members:	REI 90 + $K_2$60 alternative solution accepted by fire expert (prescriptive code requires non combustible materials) REI 90 without encapsulation for living rooms
Fire resistance rating of roof construction and associated secondary members:	REI 30

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	EN 13501-1, EN13823
Class required for wall coverings in interior exit stairs:	A1 / (A2)
Class required for wall coverings in exit corridors:	A1 / (A2)
Class required for wall coverings in rooms:	A2 / (-)
Reaction-to-fire test standard to qualify ceiling linings:	EN 13501-1, EN13823
Class required for ceiling linings in interior exit stairs:	A1 / (A2)
Class required for ceiling linings in exit corridors:	A1 / (A2)
Class required for ceiling linings in rooms:	A2 / Ds2d0 /(-)
Reaction-to-fire test standard to qualify floor coverings:	EN 13501-1, EN
Class required for floor coverings in interior exit stairs:	A1 / (Cfl s1)
Class required for floor coverings in exit corridors:	A1 / (-)
Class required for floor coverings in rooms:	Ds2d0 / (-)
Fire test standard(s) to qualify exterior claddings:	DIN 4102-20
Classification of the exterior cladding(s) used:	B1 / (B1) for the entire façade system (cladding, support structure, insulation)
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☐ No ☒ Yes The facade made of rear ventilated vertical timber boards (spruce) horizontal separation (fire stop) in each story with an overlapping metal sheet

The given "requirements" represent the status negotiated with the building authority within the fire safety concept for the specific building (Holz8 – Bad Aibling Germany) and are in some cases an alternative solution deviation from the requirements of the building code. The prescriptive requirements of the building code are given in brackets ().

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☒ No ☐ Yes Standard:
Is the building required to be sprinklered?	☒No ☐ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	-
Does adding sprinklers allow for an increase in the height and/or area of the building?	☒ No ☐Yes
Is the building equipped with smoke detectors?	☐ No ☒Yes
Is the building equipped with a fire alarm system?	☒No ☐ Yes
Does the building have an emergency voice system?	☒ No ☐ Yes
Number of exit stairs:	1
Minimum distance between exit stairs (m):	-
Are exit stairs pressurized (smoke-free)?	☒ No ☐ Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

   Prefabricated elements in general lined with gypsum boards
   Fire extinguishers in the offices
   Fire risk analysis and preventive actions

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

   - *Not done for this building*
   - *However façade fire tests were conducted in a previous research projects in 2003-2005 (see HTO Research Report HTO TP2 (High-Tech-Offensive Bavaria, Subproject 2), Brandsicherheit im mehrgeschossigem Holzbau, TU München 2009)*

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

   Primary framing members are protected with F-type gypsum board, two 18mm layers

4. Are the timber connections exposed or protected? If the connections are protected, explain how.

   All connections are fully protected

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

   Only the CLT panels in the living rooms are unprotected and visible.
   The flooring system in all flats and offices are made from a timber laminate

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 0

GENERAL INFORMATION

Building name:	Milano, Cenni di cambiamento
Street address:	Via Cenni, Milano
Building height above grade (m):	27m
Total number of stories:	4 buildings, each building with 9 stories
Number of timber stories:	all stories in timber
Total floor area, all stories (m^2):	About 9360 m^2
Maximum floor area per story (m^2):	About 260 m^2
Structural members resisting vertical loads:	CLT slabs and CLT walls
Structural members resisting horizontal loads:	CLT walls
Code compliance:	☐ Meets prescriptive requirements ☐ Prescriptive requirements with variances ☒ Meets performance-based requirements
Additional construction details:	All CLT structural elements are protected by two layers of gypsum plasterboards providing a fire resistance of EI60

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	No
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☐ No ☒ Yes Reference(s): Eurocode 5
Fire resistance rating of primary structural frame:	R60
Fire resistance rating of exterior loadbearing walls:	REI60
Fire resistance rating of interior loadbearing walls:	REI60
Fire resistance rating of exterior non-bearing walls:	Not concerned
Fire resistance rating of interior non-bearing walls:	By compartments EI60
Fire resistance rating of floor construction and associated secondary members:	REI60
Fire resistance rating of roof construction and associated secondary members:	REI60

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	EN 13501-1
Class required for wall coverings in interior exit stairs:	Noncombustible (A1 or A2)
Class required for wall coverings in exit corridors:	Noncombustible (A1 or A2)
Class required for wall coverings in rooms:	Noncombustible (A1 or A2)
Reaction-to-fire test standard to qualify ceiling linings:	EN 13501-1
Class required for ceiling linings in interior exit stairs:	Noncombustible (A1 or A2)
Class required for ceiling linings in exit corridors:	Noncombustible (A1 or A2)
Class required for ceiling linings in rooms:	Noncombustible (A1 or A2)
Reaction-to-fire test standard to qualify floor coverings:	EN 13501-1
Class required for floor coverings in interior exit stairs:	Noncombustible (A1 or A2)
Class required for floor coverings in exit corridors:	Noncombustible (A1 or A2)
Class required for floor coverings in rooms:	Noncombustible (A1 or A2)
Fire test standard(s) to qualify exterior claddings:	EN 13501-1
Classification of the exterior cladding(s) used:	E (polystyrene with graphite)
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☒ No ☐ Yes Reference(s):

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☒ No ☐ Yes Standard:
Is the building required to be sprinklered?	☒No ☐ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	-
Does adding sprinklers allow for an increase in the height and/or area of the building?	☒ No ☐ Yes (height, area, or both)
Is the building equipped with smoke detectors?	☒No ☐ Yes
Is the building equipped with a fire alarm system?	☒No ☐ Yes
Does the building have an emergency voice system?	☒No ☐ Yes
Number of exit stairs:	1
Minimum distance between exit stairs (m):	-
Are exit stairs pressurized (smoke-free)?	☒ No ☐ Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.
   Carefully recommendations and instructions of the building site workers in order to avoid fire accidents by smoking or working activities (for example steel welding working).
   A general prohibition for smoking is not authorized, because a building site is an open place.
   Controlling by the supervision of the building site.

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.
   No fire tests have been performed.

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)
   All CLT structural elements are protected by two layers of gypsum plasterboards providing a fire resistance of EI60.

4. Are the timber connections exposed or protected? If the connections are protected, explain how.
   All CLT structural elements including connections are protected by two layers of gypsum plasterboards providing a fire resistance of EI60.

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?
   Timber surfaces are protected by gypsum plasterboards.

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	Limnologen (4 buildings)
Street address:	Sjöbågen 2, 352 57 Växjö, Sweden
Completion date (or expected completion date):	2009
Building height above grade (m):	24 m
Total number of stories:	8
Number of timber stories:	7
Total floor area, all stories (m^2):	3460 m^2 (per building)
Maximum floor area per story (m^2):	430 m^2 (per building)
Use and occupancy:	☒ Apartments (floors: all) ☐ Offices (floors: ___) ☐ Hotel rooms (floors: ___) ☐ Shops (floors: ___)
Structural members resisting vertical loads:	Solid wood or timber frame structure, both protected with gypsum plaster boards
Structural members resisting horizontal loads:	Glulam beams protected underneath with gypsum plaster boards and with solid wood plates on the top (flooring side)
Code compliance:	☐ Meets prescriptive requirements ☒ Prescriptive requirements with variances ☐ Meets performance-based requirements
Additional construction details:	CLT shear walls with steel rods running continuously from top to bottom

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	EN 13501-2
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☒ No ☐ Yes Reference(s):
Fire resistance rating of primary structural frame:	R 90 (vertical)
Fire resistance rating of exterior loadbearing walls:	REI 90 (vertical)
Fire resistance rating of interior loadbearing walls:	REI 90 (vertical)
Fire resistance rating of exterior non-bearing walls:	EI 60
Fire resistance rating of interior non-bearing walls:	EI 60
Fire resistance rating of floor construction and associated secondary members:	REI 60
Fire resistance rating of roof construction and associated secondary members:	REI 60

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	EN 13501-1
Class required for wall coverings in interior exit stairs:	B-s1,d0
Class required for wall coverings in exit corridors:	B-s1,d0
Class required for wall coverings in rooms:	C-s2,d0
Reaction-to-fire test standard to qualify ceiling linings:	EN 13501-1
Class required for ceiling linings in interior exit stairs:	B-s1,d0
Class required for ceiling linings in exit corridors:	B-s1,d0
Class required for ceiling linings in rooms:	B-s1,d0
Reaction-to-fire test standard to qualify floor coverings:	EN 13501-1
Class required for floor coverings in interior exit stairs:	C_{fl}-s1
Class required for floor coverings in exit corridors:	C_{fl}-s1
Class required for floor coverings in rooms:	D_{fl}-s1
Fire test standard(s) to qualify exterior claddings:	SP Fire 105 (national standard)
Classification of the exterior cladding(s) used:	Mainly mortar, passes SP Fire 105 (by deemed to satisfy)
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☐ No ☒ Yes Reference(s): – Visible wood on the undersides of balcony plates and inner wall covering – Less vertical distance between windows (0,75 m instead of 1.2 m) than according to prescriptive rules. Both these deviations are verified by the sprinkler installation. The risk for flame spread upwards from the inner wall covering is also limited by the projection of the balcony plates that extends over the full façade.

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☐ No ☒ Yes Standard: SBF REK 2002, Swedish Fire Protection Association
Is the building required to be sprinklered?	☒ No ☐ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	Residential sprinkler
Does adding sprinklers allow for an increase in the height and/or area of the building?	☒ No ☐ Yes (height, area, or both)
Is the building equipped with smoke detectors?	☐ No ☒ Yes
Is the building equipped with a fire alarm system?	☐ No ☒ Yes
Does the building have an emergency voice system?	☒ No ☐ Yes
Number of exit stairs:	2 per building (with exits to the exterior on both sides of the building on the ground floor). Fire exits also via balconies by the rescue service (most flats have 2 balconies)
Minimum distance between exit stairs (m):	Walking distance from flats to exit stairs < 10 m.
Are exit stairs pressurized (smoke-free)?	☒ No ☐ Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

   The building site was carefully controlled with rules for good order, cleaning, non-smoking and escape routes etc.
   The two-dimensional building elements were manufactured industrially and created a separation similar to the one in the finalized building when mounted on building site.
   The building site was under a tent that gave weather protection and also a good working environment. The tent was moved upwards as further storeys were erected.
   Extinguishing equipment was available.

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

   No

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

   Protected with 2 x 13 mm gypsum board.

4. Are the timber connections exposed or protected? If the connections are protected, explain how.

   Protected with 2 x 13 mm gypsum board.

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

   Almost zero

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	Puukuokka
Street address:	Syöttäjänkatu 1, Kuokkala, Jyväskylä,Finland
Completion date (or expected completion date):	November 2014 (first building of the complex of 3 buildings)
Building height above grade (m):	24 m
Total number of stories:	8 + basement (mostly underground)
Number of timber stories:	8 (minor parts of the first floor includes concrete frames)
Total floor area, all stories (m^2):	18 650 m^2 (all buildings together)
Maximum floor area per story (m^2):	About 750 m^2 (per building)
Use and occupancy:	X Apartments (floors: 8) ☐ Offices (floors: ____) ☐ Hotel rooms (floors: ____) ☐ Shops (floors: ____)
Structural members resisting vertical loads:	CLT
Structural members resisting horizontal loads:	CLT
Code compliance:	☐ Meets prescriptive requirements X Prescriptive requirements with variances ☐ Meets performance-based requirements
Additional construction details:	The basement floor (and small parts in the floor above basement (storage rooms)) is made of concrete

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	EN 13501-2
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☐ No X Yes, partly Reference(s): EN 1995-1-2
Fire resistance rating of primary structural frame:	R60
Fire resistance rating of exterior loadbearing walls:	R60
Fire resistance rating of interior loadbearing walls:	REI60
Fire resistance rating of exterior non-bearing walls:	-
Fire resistance rating of interior non-bearing walls:	-
Fire resistance rating of floor construction and associated secondary members:	REI60
Fire resistance rating of roof construction and associated secondary members:	REI60

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	EN 13501-1
Class required for wall coverings in interior exit stairs:	A2-s1,d0
Class required for wall coverings in exit corridors:	A2-s1,d0
Class required for wall coverings in rooms:	D-s2, d2
Reaction-to-fire test standard to qualify ceiling linings:	EN 13501-1
Class required for ceiling linings in interior exit stairs:	A2-s1,d0
Class required for ceiling linings in exit corridors:	A2-s1,d0
Class required for ceiling linings in rooms:	D-s2, d2
Reaction-to-fire test standard to qualify floor coverings:	EN 13501-1
Class required for floor coverings in interior exit stairs:	D_{FL}-s1
Class required for floor coverings in exit corridors:	D_{FL}-s1
Class required for floor coverings in rooms:	- (no requirement)
Fire test standard(s) to qualify exterior claddings:	EN 13501-1
Classification of the exterior cladding(s) used:	D-s2, d2, except 1. floor above ground level have to be B-s2, d0
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☐ No X Yes Reference(s): Normal wood in thicknesses for outdoor use

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☐ No X Yes Standard: EN 12845 Note that the concrete structured basement (parking area) is not sprinklered based on fire safety engineering analysis
Is the building required to be sprinklered?	☐ No X Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	Ordinary sprinkler according to EN 12845 OH class
Does adding sprinklers allow for an increase in the height and/or area of the building?	☐ No X Yes (height, area, or both)
Is the building equipped with smoke detectors?	☐ No X Yes (Smoke detectors connected to the power supply mains)
Is the building equipped with a fire alarm system?	X No, except the basement ☐ Yes
Does the building have an emergency voice system?	X No ☐ Yes
Number of exit stairs:	1 + additionally escape through route which it is possible for the evacuees to reach safety on their own means or by the aid of the fire department (balconies in this case).
Minimum distance between exit stairs (m):	-
Are exit stairs pressurized (smoke-free)?	X No ☐ Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

   Normal rules/guidance for construction work applied, e.g. hot work rules.

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

   No.

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

   Protections used:
   - Internal walls: 15 mm F type gypsum board
   - Floors from below: Suspended ceiling made of 80 mm CLT (based of fire safety engineering analysis)
   - Eternal walls, inner surface of ventilation gap: $K_2 30$ covering made of A2-s1, d0 material (mineral wool or gypsum board)

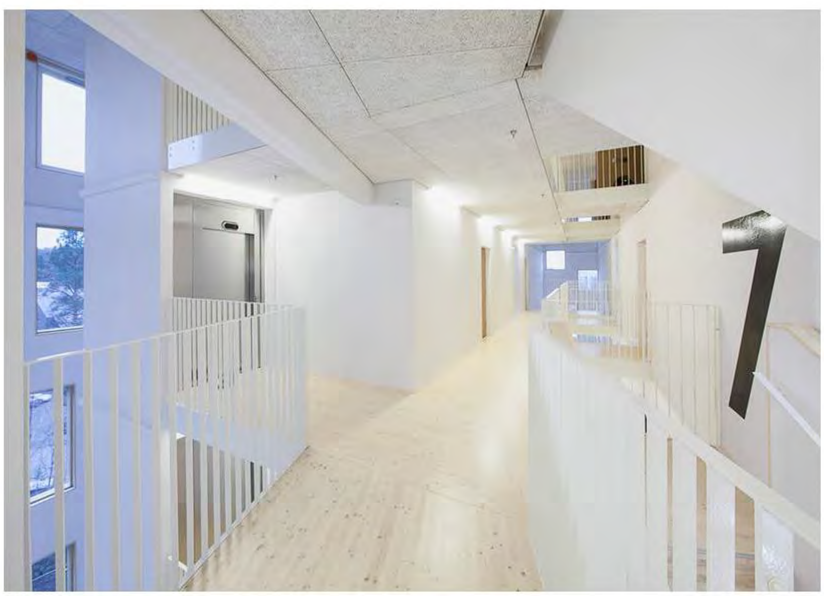
4. Are the timber connections exposed or protected? If the connections are protected, explain how.

   As above.

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

See figures below.

Apartment



Corridor:

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	Forte
Street address:	807-817, Bourke St, Docklands, VIC 3008 Australia
Completion date (or expected completion date):	2012
Building height above grade (m):	31
Total number of stories:	10
Number of timber stories:	9
Total floor area, all stories (m^2):	2410
Maximum floor area per story (m^2):	330
Use and occupancy:	✓ Apartments (floors: 9) ☐ Offices (floors: ____) ☐ Hotel rooms (floors: ____) ✓ Shops (floors: 1)
Structural members resisting vertical loads:	Cross Laminated Timber
Structural members resisting horizontal loads:	Cross Laminated Timber
Code compliance:	☐ Meets prescriptive requirements ☐ Prescriptive requirements with variances ✓ Meets performance-based requirements
Additional construction details:	

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	AS1530
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	✓ No ☐ Yes Reference(s):
Fire resistance rating of primary structural frame:	90/90/90
Fire resistance rating of exterior loadbearing walls:	60/60/30 and 90/60/30 where close to the boundary
Fire resistance rating of interior loadbearing walls:	90/90/90
Fire resistance rating of exterior non-bearing walls:	NA
Fire resistance rating of interior non-bearing walls:	NA
Fire resistance rating of floor construction and associated secondary members:	90/90/90
Fire resistance rating of roof construction and associated secondary members:	

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	
Class required for wall coverings in interior exit stairs:	
Class required for wall coverings in exit corridors:	
Class required for wall coverings in rooms:	
Reaction-to-fire test standard to qualify ceiling linings:	
Class required for ceiling linings in interior exit stairs:	
Class required for ceiling linings in exit corridors:	
Class required for ceiling linings in rooms:	
Reaction-to-fire test standard to qualify floor coverings:	
Class required for floor coverings in interior exit stairs:	
Class required for floor coverings in exit corridors:	
Class required for floor coverings in rooms:	
Fire test standard(s) to qualify exterior claddings:	
Classification of the exterior cladding(s) used:	
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☐ No ☐ Yes Reference(s):

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☐ No ✓ Yes Standard:
Is the building required to be sprinklered?	✓ No ☐ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	
Does adding sprinklers allow for an increase in the height and/or area of the building?	✓ No ☐ Yes (height, area, or both)
Is the building equipped with smoke detectors?	☐ No ✓ Yes
Is the building equipped with a fire alarm system?	☐ No ✓ Yes
Does the building have an emergency voice system?	☐ No ☐ Yes
Number of exit stairs:	1
Minimum distance between exit stairs (m):	
Are exit stairs pressurized (smoke-free)?	☐ No ☐ Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

   Load bearing and non-loadbearing furnace fire test were conducted for unprotected and protected scenarios.

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

   With the exception of one side of one wall in each apartment which is unprotected, all apartment walls are protected with a single layer of 13mm fire rated plasterboard to each side and all soffits are protected with 2 layers of 16 mm fire rated plasterboard.

   The internal surface of the lift shaft and fire escape stair are unprotected.

4. Are the timber connections exposed or protected? If the connections are protected, explain how.

   Yes, protected by timer and/or fire rated plasterboard.

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

   See above.

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	Suurstoffi
Street address:	Suurstoffi 22, 6343 Risch-Rotkreuz, Switzerland
Completion date (or expected completion date):	To be completed in 2018
Building height above grade (m):	36 m
Total number of stories:	10
Number of timber stories:	9
Total floor area, all stories (m^2):	15'260 m^2
Maximum floor area per story (m^2):	1'850 m^2
Use and occupancy:	☐ Apartments ☒ Offices ☐ Hotel rooms ☐ Shops
Structural members resisting vertical loads:	Timber
Structural members resisting horizontal loads:	Two staircases made of steel reinforced concrete
Code compliance:	☒ Meets prescriptive requirements ☐ Prescriptive requirements with variances ☐ Meets performance-based requirements
Additional construction details:	Two staircases made of steel reinforced concrete, prefabricated timber-concrete composite slabs, glulam beams and columns

Note: based on the Swiss Fire Safety Regulations tall buildings are defined as buildings with a total height of more than 30m.

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	No
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☐ No ☒ Yes Reference(s): Swiss standards (similar to Eurocode 5 EN 1995-1-2)
Fire resistance rating of primary structural frame:	R 60 (R 90 for both staircases)
Fire resistance rating of exterior loadbearing walls:	R 60 EI 0
Fire resistance rating of interior loadbearing walls:	R 60 EI 30
Fire resistance rating of exterior non-bearing walls:	EI 0
Fire resistance rating of interior non-bearing walls:	EI 30
Fire resistance rating of floor construction and associated secondary members:	R 60 EI 60
Fire resistance rating of roof construction and associated secondary members:	R 30 EI 0

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	EN 13501-1
Class required for wall coverings in interior exit stairs:	Non-combustible, class A1 or A2-s1,d0
Class required for wall coverings in exit corridors:	Non-combustible, class A1 or A2-s1,d0
Class required for wall coverings in rooms:	Combustible, class D-s2-d1 or better
Reaction-to-fire test standard to qualify ceiling linings:	EN 13501-1
Class required for ceiling linings in interior exit stairs:	Non-combustible, class A1 or A2-s1,d0
Class required for ceiling linings in exit corridors:	Non-combustible, class A1 or A2-s1,d0
Class required for ceiling linings in rooms:	Combustible, class D-s2,d1 or better
Reaction-to-fire test standard to qualify floor coverings:	EN 13501-1
Class required for floor coverings in interior exit stairs:	Non-combustible, class $A1_{fl}$ or $A2_{fl}$-s1
Class required for floor coverings in exit corridors:	Combustible, class C_{fl}-s1 or better
Class required for floor coverings in rooms:	Combustible, class E_{fl} or better
Fire test standard(s) to qualify exterior claddings:	No
Classification of the exterior cladding(s) used:	Non-combustible, class A1 or A2-s1,d0
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☒ No ☐ Yes

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☐ No ☒ Yes Standard: Swiss Standard
Is the building required to be sprinklered?	☒ No (without sprinkler, requirements on fire resistance are higher) ☐ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	Ordinary
Does adding sprinklers allow for an increase in the height and/or area of the building?	☐ No ☒ Yes, reduction of fire resistance from R90 to R60; no fire resistance requirement for the facade; structural timber elements exposed to fire
Is the building equipped with smoke detectors?	☐ No ☒ Yes, smoke detector by the staircases
Is the building equipped with a fire alarm system?	☐ No ☒ Yes
Does the building have an emergency voice system?	☒ No ☐ Yes
Number of exit stairs:	2
Minimum distance between exit stairs (m):	28 m (possible max. distance between exit stairs 75m)
Are exit stairs pressurized (smoke-free)?	☐ No ☒ Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

   According to Swiss Fire Safety Regulations.

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

   No test, only calculations.

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

   Primary framing members (glulam beams and columns) are left exposed.

4. Are the timber connections exposed or protected? If the connections are protected, explain how.

   Timber connections of primary framing members (glulam beams and columns) are left exposed.

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

   Primary framing members (glulam beams and columns) are left exposed.
   Interior wood floor, wall, and ceiling surfaces are left exposed.

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	The Cube Building
Street address:	17-21 Wenlock Road
Completion date (or expected completion date):	2015
Building height above grade (m):	30
Total number of stories:	10
Number of timber stories:	10
Total floor area, all stories (m^2):	Not known
Maximum floor area per story (m^2):	Not known
Use and occupancy:	☐ Apartments (floors: 10) ☐ Offices (floors: ____) ☐ Hotel rooms (floors: ____) ☐ Shops (floors: ____)
Structural members resisting vertical loads:	CLT and steel
Structural members resisting horizontal loads:	CLT and steel
Code compliance:	■ Meets prescriptive requirements ☐ Prescriptive requirements with variances ☐ Meets performance-based requirements
Additional construction details:	

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	BS 476:21
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☐ No ■ Yes Reference(s): EN 1991-1-2 Annex B and reduced cross-section method
Fire resistance rating of primary structural frame:	90
Fire resistance rating of exterior loadbearing walls:	90
Fire resistance rating of interior loadbearing walls:	90
Fire resistance rating of exterior non-bearing walls:	90
Fire resistance rating of interior non-bearing walls:	60
Fire resistance rating of floor construction and associated secondary members:	90
Fire resistance rating of roof construction and associated secondary members:	None

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	
Class required for wall coverings in interior exit stairs:	
Class required for wall coverings in exit corridors:	
Class required for wall coverings in rooms:	
Reaction-to-fire test standard to qualify ceiling linings:	
Class required for ceiling linings in interior exit stairs:	
Class required for ceiling linings in exit corridors:	
Class required for ceiling linings in rooms:	
Reaction-to-fire test standard to qualify floor coverings:	
Class required for floor coverings in interior exit stairs:	
Class required for floor coverings in exit corridors:	
Class required for floor coverings in rooms:	
Fire test standard(s) to qualify exterior claddings:	
Classification of the exterior cladding(s) used:	
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☐ No ☐ Yes Reference(s):

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☐ No ☐ Yes Standard:
Is the building required to be sprinklered?	☐ No ☐ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	
Does adding sprinklers allow for an increase in the height and/or area of the building?	☐ No ☐ Yes (height, area, or both)
Is the building equipped with smoke detectors?	☐ No ☐ Yes
Is the building equipped with a fire alarm system?	☐ No ☐ Yes
Does the building have an emergency voice system?	☐ No ☐ Yes
Number of exit stairs:	
Minimum distance between exit stairs (m):	
Are exit stairs pressurized (smoke-free)?	☐ No ☐ Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

4. Are the timber connections exposed or protected? If the connections are protected, explain how.

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	Framework, Portland, Oregon
Street address:	430 Northwest 10th Avenue, Portland
Completion date (or expected completion date):	2018
Building height above grade (m):	44m
Total number of stories:	12
Number of timber stories:	12
Total floor area, all stories (m^2):	8360
Maximum floor area per story (m^2):	768
Use and occupancy:	☐ Apartments (floors: 5) ☐ Offices (floors: 7) ☐ Hotel rooms (floors: 0) ☐ Shops (floors: 0)
Structural members resisting vertical loads:	Wood
Structural members resisting horizontal loads:	Wood
Code compliance:	☐ Meets prescriptive requirements ☐ Prescriptive requirements with variances ☒ Meets performance-based requirements
Additional construction details:	

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	ASTM E119
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☐ No ☐ Yes Reference(s): Tests and calculations used. TR-10 / NDS used for glulam. CLT handbook used as support for CLT.
Fire resistance rating of primary structural frame:	120 mins
Fire resistance rating of exterior loadbearing walls:	None
Fire resistance rating of interior loadbearing walls:	120 mins
Fire resistance rating of exterior non-bearing walls:	60 mins
Fire resistance rating of interior non-bearing walls:	120 mins or 60 mins
Fire resistance rating of floor construction and associated secondary members:	120 mins
Fire resistance rating of roof construction and associated secondary members:	60 mins

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	ASTM E 84
Class required for wall coverings in interior exit stairs:	B
Class required for wall coverings in exit corridors:	B
Class required for wall coverings in rooms:	C
Reaction-to-fire test standard to qualify ceiling linings:	ASTM E84
Class required for ceiling linings in interior exit stairs:	B
Class required for ceiling linings in exit corridors:	B
Class required for ceiling linings in rooms:	C
Reaction-to-fire test standard to qualify floor coverings:	
Class required for floor coverings in interior exit stairs:	
Class required for floor coverings in exit corridors:	
Class required for floor coverings in rooms:	
Fire test standard(s) to qualify exterior claddings:	Non-combustible
Classification of the exterior cladding(s) used:	
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☒ No ☐ Yes Reference(s):

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☐ No ☒ Yes Standard: NFPA 13
Is the building required to be sprinklered?	☐ No ☒ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	OH 1
Does adding sprinklers allow for an increase in the height and/or area of the building?	☐ No ☒ Yes (height, area, or both)
Is the building equipped with smoke detectors?	☐ No ☒Yes
Is the building equipped with a fire alarm system?	☐ No ☒Yes
Does the building have an emergency voice system?	☐ No ☒Yes
Number of exit stairs:	2
Minimum distance between exit stairs (m):	13
Are exit stairs pressurized (smoke-free)?	☐ No ☒ Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

Additional security, permanent staffing, no cooking on site

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

Tests on connections (glulam) and beam and floor assembly (glulam and CLT)

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

Members partly exposed. Where encapsulated, 2 layers of 5/8 Type X gypsum

4. Are the timber connections exposed or protected? If the connections are protected, explain how.

Timber connections exposed and also protected. Protected with two layers 5/8 Type X gypsum.

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

Residential unit – approx. 30% of underside of floor; and approx. 20% of beams and columns.

Office units – approx. 40% of underside of floor and beams; and approx. 80% of columns

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	UBC Brock Commons Phase 1
Street address:	6088 Walter Gage Road, Vancouver
Completion date (or expected completion date):	August 2017
Building height above grade (m):	53
Total number of stories:	18
Number of timber stories:	17
Total floor area, all stories (m^2):	15,115
Maximum floor area per story (m^2):	840
Use and occupancy: This is a Student Residence, could be considered hotel.	x Apartments (floors: __________) ☐ Offices (floors: __________) ☐ Hotel rooms (floors: __________) ☐ Shops (floors: __________)
Structural members resisting vertical loads:	Glue-lam and Parallam, 5 Ply CLT floors
Structural members resisting horizontal loads:	5ply CLT slabs,
Code compliance:	☐ Meets prescriptive requirements x Prescriptive requirements with variances ☐ Meets performance-based requirements
Additional construction details:	Hybrid – lateral resistance provided by concrete core, roof is steel structure. Building is in conformance with the BCBC (and therefor National Building Code of Canada 2015) with the exception of use of encapsulated mass timber.

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	ULC S101
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☐ No ☐ Yes Reference(s):
Fire resistance rating of primary structural frame:	2h
Fire resistance rating of exterior loadbearing walls:	2h
Fire resistance rating of interior loadbearing walls:	2h
Fire resistance rating of exterior non-bearing walls:	2h
Fire resistance rating of interior non-bearing walls:	2h
Fire resistance rating of floor construction and associated secondary members:	2h
Fire resistance rating of roof construction and associated secondary members:	0h

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	ULC S102
Class required for wall coverings in interior exit stairs:	FSR 25
Class required for wall coverings in exit corridors:	FSR 25
Class required for wall coverings in rooms:	FSR 150
Reaction-to-fire test standard to qualify ceiling linings:	ULC S102
Class required for ceiling linings in interior exit stairs:	25
Class required for ceiling linings in exit corridors:	25
Class required for ceiling linings in rooms:	25
Reaction-to-fire test standard to qualify floor coverings:	Wood Floors directly permitted
Class required for floor coverings in interior exit stairs:	
Class required for floor coverings in exit corridors:	
Class required for floor coverings in rooms:	
Fire test standard(s) to qualify exterior claddings:	ULC S134 and NBC Article 3.1.5
Classification of the exterior cladding(s) used:	
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	x No ☐ Yes Reference(s):

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☐ No x Yes Standard: NFPA 13
Is the building required to be sprinklered?	☐ No x Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	Per NFPA 13, light hazard, residential heads.
Does adding sprinklers allow for an increase in the height and/or area of the building?	x No ☐ Yes (height, area, or both)
Is the building equipped with smoke detectors?	☐ No x Yes
Is the building equipped with a fire alarm system?	☐ No x Yes
Does the building have an emergency voice system?	☐ No x Yes
Number of exit stairs:	2
Minimum distance between exit stairs (m):	Minimum 9 between doors, actual 25m
Are exit stairs pressurized (smoke-free)?	☐ No x Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

   High quality site safety program. Construction fire safety achieved by providing a single layer of 5/8in Type X gypsum wallboard on the underside of the CLT panels, installed after erection, but such that no more than 4 levels at a time are unprotected.

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

   Only fire tests performed was a penetration firestop test.

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

   Primary frame members are fully encapsulated in 3 or 4 layers of 5/8in Type X GWB to provide full 2h fire rated encapsulation.

4. Are the timber connections exposed or protected? If the connections are protected, explain how.

   All connections for gravity loads are within the above noted encapsulation.

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

   Nothing left exposed, except walls in only lounge on the top floor.

TALL WOOD BUILDING FIRE QUESTIONNAIRE

Revision 1

GENERAL INFORMATION

Building name:	Treet
Street address:	Damsgardsveien 99, Bergen, Norway
Completion date (or expected completion date):	November-December 2015
Building height above grade (m):	52,8 m
Total number of stories:	15
Number of timber stories:	14
Total floor area, all stories (m^2):	5830 m^2
Maximum floor area per story (m^2):	366 m^2
Use and occupancy:	☒ Apartments (floors: all) ☐ Offices (floors: ___) ☐ Hotel rooms (floors: ___) ☐ Shops (floors: ___)
Structural members resisting vertical loads:	Timber
Structural members resisting horizontal loads:	Timber
Code compliance:	☐ Meets prescriptive requirements ☐ Prescriptive requirements with variances ☒ Meets performance-based requirements
Additional construction details:	Concrete slabs, steel components, CLT, Glulam beams, columns

FIRE RESISTANCE

Test standard used to obtain fire resistance rating:	
Is a calculation method used in lieu of testing? If so, provide reference(s) to documents describing the method.	☐ No ☒ Yes Reference(s): EN 1995-1-2
Fire resistance rating of primary structural frame:	R 90
Fire resistance rating of exterior loadbearing walls:	-
Fire resistance rating of interior loadbearing walls:	R 90, EI 76 (according to calculations). Accepted by fire expert (withdrawal of 90 min demand)
Fire resistance rating of exterior non-bearing walls:	-
Fire resistance rating of interior non-bearing walls:	EI 60, EI 30
Fire resistance rating of floor construction and associated secondary members:	REI 60
Fire resistance rating of roof construction and associated secondary members:	REI 60

REACTION-TO-FIRE AND EXTERIOR FIRE SPREAD

Reaction-to-fire test standard to qualify wall coverings:	EN 13501-1
Class required for wall coverings in interior exit stairs:	B-s1,d0
Class required for wall coverings in exit corridors:	B-s1,d0
Class required for wall coverings in rooms:	D-s2,d0
Reaction-to-fire test standard to qualify ceiling linings:	EN 13501-1
Class required for ceiling linings in interior exit stairs:	B-s1,d0
Class required for ceiling linings in exit corridors:	B-s1,d0
Class required for ceiling linings in rooms:	D-s2,d0
Reaction-to-fire test standard to qualify floor coverings:	EN 13501-1
Class required for floor coverings in interior exit stairs:	D_{fl}-s1
Class required for floor coverings in exit corridors:	D_{fl}-s1
Class required for floor coverings in rooms:	D_{fl}-s1
Fire test standard(s) to qualify exterior claddings:	
Classification of the exterior cladding(s) used:	$K_2$10; B-s1,d0
Are bio-based exterior claddings used in the building? If so, provide a brief description and, if applicable, trade names of these materials.	☐ No ☒ Yes Some part of the facade is covered with timber boards (staircase wall, modular walls behind the glass)

ACTIVE FIRE PROTECTION AND EGRESS

Is the building protected with an automatic sprinkler system? If so, specify the sprinklers standard based on which the system is based.	☐ No ☒ Yes Standard:
Is the building required to be sprinklered?	☐ No ☒ Yes
If applicable, indicate the type of sprinkler system used (ordinary or quick response; residential, light hazard, etc.):	Quick response
Does adding sprinklers allow for an increase in the height and/or area of the building?	☐ No ☒ Yes (height, area, or both)
Is the building equipped with smoke detectors?	☐ No ☒ Yes
Is the building equipped with a fire alarm system?	☐ No ☒ Yes
Does the building have an emergency voice system?	☐ No ☒ Yes
Number of exit stairs:	2
Minimum distance between exit stairs (m):	10 m
Are exit stairs pressurized (smoke-free)?	☐ No ☒ Yes

ADDITIONAL QUESTIONS

1. Describe any measures taken to prevent fires during building construction.

   Fire extinguishers
   Fire risk analysis and preventive actions

2. Explain if any custom fire tests (e.g., furnished compartment fire experiments, fire tests of connection details, etc.) were (or will be) conducted to satisfy the local authority having jurisdiction.

   No test, only calculations

3. Are the primary framing members left exposed, or are they protected? If the primary framing members are protected, explain how (e.g., one 16 mm layer of F-type gypsum board, two 16 mm layers of F-type gypsum board, etc.)

   Primary framing members are protected (fire protective paint) and exposed to fire.

4. Are the timber connections exposed or protected? If the connections are protected, explain how.

   Timber connections are protected using fire mastics, Securo cavity vent protectors.

5. What fraction of the interior wood floor, wall, and ceiling surfaces are left exposed? How are the unexposed surfaces protected?

   CLT panels, glulam beams and columns left exposed, surfaces covered with fire protective paint.

APPENDIX B

GUIDELINES FOR FIRE SAFETY ON EXPAN CONSTRUCTION SITES

(CONSISTING OF 2 PAGES)

EXPAN
STRUCTURAL TIMBER SOLUTIONS

TECHNICAL BULLETIN No. 1 | DECEMBER 2012

Guidelines for Fire Safety on EXPAN Construction Sites

BACKGROUND

Fires can occur frequently on building construction sites, due to the nature of the works which are undertaken at this time. The most common cause of such fires is malicious arson from outside the construction site, when fires are deliberately lit for a wide variety of reasons. The other major causes of construction site fires are accidental ignition as a result of hot work, heating equipment or accidents.

If a fire starts, large amounts of combustible material can allow the fire to grow rapidly. Rubbish piles are commonplace on many construction sites, and these can provide the fuel for rapid fire growth. Timber building materials can also act as a fuel source, especially if many small pieces of timber are available to fuel a growing fire. For this reason, more care is needed on timber building sites than on other sites where no combustible material is available.

Massive timber, such as the pre-fabricated LVL elements used in most EXPAN buildings, is difficult to ignite, hence it is a much lower fire hazard than light timber frames used in typical houses, where there is a much larger surface area of unprotected timber exposed to the fire. Nevertheless, all wood can burn, so appropriate safety measures should be taken.

In the finished building, timber structural materials provide no greater fire hazard than steel or concrete, but this is not always true during construction, before installation of fire protection measures such as fire protective Gib board, fire sprinklers, and other active or passive fire systems. Environmental conditions and the arrangement and species of timber can also play a significant role in the severity of any unwanted fire.

With much taller and larger timber buildings now being built around the world, the potential fire risk is larger than in the past. The risk to life safety, property damage and the threat to neighbouring properties increases with the size of any fire, so a sensible fire protection strategy is recommended for all building sites.

FIRE SAFETY MANAGEMENT

A number of key management concepts are necessary to reduce the likelihood of fire ignition, and failing this, to control the growth and spread of any unwanted fire until extinguishment by workers on site, or the Fire Service.

The overall strategy is to:

1. Prevent access to the building site after hours.
2. Undertake a rigorous fire risk assessment, as part of an overall fire safety plan.
3. Plan for emergencies.
4. Prevent ignition and mitigate fire risk as much as possible.
5. Identify and manage potential fuel.
6. Implement early installation of fire safe construction.

Prevent Access to the Construction Site After Hours

- Maintain perimeter fencing when the site is closed.
- Control all points of entry on to the site.
- Provide after-hours security and surveillance.

Fire Safety Plan

- Identify the site fire safety officer (and deputy) responsible for on-site fire safety.
- Write the site fire safety plan. This to be done by the site fire safety officer in cooperation with the local Fire Service and the design fire engineer for the building.
- Establish reporting lines from the site fire safety officer to the site foreman.

Plan for Emergencies

- Document emergency procedures, escape routes and safe assembly points.
- Ensure regular communication with the local Fire Service.
- Maintain emergency access routes with signs.
- Carry out fire evacuation trials.
- Document training and assigned responsibilities of site operatives.

Prevent Ignition

- Implement safe working procedures and training to minimise the risk of fire ignition.
- Identify and eliminate site specific ignition sources.
- Establish safe working rules for hot-work. Inspect hot-work areas 4 hours after finishing.

- No smoking on site.
- Monitor use of electrical tools, and maintain safe site electrical systems.

Identify and Manage Potential Fuel Sources

- Identify site specific sources of combustible materials.
- Remove rubbish and other hazardous combustible materials from the site.
- Maintain good housekeeping.
- Ensure correct storage of flammable materials, solids and liquids.
- Manage gas installations.

Early Installation of Fire Safety Measures

- Make site hoses available for fire fighting, well distributed around the site.
- Install fire extinguishers immediately when each part of the building is accessible.
- Ensure early installation of windows and doors to prevent illegal access, also to limit ventilation.
- Provide temporary fire walls to divide big buildings into a number of smaller more manageable sections, with fire doors between them.
- Install fire detection and alarm systems as construction proceeds.
- Arrange early placement of plasterboard wall linings and ceilings to protect exposed timber.
- Install fire sprinklers as soon as possible.

MAINTENANCE OF FIRE PROTECTION

It is suggested that the contractor should:

- Keep a copy of this document on display in the site office, and
- Maintain monthly monitoring of all items listed above.

Structural Timber Innovation Company Ltd
P O Box 8211, Riccarton, Christchurch, 8440, New Zealand
T: 0800 222 602 W: www.expan.co.nz

APPENDIX C

REFERENCES

(CONSISTING OF 12 PAGES)

[1] A. Buchanan, "Fire Resistance of Multi-Storey Timber Buildings," in *10th Asia-Oceania Symposium on Fire Science and Technology*, Tsukuba, Japan, 2015, pp. 9-16. doi:10.1007/978-981-10-0376-9_2
[2] B. Östman and D. Rydholm, "National Fire Regulations in Relation to the Use of Wood in European and Some Other Countries," Trätek, Swedish Institute for Wood Technology Research, Stockholm, Sweden, Publication 0212044, 2002 (partly updated 2006).
[3] M. Klippel, J. Schmid, and A. Frangi, "Fire Design of CLT," in *Joint Conference of COST Actions FP1402 and FP1404 on CLT* Stockholm, Sweden, 2016.
[4] M. Sultan, "Performance of Different Temperature Sensors in Standard Fire Resistance Test Furnaces," *Fire Technology,* vol. 46, pp. 853-881, 2010. doi:10.1007/s10694-010-0166-9
[5] D. Hopkin, M. Milner, and S. Anastasov, "A UK Engineering Approach to Mitigation of Fire Spread Risks from Timber Frame Construction Sites," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 130-133.
[6] P. Eriksson, T. Nord, and B. Östman, "Kartläggning av Brandincidenter i Flervåningshus med Trästomme – Erfarenheter från 20 Års Brukande," SP Sveriges Tekniska Forskningsinstitut, Borås, Sweden, SP Report 2016:12, 2016.
[7] T. Lennon, M. Bullock, and V. Enjily, "The Fire Resistance Of Medium-Rise Timber Frame Buildings," BRE, Watford, UK., BRE Report No 79485-1, 2000.
[8] P. Hovde and H. Landrø, "Fire Safety of Wooden Buildings in Urban Areas," in *Interflam 2004, 10th International Fire Conference*, Edinburgh, Scotland, 2004, pp. 525-530.
[9] A. Frangi and M. Fontana, "Fire Safety of Multistorey Timber Buildings," *Structures and Buildings,* vol. 163, pp. 213–226, 2010. doi: 10.1680/stbu.2010.163.4.213
[10] B. Östman, "Fire Safety in Timber Buildings - First European Guideline," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1823-1828.
[11] R. Gerard, D. Barber, and A. Wolski, "Fire Safety Challenges of Tall Wood Buildings," Fire Protection Research Foundation, Quincy, MA, 2013.
[12] J. Su and G. Lougheed, "Report to Research Consortium for Wood and Wood Hybrid Mid-Rise buildings – Fire Safety Summary – Fire Research Conducted for the Project on Mid-Rise Wood Construction," National Research Council Canada, Ottawa, ON, Canada., Client Report: A1-004377.1, 2014.
[13] D. Barber and R. Gerard, "Summary of the Fire Protection Foundation Report - Fire Safety Challenges of Tall Wood Buildings," *Fire Science Reviews,* vol. 4, 2015. doi 10.1186/s40038-015-0009-3
[14] A. Buchanan, B. Östman, and A. Frangi, "White Paper: Fire Resistance of Timber Structures," in *International R&D Roadmap for Fire Resistance of Structures: Summary of NIST/CIB Workshop*, J. Yang, M. Bundy, J. Gross, A. Hamins, F. Sadek, and A. Raghunathan, Eds. Gaithersburg, MD: National Institute of Standards and Technology, 2015, pp. F46-F91.
[15] D. Brandon and B. Östman, "Fire Safety Challenges of Tall Wood Buildings – Phase 2: Task 1 - Literature Review," Fire Protection Research Foundation Quincy, MA, Report number: FRPF-2016-14, 2016.
[16] A. Frangi and M. Fontana, "Charring Rates and Temperature Profiles of Wood Sections," *Fire and Materials,* vol. 27, pp. 91–102, 2003. doi: 10.1002/fam.819
[17] J. König and J. Schmid, "Bonded Timber Deck Plates in Fire," in *International Council for Research and Innovation in Building and Construction, Working Commission W18 - Timber Structures, Meeting 40*, 2007.
[18] A. Frangi, M. Fontana, M. Knobloch, and G. Bochicchio, "Fire Behaviour of Cross-Laminated Solid Timber Panels," in *Fire Safety Science, 9th International Symposium* Karlsruhe, Germany, 2008, pp. 1279-1290. doi:10.3801/IAFSS.FSS.9-1279
[19] A. Frangi, M. Fontana, e. Hugi, and R. Jöbstl, "Experimental Analysis of Cross-Laminated Timber Panels in Fire," *Fire Safety Journal,* vol. 44, pp. 1078–1087, 2009. doi:10.1016/j.firesaf.2009.07.007

[20] T. Yang, S. Wang, M. Tsai, and C. Lin, "The Charring Depth and Charring Rate of Glued Laminated Timber After a Standard Fire Exposure Test," *Building and Environment,* vol. 44, pp. 231-236, 2009. doi: 10.1016/j.buildenv.2008.02.010

[21] K. Friquin, "Experimental Charring Rates for Cross-Laminated Timber Panels Compared to Calculated Charring Rates," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1659-1664.

[22] J. Schmid, J. König, and J. Köhler, "Fire-Exposed Cross-Laminated Timber – Modelling And Tests," in *World Conference on Timber Engineering* Trento, Italy, 2010, pp. 3268-3276.

[23] S. Craft and J. Mehaffey, "Investigation of the Behavior of CLT Panels Exposed to Fire," in *12rth Fire and Materials Conference*, San Francisco, CA, 2011, pp. 441-454.

[24] M. Fragiacomo, A. Menis, I. Clemente, G. Bochicchio, and B. Tessadri, "Experimental and Numerical Behaviour of Cross-Laminated Timber Floors in Fire Conditions," in *World Conference on Timber Engineering* Auckland, New Zealand, 2012, pp. 177-178.

[25] P. Spellman, "The Fire Performance of Post-Tensioned Timber Beams," ME Thesis, University of Canterbury, Christchurch, New Zealand, 2012.

[26] P. Spellman, D. Carradine, A. Abu, P. Moss, and A. Buchanan, "Full-Scale Fire Tests of Post Tensioned Timber Beams," in *World Conference on Timber Engineering* Auckland, New Zealand, 2012, pp. 229-230.

[27] M. Stepinac, V. Rajcic, B. Androic, and D. Cizmar, "Reliability of Glulam Beams Exposed to Fire," in *World Conference on Timber Engineering* Auckland, New Zealand, 2012, pp. 127-128.

[28] M. Aguanno, "Fire Resistance Tests of Cross-Laminated Timber Floor Panels: An Experimental and Numerical Analysis," MS Thesis, Carleton University, Ottawa, ON, Canada, 2013.

[29] M. Aguanno, G. Hadjisophocleous, and S. Craft, "Fire Resistance Tests of Cross-Laminated Timber Floor Panels: An Experimental and Numerical Analysis," in *13rth Fire and Materials Conference*, San Francisco, CA, 2013, pp. 115-125.

[30] R. Costello, "The Fire Performance of Post-Tensioned Timber Buildings," ME Thesis, University of Canterbury, Christchurch, New Zealand, 2013.

[31] C. Dagenais, L. Osborne, and N. Bénichou, "Full-Scale Fire Performance of Cross-Laminated Timber Walls and Floors," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1157-1168.

[32] M. Fragiacomo, A. Menis, I. Clemente, G. Bochicchio, and A. Ceccotti, "Fire Resistance of Cross-Laminated Timber Panels Loaded Out of Plane," *Journal of Structural Engineering,* vol. 139, 2013. doi:10.1061/(ASCE)ST.1943-541X.0000787#sthash.PqkAGXCb.dpuf

[33] J. O'Neill, "The Fire Performance of Timber Floors in Multi-Storey Buildings," Ph.D. Thesis, University of Canterbury, Christchurch, New Zealand, 2013.

[34] J. Schmid, M. Klippel, A. Just, and A. Frangi, "Comparison of the Fire Resistance of Timber Members in Tests and Calculation Models," in *International Council for Research and Innovation in Building and Construction, Working Commission W18 – Timber Structures, Meeting 46*, 2013.

[35] J. Schmid, A. Menis, M. Fragiocomo, L. Boström, A. Just, A. Gustafsson, and G. Bochicchio, "The Load-Bearing Performance of Wall Elements in Full-Scale Fire Tests," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1143-1155.

[36] R. Costello, A. Abu, P. Moss, and A. Buchanan, "Full Scale Tests of Timber Box Beams in Fire Conditions," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 601-608.

[37] H. Kinjo, S. Yusa, T. Horio, T. Hirashima, T. Matsumoto, and K. Saito, "Fire Performance, Including the Cooling Phase, of Structural Glued Laminated Timber Beams," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 593-600.

[38] M. Klippel, C. Leyder, A. Frangi, M. Fontana, F. Lam, and A. Ceccotti, "Fire Tests on Loaded Cross-Laminated Timber Wall and Floor Elements," *Fire Safety Science,* vol. 11, pp. 626-639, 2014. doi: 10.3801/IAFSS.FSS.11-626

[39] J. Schmid, M. Klippel, A. Just, and A. Frangi, "Review and Analysis of Fire Resistance Tests of Timber Members in Bending, Tension and Compression with Respect to the Reduced Cross-Section Method," *Fire Safety Journal,* vol. 68, pp. 81–99, 2014. 10.1016/j.firesaf.2014.05.006
[40] M. Klippel and A. Frangi, "Fire Behaviour of Cross- Laminated Timber (CLT)," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 103-106.
[41] S. Månsson, D. Ronstad, D. Lange, and L. Boström, "Mini- Furnace Testing of Timber Elements Exposed to Parametric Fires," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 93-94.
[42] J. Schmid, M. Klippel, A. Liew, A. Just, and A. Frangi, "Analysis Of Fire Resistance Tests On Timber Column Buckling With Respect To The Reduced Cross-Section Method," in *International Network on Timber Engineering Research , Meeting 48* Karlsruhe, Germany: Timber Scientific Publishing, 2015, pp. 317-332.
[43] J. Schmid, A. Menis, M. Fragiacomo, I. Clemente, and G. Bochicchio, "Behaviour of Loaded Cross-Laminated Timber Wall Elements in Fire Conditions," *Fire Technology,* vol. 51, pp. 1341-1370, 2015. doi:10.1007/s10694-015-0516-8
[44] K. Yusuke, H. Kinjo, T. Hirashima, S. Yusa, and K. Saito, "Deflection Behavior and Load-Bearing-Period of Structural Glued Laminated Timber Beams in Fire Including Cooling Phase," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 667-674.
[45] M. Janssens and J. Huczek, "Using CFAST and FDS to Evaluate the Response of CLT in Natural and Standard Fires," in *15rth Fire and Materials Conference*, San Francisco, CA, 2017, pp. 567-578.
[46] A. Buchanan and P. Moss, "Design of Epoxied Steel Rods in Glulam Timber," in *Pacific Timber Engineering Conference* PTEC, 1999, pp. 286-293.
[47] S. Harris, "Fire Resistance of Epoxy-grouted Steel Rod Connections in Laminated Veneer Lumber (LVL)," University of Canterbury, Christchurch, New Zealand, Fire Engineering Research Report 04/7, 2004.
[48] C. Erchinger, A. Frangi, and A. Mischler, "Thermal Investigations on Multiple Shear Steel-to-Timber Connections," in *9th World Conference on Timber Engineering* Portland, Oregon, USA: Curran Associates, Red Hook, NY, 2006, pp. 263-270.
[49] P. Lau, "Fire Resistance of Connections in Laminated Veneer Lumber," University of Canterbury, Christchurch, New Zealand, Fire Engineering Research Report 06/3, 2006.
[50] T. Chuo, "Fire Performance of Connections in Laminated Veneer Lumber," Canterbury University, Christchurch, New Zealand, Fire Engineering Research Report 07/4, 2007.
[51] P. Moss, A. Buchanan, M. Fragiacomo, P. Lau, and T. Chuo, "Fire Performance of Bolted Connections in Laminated Veneer Lumber," *Fire and Materials,* vol. 33, pp. 223-243, 2009. doi: 10.1002/fam.999
[52] A. Frangi, C. Erchinger, and M. Fontana, "Experimental Fire Analysis of Steel-to-Timber Connections Using Dowels and Nails," *Fire and Materials,* vol. 34, pp. 1–19, 2010. doi: 10.1002/fam.994
[53] P. Moss, A. Buchanan, M. Fragiocomo, and C. Austruy, "Experimental Testing and Analytical Prediction of the Behaviour of Timber Bolted Connections Subjected to Fire," *Fire Technology,* vol. 46, pp. 129-148, 2010. doi: 10.1007/s10694-009-0096-6
[54] L. Peng, G. Hadjisophocleous, J. Mehaffey, and M. Mohammad, "On the Fire Performance of Wood-Wood-Wood and Wood-Steel-Wood Connections Using Bolts and Dowels as Fasteners," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 83-94.
[55] L. Peng, G. Hadjisophocleous, J. Mehaffey, and M. Mohammad, "Fire Resistance Performance of Unprotected Wood–Wood–Wood And Wood–Steel–Wood Connections: A Literature Review and New Data Correlations," *Fire Safety Journal,* vol. 45, pp. 392–399, 2010. doi:10.1016/j.firesaf.2010.08.003

[56] M. Audebert, D. Dhima, A. Bouchaïr, and M. Taazount, "Experimental and Numerical Analysis of the Thermo-Mechanical Behaviour of Steel-to-Timber Connections in Tension Perpendicular to the Grain," in *Structures in Fire, Seventh International Conference*, Zurch, Switzerland, 2012, pp. 367-376. doi: 10.3929/ethz-a-007050197

[57] D. Dhima, M. Audebert, A. Bouchaïr, and M. Taazount, "Experimental and Numerical Analysis of the Thermo-Mechanical Behavior of Steel-to-Timber Connections in Bending," in *Structures in Fire, Seventh International Conference*, Zurch, Switzerland, 2012, pp. 407-416. doi: 10.3929/ethz-a-007050197

[58] S. Ali and G. Hadjisophocleous, "Full-Scale Tests to Study the Influence of Various Parameters on the Fire Performance of Hybrid Timber Connections," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1169-1179.

[59] V. Hofmann, M. Gräfe, N. Werther, and S. Winter, "Fire Resistance of Primary Beam – Secondary Beam Connections in Timber Structures," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 529-536.

[60] P. Palma, A. Frangi, E. Hugi, P. Cachim, and H. Cruz, "Fire Resistance Tests on Beam-To-Column Shear Connections," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 545-556.

[61] P. Racher, D. Dhima, M. Audebert, A. Bouchaïr, and C. Florence, "Fire Behaviour of Blind Dovetail Timber Connections," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 557-566.

[62] P. Palma, A. Frangi, E. Hugi, P. Cachim, and H. Cruz, "Fire Resistance Tests on Timber Beam-to-Column Shear Connections," *Journal of Structural Fire Engineering,* vol. 7, pp. 41–57, 2016. doi: 10.1108/JSFE-03-2016-004

[63] C. Gonzalez, O. Salem, and G. Hadjisophocleous, "Performance of Beam-To-Column Concealed Connections in Standard Fires," in *15rth Fire and Materials Conference*, San Francisco, CA, 2017, pp. 629-642.

[64] L. D. Tsantaridis, B. A. L. Östman, and J. König, "Fire Protection of Wood by Different Gypsum Plasterboards," *Fire and Materials,* vol. 23, pp. 45-48, 1999. doi:10.1002/(SICI)1099-1018(199901/02)23:1<45::AID-FAM662>3.0.CO;2-6

[65] R. Thomas, M. Sultan, and J. Latour, "Impact of the Variability of Type X Gypsum Board," in *9rth Fire and Materials Conference*, San Francisco, CA, 2005, pp. 131-137.

[66] A. Bwalya, M. Sultan, and R. Thomas, "Impact of Board Orientation on the Fire Performance of Regular Gypsum Board Walls," in *10rth Fire and Materials Conference*, San Francisco, CA, 2007, pp. 119-120.

[67] E. Elewini, M. Sultan, and G. Hadjisophocleous, "Gypsum Board Fall-Off in Floor Assemblies Exposed to a Standard Fire," in *10rth Fire and Materials Conference*, San Francisco, CA, 2007, pp. 117-118.

[68] R. White, "Fire Resistance of Wood Members with Directly Applied Protection," in *11rth Fire and Materials Conference*, San Francisco, CA, 2009, pp. 463-474.

[69] A. Frangi, V. Schleifer, M. Fontana, and E. Hugi, "Experimental and Numerical Analysis of Gypsum Plasterboards in Fire," *Fire Technology,* vol. 46, pp. 149–167, 2010. doi:10.1007/s10694-009-0097-5

[70] A. Just, "Structural Fire Design of Timber Frame Assemblies Insulated by Glasswool and Covered by Gypsum Plasterboards," D.Sc. Thesis, Tallinn University of Technology, Tallinn, Estonia, 2010.

[71] A. Just, J. Schmid, and J. König, "Failure Times of Gypsum Boards," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1695-1700.

[72] A. Just, J. Schmid, and J. König, "Failure Times of Gypsum Boards," in *Structures in Fire, Sixth International Conference*, East Lansing, MI, USA, 2010, pp. 1695-1700.

[73] T. Lennon, D. Hopkin, J. El-Rimawi, and V. Silberschmidt, "Large Scale Natural Fire Tests On Protected Engineered Timber Floor Systems," *Fire Safety Journal,* vol. 45., pp. 168-182, 2010. doi:10.1016/j.firesaf.2010.02.006

[74] B. Östman, "Fire Protection Ability of Wood Products - A Status Report," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 71-81.
[75] M. Sultan, "Comparison of Gypsum Board Fall-off in Wall and Floor Assemblies Exposed to Furnace Heat," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1677-1682.
[76] A. Just, J. Schmid, and J. König, "Gypsum Plasterboards and Gypsum Fibreboards - Protective Times for Fire Safety Design of Timber Structures," in *International Council for Research and Innovation in Building and Construction: Working Commission W18 – Timber Structures CIB-W18 Meeting 44* Alghero, Italy, 2011, pp. Paper 16-1.
[77] A. Just, J. Schmid, and B. Östman, "Fire Protection Abilities Provided by Gypsum Plasterboards," in *World Conference on Timber Engineering* Aukland, New Zealand, 2012, pp. 540-544.
[78] A. Just, J. Schmid, N. Werther, and A. Frangi, "Fire Protection of Timber Members – Determination of the Fire Protection System Characteristics for the Verification of the Load-Bearing Resistance by Means of Calculation Models," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 567-576.
[79] D. Kolaitis, E. Asimakopoulou, and F. M., "Fire Protection of Light and Massive Timber Elements Using Gypsum Plasterboards and Wood Based Panels: A Large-Scale Compartment Fire Test.," *Construction and Building Materials,* vol. 73, pp. 163-170, 2014. doi:10.1016/j.conbuildmat.2014.09.027
[80] B. Östman and L. Boström, "Fire Protection Ability of Wood Coverings," *Fire Technology,* vol. 51, pp. 1475-1493, 2015. doi:10.1007/s10694-014-0452-z
[81] B. Andres and P. van Hees, "Mechanical Properties of Gypsum Plasterboard Exposed to Standard Fires," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1051-1062.
[82] B. Kandola, A. Alkazaleh, and G. Milnes, "The Fire Behaviour of Gypsum Boards Incorporating Phase Change Materials For Energy Storage in Building Applications," in *15rth Fire and Materials Conference*, San Francisco, CA, 2017, pp. 517-527.
[83] M. Sultan and A. Roy-Poirier, "Gypsum Board Fall-Off Temperature in Floor Assemblies Exposed to Standard Fires," in *Interflam 2007, 11th International Fire Conference*, London, England, 2007, pp. 979-991.
[84] P. Collier, "The Influence of Damage to Passive Fire Protection Systems Caused by Earthquakes," in *13rth Fire and Materials Conference*, San Francisco, CA, 2013, pp. 127-138.
[85] A. Just, K. Kraudok, J. Schmid, and B. Östman, "Protection by Gypsum Plasterboards - State of the Art," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 107-110.
[86] M. Janssens, "Fire Resistance of Exposed Timber Beams and Columns," in *3rd Fire and Materials Conference*, Crystal City, VA, 1994, pp. 31-40.
[87] T. Harada and S. Uesugi, "Fire Resistance of Engineered Wood for Structural Members," in *Interflam 1999, 8th International Fire Conference*, Edinburgh, Scotland, 1999, pp. 1241-1245.
[88] J. König, "Structural Fire Design of Timber Structures According to Eurocode 5," in *Fire Safety Science, 8th International Symposium*, Beijing, China, 2005, pp. 303-313. doi:10.3801/IAFSS.FSS.8-303
[89] J. König, "Structural Fire Design According to Eurocode 5 - Design Rules and Their Background," *Fire and Materials,* vol. 29 pp. 147-163, 2005. doi: 10.1002/fam.873
[90] J. Schmid, J. König, and J. Köhler, "Design Model for Fire Exposed Cross-Laminated Timber," in *Structures in Fire, Sixth International Conference*, East Lansing, MI, USA, 2010, pp. 511-519.
[91] M. Klippel, J. Schmid, A. Frangi, and 2012, "The Reduced Cross-Section Method for Timber Members Subjected to Compression, Tension and Bending in Fire," in *International Council for Research and Innovation in Building and Construction, Working Commission W18 – Timber Structures, Meeting 45*, 2012.

[92] J. Schmid, J. König, and A. Just, "The Reduced Cross-Section Method for the Design of Timber Structures Exposed to Fire–Background, Limitations and New Developments," *Structural Engineering International,* vol. 22, pp. 514-522, 2012. 10.2749/101686612X13363929517578
[93] M. Teibinger, "Fire Resistance of Timber Construction - Evaluation of Improved Design Models," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1465-1476.
[94] S. Ali, A. Akotuah, J. Erochko, and G. Hadjisophocleous, "Design Model for Fire Exposed Cross-Laminated Timber," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 511-520.
[95] M. Klippel, J. Schmid, A. Frangi, and G. Fink, "Fire Design of Glued-Laminated Timber Beams with Regard to the Adhesive Performance Using the Reduced Cross-Section Method," in *International Network on Timber Engineering Research, Meeting 47* Karlsruhe, Germany: Timber Scientific Publishing, 2014, pp. 337-348.
[96] J. Schmid, A. Just, M. Klippel, M. Fragiacomo, and D. Lange, "Verification of the Load-Bearing Resistance of Timber Members by Means of the Reduced Cross-Section Method – Background to the Eurocode Model and Comparison to Fire Tests in Bending," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 577-584.
[97] J. Schmid, A. Just, M. Klippel, and M. Fragiacomo, "The Reduced Cross-Section Method For Evaluation Of The Fire Resistance Of Timber Members: Discussion And Determination Of The Zero-Strength Layer," *Fire Technology,* vol. 51, pp. 1285-1309, 2015. doi:10.1007/s10694-014-0421-6
[98] A. Bartlett, R. Hadden, L. Bisby, and B. Lane, "Sectional Analysis of Cross-Laminated Timber as a Design for Fire Methodology," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 684-691.
[99] M. Klippel, J. Schmid, and A. Frangi, "Fire Design of CLT," in *Joint Conference of COST Actions FP1402 and FP1404: Cross Laminated Timber – A Competitive Wood Product for Visionary and Fire Safe Buildings* Stockholm, Sweden, 2016.
[100] S. Craft and I. Van Zeeland, "Rationalization of Cross-Laminated Timber Design Standards," in *15rth Fire and Materials Conference*, San Francisco, CA, 2017, pp. 643-654.
[101] M. Teibinger, "Fire Stops and Fire-Resistant Sealing in Timber Construction," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 723-734.
[102] N. Werther, J. Denzler, R. Stein, and S. Winter, "Detailing of CLT with Respect to Fire Resistance," in *Joint Conference of COST Actions FP1402 and FP1404: Cross Laminated Timber – A Competitive Wood Product for Visionary and Fire Safe Buildings* Stockholm, Sweden, 2016.
[103] L. Wullschleger and K. Ghazi Wakili, "Numerical Parameter Study of the Thermal Behaviour of a Gypsum Plaster Board at Fire Temperatures," *Fire and Materials,* vol. 32, pp. 103-119, 2008. doi:10.1002/fam.956
[104] M. Janssens, "Eurocode 5 Advanced Method Predictions of Glulam Beam Fire Test Performance," in *12rth Fire and Materials Conference*, San Francisco, CA, 2011, pp. 427-439.
[105] L. Peng, G. Hadjisophocleous, J. Mehaffey, M. Mohammad, and L. Lu, "Calculating Fire Resistance of Timber Connections," in *12rth Fire and Materials Conference*, San Francisco, CA, 2011, pp. 455-465.
[106] D. Hopkin, T. Lennon, J. El-Rimawi, and V. Silberschmidt, "A Numerical Study of Gypsum Plasterboard Behaviour under Standard and Natural Fire Conditions," *Fire and Materials,* vol. 36, pp. 107–126, 2012. doi: 10.1002/fam.1092
[107] J. O'Neill, A. Abu, D. Carradine, P. Moss, and A. Buchanan, "Modelling the Performance of Structural Timber Floors," in *Structures in Fire, Seventh International Conference*, Zurch, Switzerland, 2012, pp. 397-406. doi: 10.3929/ethz-a-007050197
[108] L. Peng, G. Hadjisophocleous, J. Mehaffey, and M. Mohammad, "Fire Performance of Timber Connections, Part 2: Thermal and Structural Modelling," *Journal of Structural Fire Engineering,* vol. 3, pp. 133-154., 2012. doi: 10.1260/2040-2317.3.2.133

[109] M. Tabaddor, "Modeling the Thermal and Structural Behavior of Wood Beams in a Fire Environment," in *13rth Fire and Materials Conference*, San Francisco, CA, 2013, pp. 209-220.

[110] M. Klippel and A. Frangi, "Numerical Investigations on the Fire Behaviour of Glued-Laminated Timber Beams Taking into Account the Influence of Adhesives," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 537-544.

[111] J. O'Neill, A. Abu, D. Carradine, P. Mossand, and A. Buchanan, "Predicting the Fire Performance of Structural Timber Floors," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 585-592.

[112] M. Fragiacomo and A. Meni, "Evaluation of the Fire Resistance of Cross- Laminated Timber Floor Elements," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 54-57.

[113] M. Janssens, J. Huczek, and N. Albracht, "Performance of Gypsum-Protected CLT and NLT in Natural and Standard Fires," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 1124-1131.

[114] O. Axenenko and G. Thorpe, "The Modelling of Dehydration and Stress Analysis of Gypsum Plasterboards Exposed to Fire," *Computational Materials Science,* vol. 6, pp. 281-294, 1996. doi:10.1016/0927-0256(96)00019-5

[115] N. Bénichou, "Thermal Properties of Components of Lightweight Wood-Framed Assemblies at Elevated Temperatures," in *7rth Fire and Materials Conference*, San Francisco, CA, 2001, pp. 447-458.

[116] G. Thomas, "Thermal properties of gypsum plasterboard at high temperatures," *Fire and Materials,* vol. 26, pp. 37-45, 2002. doi:10.1002/fam.786

[117] S. Cramer, "Mechanical Properties of Gypsum Board at Elevated Temperatures," in *8rth Fire and Materials Conference*, San Francisco, CA, 2003, pp. 33-42.

[118] C. N. Ang and Y. C. Wang, "The Effect of Water Movement on Specific Heat of Gypsum Plasterboard in Heat Transfer Analysis under Natural Fire Exposure," *Construction and Building Materials,* vol. 18, pp. 505-515, 2004. doi:10.1016/j.conbuildmat.2004.04.003

[119] A. Belmiloudi and G. Le Meur, "Mathematical and Numerical Analysis of Dehydratation of Gypsum Plasterboards Exposed to Fire," *Applied Mathematics and Computation,* vol. 163, pp. 1023-1041, 2005. doi:10.1016/j.amc.2004.06.013

[120] J. König, "Effective Thermal Actions and Thermal Properties of Timber Members in Natural Fires " *Fire and Materials,* vol. 30, pp. 51-63, 2006. doi:10.1002/fam.898

[121] K. Ghazi Wakili, E. Hugi, L. Wullschleger, and T. Frank, "Gypsum Board in Fire - Modeling and Experimental Validation," *Journal of Fire Sciences,* vol. 25, pp. 267-282, 2007. doi:10.1177/0734904107072883

[122] S. Craft, B. Isgor, G. Hadjisophocleous, and J. Mehaffey, "Predicting the Thermal Response of Gypsum Board Subjected to a Constant Heat Flux," *Fire and Materials,* vol. 32, pp. 333-355, 2008. doi:10.1002/fam.971

[123] C. N. Ang and Y. C. Wang, "Effect of Moisture Transfer on Specific Heat of Gypsum Plasterboard at High Temperatures," *Construction and Building Materials,* vol. 23, pp. 675-686, 2009. doi:10.1016/j.conbuildmat.2008.02.016

[124] K. Ghazi Wakili and E. Hugi, "Four Types of Gypsum Plaster Boards and their Thermophysical Properties Under Fire Condition," *Journal of Fire Sciences,* vol. 27, pp. 27-43, 2009. doi:10.1177/0734904108094514

[125] A. de Korte and H. Brouwers, "Calculation of Thermal Conductivity of Gypsum Plasterboards at Ambient and Elevated Temperature," *Fire and Materials,* vol. 34, pp. 55-75, 2010. doi:10.1002/fam.1009

[126] S. Park, S. Manzello, D. Bentz, and T. Mizukami, "Determining thermal properties of gypsum board at elevated temperatures," *Fire and Materials,* vol. 34, pp. 237–250, 2010. doi:10.1002/fam.1017

[127] Q. Yu and P. Shipp, "Thermophysical Characterization of Type X Special Fire Resistant Board," in *12rth Fire and Materials Conference*, San Francisco, CA, 2011, pp. 417-428.

[128] M. Gilani and E. Hugi, "Fire Induced Desorption and Migration of Hygroscopic Moisture in Wood," in *Structures in Fire, Seventh International Conference*, Zurch, Switzerland, 2012, pp. 387-396. doi: 10.3929/ethz-a-007050197
[129] G. Semitelos, I. Mandilaras, D. Kontogeorgos, and M. Founti, "Simplified Correlations of Gypsum Board Thermal Properties for Simulation Tools," *Fire and Materials,* vol. 40, pp. 229-245, 2014. doi: 10.1002/fam.2282
[130] D. Kontogeorgos, I. Mandilaras, and M. Founti, "Fire Behavior of Regular and Latent Heat Storage Gypsum Boards," *Fire and Materials,* vol. 39, pp. 507-517, 2015. doi: 10.1002/fam.2246
[131] M. Dodangoda, M. Mahendran, K. Poologanathan, and R. Frost, "Material Characterization and Numerical Modelling of Gypsum Plasterboards in Fire," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 1116-1123.
[132] S. Boadi and G. Hadjisophocleous, "Full Scale Tests on the Performance of Hybrid Timber Connections in Real Fires," in *15rth Fire and Materials Conference*, San Francisco, CA, 2017, pp. 613-628.
[133] B. Jones, "Performance of Gypsum Plasterboard Assemblies Exposed to Real Building Fires," University of Canterbury, Christchurch, New Zealand, Fire Engineering Research Report 01/4, 2001.
[134] T. Hakkarainen, "Post-Flashover Fires in Light and Heavy Timber Construction Compartments," *Journal of Fire Sciences,* vol. 20, 2002. doi:10.1177/0734904102020002074
[135] A. Frangi and M. Fontana, "Fire Performance of Timber Structures under Natural Fire Conditions," in *Fire Safety Science, 8th International Symposium*, Beijing, China, 2005, pp. 279–290. doi: 10.3801/IAFSS.FSS.8-279
[136] A. Frangi, G. Bochicchio, A. Ceccotti, and M. Lauriola, "Natural Full-Scale Fire Test on a 3 Storey XLam Timber Building," in *World Conference on Timber Engineering* Miyazaki, Japan: Engineered Wood Products Association, Madison, WI, USA, 2008.
[137] D. Kolaitis, E. Asimakopoulou, G. Zannis, and M. Founti, "A Natural Fire Test to Assess the Behavior of Modern Timber Construction: Light Timber Frame vs. Glued Laminated Timber," in *Interflam 2013, 13th International Fire Conference*, london, England, 2013, pp. 589-592.
[138] C. McGregor, G. Hadjisophocleous, and S. Craft, "Contribution of Cross-Laminated Timber Panels to Room Fires," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1453-1464.
[139] A. Hevia, "Fire Resistance of Partially Protected Cross-Laminated Timber Rooms," ME Thesis, Carleton University, Ottawa, ON, Canada, 2014.
[140] C. McGregor, "Contribution of Cross-Laminated Timber Panels to Room Fires. ," ME Thesis, Carleton University, Ottawa, ON, Canada, 2014.
[141] C. Dagenais, J. Su, G. Lougheed, L. Osborne, and I. Van Zeeland, "Performance of CLT Construction in Real Fire Conditions," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 47-50.
[142] K. Hox, "Branntest av Massivtre," SP Fire Research, Trondheim, Norway, SPFR-rapport A15101, 2015.
[143] M. Janssens, N. Albracht, and K. Carpenter, "Full-Scale Tests in a Furnished Living Room to Evaluate the Fire Performance of Protected Cross-Laminated and Nail Laminated Timber Construction," Southwest Research Institute, San Antyonio, TX, Final Report for SwRI Project No.: 01.21428.01.001, 2015.
[144] X. Li, X. Zhang, G. Hadjisophocleous, and C. McGregor, "Experimental Study of Combustible and Non-Combustible Construction in a Natural Fire," *Fire Technology,* vol. 51, pp. 1447–1474, 2015. doi:10.1007/s10694-014-0407-4
[145] L. Osborne and C. Dagenais, "Full-Scale Mass Timber Shaft Demonstration Fire," FPInnovations, Pointe-Claire, QC, Canada, 2015.
[146] J. Su and S. Muradori, "Fire Demonstration – Cross-Laminated Timber Stair/Elevator Shaft," National Research Council Canada Ottawa, ON, Canada., Client Report: A1-004377.1, 2015.

[147] K. Hox and G. Baker, "Full-Scale Fire Test of CLT Structure Used for Student Housing," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1087-1093.
[148] P. Whiting, "Behaviour of Light Timber-Framed Floors Subjected to Fire Attack From Above," Building Research Association of New Zealand, Porirua, New Zealand, Study Report No. 117, 2003.
[149] S. Ingberg, "Tests of the Severity of Building Fires," *National Fire Protection Association Quarterly,* vol. 22, pp. 43-61, 1928.
[150] M. Law, "A Relationship Between Fire Grading and Building Design and Contents," Fire Research Station, Borehamwood, England, Fire Research Note No. 877, 1971.
[151] M. Law, "Prediction of Fire Resistance," in *Symposium No. 5: Fire Resistance Requirements for Buildings - A New Approach* Fire Research Station, Borehamwood, England, 1971.
[152] P. Thomas and A. Heselden, "Fully Developed Fires in Single Compartments - A Co-Operative research Programme of the Conseil International du Bâtiment," Fire Research Station, Borehamwood, England, Fire Research Note No. 923, 1972.
[153] T. Harmathy and J. Mehaffey, "Post-Flashover Compartment Fires," *Fire and Materials,* vol. 7, pp. 49-61, 1983. doi: 10.1002/fam.810070202
[154] G. Thomas, A. Buchanan, and C. Fleischman, "Structural Fire Design: The Role of Time Equivalence," in *Fire Safety Science, 5th International Symposium*, Melbourne, Australia, 1997, pp. 607-618. doi:10.3801/IAFSS.FSS.5-607
[155] J. Nyman, "Equivalent Fire Resistance Ratings of Construction Elements Exposed to Realistic Fires," University of Canterbury, Christchurch, New Zealand, Fire Engineering Research Report 02/13, 2002.
[156] H. Gerlich, A. Buchanan, J. Nyman, and C. Wade, "Equivalent Fire Resistance of Drywall Construction Exposed to Compartment Fire," in *8rth Fire and Materials Conference*, San Francisco, CA, 2003, pp. 21-32.
[157] A. Abu, H. Gerlich, and C. Wade, "Limitations of Existing Time-Equivalence Formula for Determining Fire Resistance Requirements of Buildings," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1441-1452.
[158] A. Law, J. Stern-Gottfried , and N. Butterworth, "Solving Design Challenges: Revisiting Time Equivalence," in *Interflam 2013, 13th International Fire Conference*, london, England, 2013, pp. 583-588.
[159] C. Wade, C. Fleischman, M. Spearpoint, and A. Abu, "Revisiting Normalized Heat Load and Its Application in a Computer Fire Model," in *14rth Fire and Materials Conference*, San Francisco, CA, 2015, pp. 682-696.
[160] R. White, "Charring Rates of Diffferent Wood Species," Ph.D. Thesis, University of Wisconsin, Madison, WI, 1988.
[161] W. Gardner and D. Syme, "Charring of Glued-Laminated Beams of Eight Australian-Grown Timber Species and the Effect of 13 mm Gypsum Plasterboard Protection on their Charring," N.S.W. Timber Advisory Council, Sydney, Australia, Technical Report No. 5, ODC 843.4-015, 1991.
[162] P. Collier, "Charring Rates of Timber," Building Research Association of New Zealand, Judgeford, New Zealand, Study Report No. 42, 1992.
[163] R. White and E. Nordheim, "Charring Rate of Wood for ASTM E 119 Exposure," *Fire Technology,* vol. 28, pp. 5–30, 1992. doi: 10.1007/BF01858049
[164] P. Lau, I. Van Zeeland, and R. White, "Modeling the Char Behavior of Structural Timber," in *5rth Fire and Materials Conference*, San Antonio, TX, 1998, pp. 123-135.
[165] S. Inaba, Y. Hasemi, S. Tsuchiya, N. Yasui, M. Yoshida, and N. Kawamura, "Prediction of Fire Exposure and Characteristic Rate of the Burning Behavior of Wood for the Design of a Heavy Timber "Fire-Proof" Building under Localized Fire Scenario," in *10rth Fire and Materials Conference*, San Francisco, CA, 2007, pp. 47-48.
[166] K. Tsai, "Charring Rates for Different Cross Sections of Laminated Veneer Lumber (LVL)," University of Canterbury, Christchurch, New Zealand, Fire Engineering Research Report 10/5, 2010.

[167] A. Frangi and J. König, "Effect of Increased Charring on the Narrow Side of Rectangular Timber Cross-Sections Exposed to Fire on Three or Four Sides," *Fire and Materials,* vol. 35, pp. 593–605, 2011. doi: 10.1002/fam.1078

[168] K. Friquin, "Material Properties and External Factors Influencing the Charring Rate of Solid Wood and Glue- Laminated Timber," *Fire and Materials,* vol. 35, pp. 303-327, 2011. doi: 10.1002/fam.1055

[169] K. Tsai, D. Carradine, P. Moss, and A. Buchanan, "Charring Rates for Double Beams Made from Laminated Veneer Lumber (LVL)," *Fire and Materials,* vol. 37, pp. 58–74, 2012. doi: 10.1002/fam.2112

[170] D. Lange, L. Boström, J. Schmid, and J. Albrektsson, "Charring Rate of Timber In Natural Fires," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 521-528.

[171] A. Bartlett, R. Hadden, L. Bisby, and A. Law, "Analysis of Cross-Laminated Timber Charring Rates Upon Exposure to Non-Standard Heating Conditions," in *14rth Fire and Materials Conference*, San Francisco, CA, 2015, pp. 667-680.

[172] K. Pandtle, "Evaluation of Differences Between the Determination of the Charring Rate Following the DIN and EN Standard Using Comparable Experimental Setups," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 89-90.

[173] M. Tiso, J. Schmid, and M. Fragiacomo, "Charring Behaviour of Cross Laminated Timber with Respect to the Fire Protection, Comparison Of Different Methods," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 58-61.

[174] C. Mindeguia, G. Cueff, V. Drean, and G. Auguin, "Simulation of Charring Depth of Wood-Based Products when Exposed to Non-Standardized Fire Curves," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 675-683.

[175] J. Schmid, D. Brandon, A. Santomaso, U. Wickström, and A. Frangi, "Timber under Real Fire Conditions - The Influence of Oxygen Content and Gas Veloicity on the Charring Behavior," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 692-699.

[176] N. Werther, "External and Internal Factors Influencing the Charring of Timber - an Experimental Study with Respect to Natural Fires and Moisture Conditions," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 650-658.

[177] J. Carlsson and B. Karlsson, "Using CFD Models to Calculate Flame Spread and Fire Growth on Practical Building Façade Materials," in *5rth Fire and Materials Conference*, San Francisco, CA, 2001, pp. 147-158.

[178] B. Östman, "Wooden Façades in Multi-Storey Buildings," in *7rth Fire and Materials Conference*, San Francisco, CA, 2001, pp. 185-196.

[179] T. Hakkarainen and T. Oksanen, "Fire Safety Assessment of Wooden Façades," *Fire and Materials,* vol. 26, pp. 7-27, 2002. doi:10.1002/fam.780

[180] S. Colwell, J. Bregulla, and R. Cullman, "Fire Safety of External Timber Wall Façades," in *Interflam 2007, 11th International Fire Conference* London, England: Interscience Communications, London, England, 2007, pp. 771-777.

[181] J. Anderson and R. Jansson, "Fire Dynamics in Façade Fire Tests: Measurement and Modelling," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 93-104.

[182] M. Giraldo, A. Lacasta, and J. Avellaneda, "CFD Simulation Study on Fire Propagation in Wooden Façades and the Influence of Façade's Geometry," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 36-39.

[183] J. Anderson, L. Boström, and R. Jansson, "Experimental Assessment of Repeatability in Façade Fire Testing," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 653-658.

[184] J. Anderson, L. Boström, and R. Jansson, "Modeling of Fire Exposure in Façade Fire Testing," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1115-1125.

[185] S. Koo, "A Probabilistic and Time Dependent Approach to External Fire Spread and Building Separation Distance," in *Interflam 2016, 14th International Fire Conference* London, England: Interscience Communications, London, England, 2016, pp. 677-682.

[186] M. Nilsson, A. Mossberg, B. Husted, and J. Anderson, "Protection Against External Fire Spread - Horizontal Projections or Spandrels?," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1163-1174.

[187] K. Park, M. Smolka, Y. Yoo, and H. Yoshioka, "Development of the Advanced Technical Method and Test Standard for the Purpose of the Fire Safety of Façade Materials in Buildings," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1103-1114.

[188] M. Smolka, B. Messerschmidt, L. Boström, T. Crimi, V. Dowloing, K. Park, and H. Yoshioka, "Principles of Testing and Regulating Fire Safety of Façades," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 659-664.

[189] E. Janse and P. van de Leur, "Fire Safe Building Separation Distances in the Netherlands," in *Interflam 2001, 9th International Fire Conference*, Edinburgh, Scotland, 2001, pp. 1281-1286.

[190] R. Chitty and S. Kumar, "Building Separation Calcluations Revisited using Advanced Fire Models," in *Interflam 2004, 10th International Fire Conference*, Edinburgh, Scotland, 2004, pp. 447-458.

[191] P. W., L. Hu, R. Yang, Q. LV, F. Tang, Y. Xu, and L. Wang, "Full Scale Test on Fire Spread and Control of Wooden Buildings," *Procedia Engineering,* vol. 11, pp. 355-359, 2011. doi:10.1016/j.proeng.2011.04.669

[192] A. Steen- Hansen, K. Storesund, R. Fjellgaard Mikalsen, J. Stensaas, A. Gagnat Bøe, and K. Hox, "Fire Safety in Towns with Wooden Buildings. Experience from Investigation of Large Fires," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 111-115.

[193] G. De Sanctis, "Generic Risk Assessment for Fire Safety - Performance Evaluation and Optimisation of Design Provisions," Ph.D. Thesis, ETH Zurich, Zurch, Switzerland, 2015.

[194] D. Yung, G. Hadjisophocleous, and H. Takeda, "Comparative Risk Assessments of 3-Storey Wood-Frame and Masonry Construction Appartment Buildings," in *Interflam 1993, 6th International Fire Conference*, Oxford, England, 1993, pp. 499-508.

[195] N. Bénichou, D. Yung, and G. Hadjisophocleous, "Impact of Fire Department Response and Mandatory Sprinkler Protection on Life Risks in Residential Communities," in *Interflam 1999, 8th International Fire Conference*, Edinburgh, Scotland, 1999, pp. 521-532.

[196] B. Karlsson and B. Tómasson, "A Fire-Risk Index Method for Multi-Storey Apartment Buildings," in *Interflam 2001, 9th International Fire Conference*, Edinburgh, Scotland, 2001, pp. 221-232.

[197] A. Barowy, K. Notarianni, and L. Moore-Merrell, "Community Risk Assessment Modeling: Results of Residential Fireground Field Experiments," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1875-1886.

[198] D. Berry, "The Provision of a Risk Information System for the English Fire and Rescue Service," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1493-1498.

[199] C. English and S. Bennett, "Fire Compartment Sizes and the Benefit of Sprinklers - A Risk Based Approach Using Monte Carlo Simulations," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1007-1018.

[200] S. Raue, C. Johnson, D. Bouchlaghem, and S. Konucku, "Supporting Integrated Risk Management Planning for the UK Fire and Rescue Services: Evaluation of Prevention and Protection Activities of Commercial, Public and Heritage Buildings," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1523-1529.

[201] D. Charters and C. Sherwood, "Quantitative Analysis of Fire Risks in Tall Buildings," in *Interflam 2013, 13th International Fire Conference* London, England: Interscience Communications, London, England, 2013, pp. 451-454.

[202] X. Li, P. Rao, X. Zhang, and G. Hadjisophocleous, "A Case Study on the Effect of Building Construction Type, Height, and Area on the Building Fire Risk Using the Fire Risk Assessment Model CURISK," in *14[rth] Fire and Materials Conference*, San Francisco, CA, 2015.

[203] B. Najafi, S. Nowlen, F. Joglar, D. Funk, G. Hannaman, R. Anoba, M. Kazarians, F. Wyant, A. Kolaczkowski, and J. Forester, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities, Volume 2: Detailed Methodology," Electric Power Research Institute (EPRI), Palo Alto, CA, and U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (RES), Washington, D.C., EPRI - 1011989 and NUREG/CR-6850, Vol. 2, 2005.

APPENDIX D

REFERENCES ARRANGED BY TOPIC

(CONSISTING OF 17 PAGES)

TABLE OF CONTENTS

PAGE

1.0 FIRE SAFETY CHALLENGES OF TALL WOOD BUILDINGS 1

2.0 STANDARD FIRE RESISTANCE FURNACE TESTING 1

2.1 Mass Timber Members 1

2.2 Connections 3

2.3 Protective Membranes 4

2.4 Gypsum Board Fall-off 5

2.5 Cooling Phase 6

3.0 SIMPLIFIED CALCULATION METHODS FOR STANDARD FIRE EXPOSURE 6

4.0 DETAILED STRUCTURAL FIRE MODELING FOR STANDARD FIRE EXPOSURE 8

4.1 General 8

4.2 Material Properties 9

5.0 PERFORMANCE-BASED ASSESSMENT 10

5.1 Custom Furnace Tests 10

5.2 Compartment Fire Tests 10

5.3 Simplified Calculation Methods 11

6.0 CHARRING RATE OF MASS TIMBER 12

7.0 CONTRIBUTION OF EXPOSED WOOD 13

7.1 CLT 13

7.2 Façade Fires 14

7.3 Fire Spread to Adjacent Structures 15

8.0 FIRE RISK ASSESSMENT 15

9.0 DETAILING 16

1.0 FIRE SAFETY CHALLENGES OF TALL WOOD BUILDINGS

[1] T. Lennon, M. Bullock, and V. Enjily, "The Fire Resistance Of Medium-Rise Timber Frame Buildings," BRE, Watford, UK., BRE Report No 79485-1, 2000.

[2] P. Hovde and H. Landrø, "Fire Safety of Wooden Buildings in Urban Areas," in *Interflam 2004, 10th International Fire Conference*, Edinburgh, Scotland, 2004, pp. 525-530.

[3] A. Frangi and M. Fontana, "Fire Safety of Multistorey Timber Buildings," *Structures and Buildings,* vol. 163, pp. 213–226, 2010. doi: 10.1680/stbu.2010.163.4.213

[4] B. Östman, "Fire Safety in Timber Buildings - First European Guideline," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1823-1828.

[5] R. Gerard, D. Barber, and A. Wolski, "Fire Safety Challenges of Tall Wood Buildings," Fire Protection Research Foundation, Quincy, MA, 2013.

[6] J. Su and G. Lougheed, "Report to Research Consortium for Wood and Wood Hybrid Mid-Rise buildings – Fire Safety Summary – Fire Research Conducted for the Project on Mid-Rise Wood Construction," National Research Council Canada, Ottawa, ON, Canada., Client Report: A1-004377.1, 2014.

[7] D. Barber and R. Gerard, "Summary of the Fire Protection Foundation Report - Fire Safety Challenges of Tall Wood Buildings," *Fire Science Reviews,* vol. 4, 2015. doi 10.1186/s40038-015-0009-3

[8] A. Buchanan, "Fire Resistance of Multi-Storey Timber Buildings," in *10th Asia-Oceania Symposium on Fire Science and Technology*, Tsukuba, Japan, 2015, pp. 9-16. doi:10.1007/978-981-10-0376-9_2

[9] A. Buchanan, B. Östman, and A. Frangi, "White Paper: Fire Resistance of Timber Structures," in *International R&D Roadmap for Fire Resistance of Structures: Summary of NIST/CIB Workshop*, J. Yang, M. Bundy, J. Gross, A. Hamins, F. Sadek, and A. Raghunathan, Eds. Gaithersburg, MD: National Institute of Standards and Technology, 2015, pp. F46-F91.

[10] D. Brandon and B. Östman, "Fire Safety Challenges of Tall Wood Buildings – Phase 2: Task 1 - Literature Review," Fire Protection Research Foundation Quincy, MA, Report number: FRPF-2016-14, 2016.

2.0 STANDARD FIRE RESISTANCE FURNACE TESTING

2.1 Mass Timber Members

[1] A. Frangi and M. Fontana, "Charring Rates and Temperature Profiles of Wood Sections," *Fire and Materials,* vol. 27, pp. 91–102, 2003. doi: 10.1002/fam.819

[2] J. König and J. Schmid, "Bonded Timber Deck Plates in Fire," in *International Council for Research and Innovation in Building and Construction, Working Commission W18 - Timber Structures, Meeting 40*, 2007.

[3] A. Frangi, M. Fontana, M. Knobloch, and G. Bochicchio, "Fire Behaviour of Cross-Laminated Solid Timber Panels," in *Fire Safety Science, 9th International Symposium* Karlsruhe, Germany, 2008, pp. 1279-1290. doi:10.3801/IAFSS.FSS.9-1279

[4] A. Frangi, M. Fontana, e. Hugi, and R. Jöbstl, "Experimental Analysis of Cross-Laminated Timber Panels in Fire," *Fire Safety Journal,* vol. 44, pp. 1078–1087, 2009. doi:10.1016/j.firesaf.2009.07.007

[5] T. Yang, S. Wang, M. Tsai, and C. Lin, "The Charring Depth and Charring Rate of Glued Laminated Timber After a Standard Fire Exposure Test," *Building and Environment,* vol. 44, pp. 231-236, 2009. doi: 10.1016/j.buildenv.2008.02.010

[6] K. Friquin, "Experimental Charring Rates for Cross-Laminated Timber Panels Compared to Calculated Charring Rates," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1659-1664.
[7] J. Schmid, J. König, and J. Köhler, "Fire-Exposed Cross-Laminated Timber – Modelling And Tests," in *World Conference on Timber Engineering* Trento, Italy, 2010, pp. 3268-3276.
[8] S. Craft and J. Mehaffey, "Investigation of the Behavior of CLT Panels Exposed to Fire," in *12th Fire and Materials Conference*, San Francisco, CA, 2011, pp. 441-454.
[9] M. Fragiacomo, A. Menis, I. Clemente, G. Bochicchio, and B. Tessadri, "Experimental and Numerical Behaviour of Cross-Laminated Timber Floors in Fire Conditions," in *World Conference on Timber Engineering* Auckland, New Zealand, 2012, pp. 177-178.
[10] P. Spellman, "The Fire Performance of Post-Tensioned Timber Beams," ME Thesis, University of Canterbury, Christchurch, New Zealand, 2012.
[11] P. Spellman, D. Carradine, A. Abu, P. Moss, and A. Buchanan, "Full-Scale Fire Tests of Post Tensioned Timber Beams," in *World Conference on Timber Engineering* Auckland, New Zealand, 2012, pp. 229-230.
[12] M. Stepinac, V. Rajcic, B. Androic, and D. Cizmar, "Reliability of Glulam Beams Exposed to Fire," in *World Conference on Timber Engineering* Auckland, New Zealand, 2012, pp. 127-128.
[13] M. Aguanno, "Fire Resistance Tests of Cross-Laminated Timber Floor Panels: An Experimental and Numerical Analysis," MS Thesis, Carleton University, Ottawa, ON, Canada, 2013.
[14] M. Aguanno, G. Hadjisophocleous, and S. Craft, "Fire Resistance Tests of Cross-Laminated Timber Floor Panels: An Experimental and Numerical Analysis," in *13th Fire and Materials Conference*, San Francisco, CA, 2013, pp. 115-125.
[15] R. Costello, "The Fire Performance of Post-Tensioned Timber Buildings," ME Thesis, University of Canterbury, Christchurch, New Zealand, 2013.
[16] C. Dagenais, L. Osborne, and N. Bénichou, "Full-Scale Fire Performance of Cross-Laminated Timber Walls and Floors," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1157-1168.
[17] M. Fragiacomo, A. Menis, I. Clemente, G. Bochicchio, and A. Ceccotti, "Fire Resistance of Cross-Laminated Timber Panels Loaded Out of Plane," *Journal of Structural Engineering,* vol. 139, 2013. doi:10.1061/(ASCE)ST.1943-541X.0000787#sthash.PqkAGXCb.dpuf
[18] J. O'Neill, "The Fire Performance of Timber Floors in Multi-Storey Buildings," Ph.D. Thesis, University of Canterbury, Christchurch, New Zealand, 2013.
[19] J. Schmid, M. Klippel, A. Just, and A. Frangi, "Comparison of the Fire Resistance of Timber Members in Tests and Calculation Models," in *International Council for Research and Innovation in Building and Construction, Working Commission W18 – Timber Structures, Meeting 46*, 2013.
[20] J. Schmid, A. Menis, M. Fragiocomo, L. Boström, A. Just, A. Gustafsson, and G. Bochicchio, "The Load-Bearing Performance of Wall Elements in Full-Scale Fire Tests," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1143-1155.
[21] R. Costello, A. Abu, P. Moss, and A. Buchanan, "Full Scale Tests of Timber Box Beams in Fire Conditions," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 601-608.
[22] H. Kinjo, S. Yusa, T. Horio, T. Hirashima, T. Matsumoto, and K. Saito, "Fire Performance, Including the Cooling Phase, of Structural Glued Laminated Timber Beams," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 593-600.
[23] M. Klippel, C. Leyder, A. Frangi, M. Fontana, F. Lam, and A. Ceccotti, "Fire Tests on Loaded Cross-Laminated Timber Wall and Floor Elements," *Fire Safety Science,* vol. 11, pp. 626-639, 2014. doi: 10.3801/IAFSS.FSS.11-626
[24] J. Schmid, M. Klippel, A. Just, and A. Frangi, "Review and Analysis of Fire Resistance Tests of Timber Members in Bending, Tension and Compression with Respect to the Reduced Cross-Section Method," *Fire Safety Journal,* vol. 68, pp. 81–99, 2014. 10.1016/j.firesaf.2014.05.006

[25] M. Klippel and A. Frangi, "Fire Behaviour of Cross- Laminated Timber (CLT)," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 103-106.
[26] S. Månsson, D. Ronstad, D. Lange, and L. Boström, "Mini- Furnace Testing of Timber Elements Exposed to Parametric Fires," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 93-94.
[27] J. Schmid, M. Klippel, A. Liew, A. Just, and A. Frangi, "Analysis Of Fire Resistance Tests On Timber Column Buckling With Respect To The Reduced Cross-Section Method," in *International Network on Timber Engineering Research , Meeting 48* Karlsruhe, Germany: Timber Scientific Publishing, 2015, pp. 317-332.
[28] J. Schmid, A. Menis, M. Fragiacomo, I. Clemente, and G. Bochicchio, "Behaviour of Loaded Cross-Laminated Timber Wall Elements in Fire Conditions," *Fire Technology,* vol. 51, pp. 1341-1370, 2015. doi:10.1007/s10694-015-0516-8
[29] K. Yusuke, H. Kinjo, T. Hirashima, S. Yusa, and K. Saito, "Deflection Behavior and Load-Bearing-Period of Structural Glued Laminated Timber Beams in Fire Including Cooling Phase," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 667-674.
[30] M. Janssens and J. Huczek, "Using CFAST and FDS to Evaluate the Response of CLT in Natural and Standard Fires," in *15th Fire and Materials Conference*, San Francisco, CA, 2017, pp. 567-578.

2.2 Connections

[1] A. Buchanan and P. Moss, "Design of Epoxied Steel Rods in Glulam Timber," in *Pacific Timber Engineering Conference* PTEC, 1999, pp. 286-293.
[2] S. Harris, "Fire Resistance of Epoxy-grouted Steel Rod Connections in Laminated Veneer Lumber (LVL)," University of Canterbury, Christchurch, New Zealand, Fire Engineering Research Report 04/7, 2004.
[3] C. Erchinger, A. Frangi, and A. Mischler, "Thermal Investigations on Multiple Shear Steel-to-Timber Connections," in *9th World Conference on Timber Engineering* Portland, Oregon, USA: Curran Associates, Red Hook, NY, 2006, pp. 263-270.
[4] P. Lau, "Fire Resistance of Connections in Laminated Veneer Lumber," University of Canterbury, Christchurch, New Zealand, Fire Engineering Research Report 06/3, 2006.
[5] T. Chuo, "Fire Performance of Connections in Laminated Veneer Lumber," Canterbury University, Christchurch, New Zealand, Fire Engineering Research Report 07/4, 2007.
[6] P. Moss, A. Buchanan, M. Fragiacomo, P. Lau, and T. Chuo, "Fire Performance of Bolted Connections in Laminated Veneer Lumber," *Fire and Materials,* vol. 33, pp. 223-243, 2009. doi: 10.1002/fam.999
[7] A. Frangi, C. Erchinger, and M. Fontana, "Experimental Fire Analysis of Steel-to-Timber Connections Using Dowels and Nails," *Fire and Materials,* vol. 34, pp. 1–19, 2010. doi: 10.1002/fam.994
[8] P. Moss, A. Buchanan, M. Fragiocomo, and C. Austruy, "Experimental Testing and Analytical Prediction of the Behaviour of Timber Bolted Connections Subjected to Fire," *Fire Technology,* vol. 46, pp. 129-148, 2010. doi: 10.1007/s10694-009-0096-6
[9] L. Peng, G. Hadjisophocleous, J. Mehaffey, and M. Mohammad, "On the Fire Performance of Wood-Wood-Wood and Wood-Steel-Wood Connections Using Bolts and Dowels as Fasteners," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 83-94.

[10] L. Peng, G. Hadjisophocleous, J. Mehaffey, and M. Mohammad, "Fire Resistance Performance of Unprotected Wood–Wood–Wood And Wood–Steel–Wood Connections: A Literature Review and New Data Correlations," *Fire Safety Journal,* vol. 45, pp. 392–399, 2010. doi:10.1016/j.firesaf.2010.08.003

[11] M. Audebert, D. Dhima, A. Bouchaïr, and M. Taazount, "Experimental and Numerical Analysis of the Thermo-Mechanical Behaviour of Steel-to-Timber Connections in Tension Perpendicular to the Grain," in *Structures in Fire, Seventh International Conference*, Zurch, Switzerland, 2012, pp. 367-376. doi: 10.3929/ethz-a-007050197

[12] D. Dhima, M. Audebert, A. Bouchaïr, and M. Taazount, "Experimental and Numerical Analysis of the Thermo-Mechanical Behavior of Steel-to-Timber Connections in Bending," in *Structures in Fire, Seventh International Conference*, Zurch, Switzerland, 2012, pp. 407-416. doi: 10.3929/ethz-a-007050197

[13] S. Ali and G. Hadjisophocleous, "Full-Scale Tests to Study the Influence of Various Parameters on the Fire Performance of Hybrid Timber Connections," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1169-1179.

[14] V. Hofmann, M. Gräfe, N. Werther, and S. Winter, "Fire Resistance of Primary Beam – Secondary Beam Connections in Timber Structures," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 529-536.

[15] P. Palma, A. Frangi, E. Hugi, P. Cachim, and H. Cruz, "Fire Resistance Tests on Beam-To-Column Shear Connections," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 545-556.

[16] P. Racher, D. Dhima, M. Audebert, A. Bouchaïr, and C. Florence, "Fire Behaviour of Blind Dovetail Timber Connections," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 557-566.

[17] P. Palma, A. Frangi, E. Hugi, P. Cachim, and H. Cruz, "Fire Resistance Tests on Timber Beam-to-Column Shear Connections," *Journal of Structural Fire Engineering,* vol. 7, pp. 41–57, 2016. doi: 10.1108/JSFE-03-2016-004

[18] C. Gonzalez, O. Salem, and G. Hadjisophocleous, "Performance of Beam-To-Column Concealed Connections in Standard Fires," in *15th Fire and Materials Conference*, San Francisco, CA, 2017, pp. 629-642.

2.3 Protective Membranes

[1] L. D. Tsantaridis, B. A. L. Östman, and J. König, "Fire Protection of Wood by Different Gypsum Plasterboards," *Fire and Materials,* vol. 23, pp. 45-48, 1999. doi:10.1002/(SICI)1099-1018(199901/02)23:1<45::AID-FAM662>3.0.CO;2-6

[2] R. Thomas, M. Sultan, and J. Latour, "Impact of the Variability of Type X Gypsum Board," in *9th Fire and Materials Conference*, San Francisco, CA, 2005, pp. 131-137.

[3] A. Bwalya, M. Sultan, and R. Thomas, "Impact of Board Orientation on the Fire Performance of Regular Gypsum Board Walls," in *10th Fire and Materials Conference*, San Francisco, CA, 2007, pp. 119-120.

[4] E. Elewini, M. Sultan, and G. Hadjisophocleous, "Gypsum Board Fall-Off in Floor Assemblies Exposed to a Standard Fire," in *10th Fire and Materials Conference*, San Francisco, CA, 2007, pp. 117-118.

[5] R. White, "Fire Resistance of Wood Members with Directly Applied Protection," in *11th Fire and Materials Conference*, San Francisco, CA, 2009, pp. 463-474.

[6] A. Frangi, V. Schleifer, M. Fontana, and E. Hugi, "Experimental and Numerical Analysis of Gypsum Plasterboards in Fire," *Fire Technology,* vol. 46, pp. 149–167, 2010. doi:10.1007/s10694-009-0097-5

[7] A. Just, "Structural Fire Design of Timber Frame Assemblies Insulated by Glasswool and Covered by Gypsum Plasterboards," D.Sc. Thesis, Tallinn University of Technology, Tallinn, Estonia, 2010.
[8] A. Just, J. Schmid, and J. König, "Failure Times of Gypsum Boards," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1695-1700.
[9] A. Just, J. Schmid, and J. König, "Failure Times of Gypsum Boards," in *Structures in Fire, Sixth International Conference*, East Lansing, MI, USA, 2010, pp. 1695-1700.
[10] T. Lennon, D. Hopkin, J. El-Rimawi, and V. Silberschmidt, "Large Scale Natural Fire Tests On Protected Engineered Timber Floor Systems," *Fire Safety Journal,* vol. 45., pp. 168-182, 2010. doi:10.1016/j.firesaf.2010.02.006
[11] B. Östman, "Fire Protection Ability of Wood Products - A Status Report," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 71-81.
[12] M. Sultan, "Comparison of Gypsum Board Fall-off in Wall and Floor Assemblies Exposed to Furnace Heat," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1677-1682.
[13] A. Just, J. Schmid, and J. König, "Gypsum Plasterboards and Gypsum Fibreboards - Protective Times for Fire Safety Design of Timber Structures," in *International Council for Research and Innovation in Building and Construction: Working Commission W18 – Timber Structures CIB-W18 Meeting 44* Alghero, Italy, 2011, pp. Paper 16-1.
[14] A. Just, J. Schmid, and B. Östman, "Fire Protection Abilities Provided by Gypsum Plasterboards," in *World Conference on Timber Engineering* Aukland, New Zealand, 2012, pp. 540-544.
[15] A. Just, J. Schmid, N. Werther, and A. Frangi, "Fire Protection of Timber Members – Determination of the Fire Protection System Characteristics for the Verification of the Load-Bearing Resistance by Means of Calculation Models," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 567-576.
[16] D. Kolaitis, E. Asimakopoulou, and F. M., "Fire Protection of Light and Massive Timber Elements Using Gypsum Plasterboards and Wood Based Panels: A Large-Scale Compartment Fire Test.," *Construction and Building Materials,* vol. 73, pp. 163-170, 2014. doi:10.1016/j.conbuildmat.2014.09.027
[17] B. Östman and L. Boström, "Fire Protection Ability of Wood Coverings," *Fire Technology,* vol. 51, pp. 1475-1493, 2015. doi:10.1007/s10694-014-0452-z
[18] B. Andres and P. van Hees, "Mechanical Properties of Gypsum Plasterboard Exposed to Standard Fires," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1051-1062.
[19] B. Kandola, A. Alkazaleh, and G. Milnes, "The Fire Behaviour of Gypsum Boards Incorporating Phase Change Materials For Energy Storage in Building Applications," in *15th Fire and Materials Conference*, San Francisco, CA, 2017, pp. 517-527.

2.4 Gypsum Board Fall-off

[1] E. Elewini, M. Sultan, and G. Hadjisophocleous, "Gypsum Board Fall-Off in Floor Assemblies Exposed to a Standard Fire," in *10th Fire and Materials Conference*, San Francisco, CA, 2007, pp. 117-118.
[2] M. Sultan and A. Roy-Poirier, "Gypsum Board Fall-Off Temperature in Floor Assemblies Exposed to Standard Fires," in *Interflam 2007, 11th International Fire Conference*, London, England, 2007, pp. 979-991.
[3] A. Just, "Structural Fire Design of Timber Frame Assemblies Insulated by Glasswool and Covered by Gypsum Plasterboards," D.Sc. Thesis, Tallinn University of Technology, Tallinn, Estonia, 2010.

[4] M. Sultan, "Comparison of Gypsum Board Fall-off in Wall and Floor Assemblies Exposed to Furnace Heat," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1677-1682.
[5] A. Just, J. Schmid, and J. König, "Gypsum Plasterboards and Gypsum Fibreboards - Protective Times for Fire Safety Design of Timber Structures," in *International Council for Research and Innovation in Building and Construction: Working Commission W18 – Timber Structures CIB-W18 Meeting 44* Alghero, Italy, 2011, pp. Paper 16-1.
[6] A. Just, J. Schmid, and B. Östman, "Fire Protection Abilities Provided by Gypsum Plasterboards," in *World Conference on Timber Engineering* Aukland, New Zealand, 2012, pp. 540-544.
[7] P. Collier, "The Influence of Damage to Passive Fire Protection Systems Caused by Earthquakes," in *13th Fire and Materials Conference*, San Francisco, CA, 2013, pp. 127-138.
[8] A. Just, K. Kraudok, J. Schmid, and B. Östman, "Protection by Gypsum Plasterboards - State of the Art," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 107-110.

2.5 Cooling Phase

[1] H. Kinjo, S. Yusa, T. Horio, T. Hirashima, T. Matsumoto, and K. Saito, "Fire Performance, Including the Cooling Phase, of Structural Glued Laminated Timber Beams," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 593-600.
[2] K. Yusuke, H. Kinjo, T. Hirashima, S. Yusa, and K. Saito, "Deflection Behavior and Load-Bearing-Period of Structural Glued Laminated Timber Beams in Fire Including Cooling Phase," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 667-674.
[3] M. Janssens and J. Huczek, "Using CFAST and FDS to Evaluate the Response of CLT in Natural and Standard Fires," in *15th Fire and Materials Conference*, San Francisco, CA, 2017, pp. 567-578.

3.0 SIMPLIFIED CALCULATION METHODS FOR STANDARD FIRE EXPOSURE

[1] M. Janssens, "Fire Resistance of Exposed Timber Beams and Columns," in *3rd Fire and Materials Conference*, Crystal City, VA, 1994, pp. 31-40.
[2] T. Harada and S. Uesugi, "Fire Resistance of Engineered Wood for Structural Members," in *Interflam 1999, 8th International Fire Conference*, Edinburgh, Scotland, 1999, pp. 1241-1245.
[3] J. König, "Structural Fire Design of Timber Structures According to Eurocode 5," in *Fire Safety Science, 8th International Symposium*, Beijing, China, 2005, pp. 303-313. doi:10.3801/IAFSS.FSS.8-303
[4] J. König, "Structural Fire Design According to Eurocode 5 - Design Rules and Their Background," *Fire and Materials,* vol. 29 pp. 147-163, 2005. doi: 10.1002/fam.873
[5] J. Schmid, J. König, and J. Köhler, "Fire-Exposed Cross-Laminated Timber – Modelling And Tests," in *World Conference on Timber Engineering* Trento, Italy, 2010, pp. 3268-3276.
[6] J. Schmid, J. König, and J. Köhler, "Design Model for Fire Exposed Cross-Laminated Timber," in *Structures in Fire, Sixth International Conference*, East Lansing, MI, USA, 2010, pp. 511-519.
[7] M. Fragiacomo, A. Menis, I. Clemente, G. Bochicchio, and B. Tessadri, "Experimental and Numerical Behaviour of Cross-Laminated Timber Floors in Fire Conditions," in *World Conference on Timber Engineering* Auckland, New Zealand, 2012, pp. 177-178.

[8] M. Klippel, J. Schmid, A. Frangi, and 2012, "The Reduced Cross-Section Method for Timber Members Subjected to Compression, Tension and Bending in Fire," in *International Council for Research and Innovation in Building and Construction, Working Commission W18 – Timber Structures, Meeting 45*, 2012.

[9] J. Schmid, J. König, and A. Just, "The Reduced Cross-Section Method for the Design of Timber Structures Exposed to Fire–Background, Limitations and New Developments," *Structural Engineering International,* vol. 22, pp. 514-522, 2012. 10.2749/101686612X13363929517578

[10] M. Aguanno, "Fire Resistance Tests of Cross-Laminated Timber Floor Panels: An Experimental and Numerical Analysis," MS Thesis, Carleton University, Ottawa, ON, Canada, 2013.

[11] M. Aguanno, G. Hadjisophocleous, and S. Craft, "Fire Resistance Tests of Cross-Laminated Timber Floor Panels: An Experimental and Numerical Analysis," in *13th Fire and Materials Conference*, San Francisco, CA, 2013, pp. 115-125.

[12] J. Schmid, M. Klippel, A. Just, and A. Frangi, "Comparison of the Fire Resistance of Timber Members in Tests and Calculation Models," in *International Council for Research and Innovation in Building and Construction, Working Commission W18 – Timber Structures, Meeting 46*, 2013.

[13] M. Teibinger, "Fire Resistance of Timber Construction - Evaluation of Improved Design Models," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1465-1476.

[14] S. Ali, A. Akotuah, J. Erochko, and G. Hadjisophocleous, "Design Model for Fire Exposed Cross-Laminated Timber," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 511-520.

[15] M. Klippel, J. Schmid, A. Frangi, and G. Fink, "Fire Design of Glued-Laminated Timber Beams with Regard to the Adhesive Performance Using the Reduced Cross-Section Method," in *International Network on Timber Engineering Research, Meeting 47* Karlsruhe, Germany: Timber Scientific Publishing, 2014, pp. 337-348.

[16] J. Schmid, A. Just, M. Klippel, M. Fragiacomo, and D. Lange, "Verification of the Load-Bearing Resistance of Timber Members by Means of the Reduced Cross-Section Method – Background to the Eurocode Model and Comparison to Fire Tests in Bending," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 577-584.

[17] M. Klippel and A. Frangi, "Fire Behaviour of Cross- Laminated Timber (CLT)," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 103-106.

[18] J. Schmid, A. Just, M. Klippel, and M. Fragiacomo, "The Reduced Cross-Section Method For Evaluation Of The Fire Resistance Of Timber Members: Discussion And Determination Of The Zero-Strength Layer," *Fire Technology,* vol. 51, pp. 1285-1309, 2015. doi:10.1007/s10694-014-0421-6

[19] J. Schmid, M. Klippel, A. Liew, A. Just, and A. Frangi, "Analysis Of Fire Resistance Tests On Timber Column Buckling With Respect To The Reduced Cross-Section Method," in *International Network on Timber Engineering Research , Meeting 48* Karlsruhe, Germany: Timber Scientific Publishing, 2015, pp. 317-332.

[20] A. Bartlett, R. Hadden, L. Bisby, and B. Lane, "Sectional Analysis of Cross-Laminated Timber as a Design for Fire Methodology," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 684-691.

[21] M. Klippel, J. Schmid, and A. Frangi, "Fire Design of CLT," in *Joint Conference of COST Actions FP1402 and FP1404: Cross Laminated Timber – A Competitive Wood Product for Visionary and Fire Safe Buildings* Stockholm, Sweden, 2016.

[22] S. Craft and I. Van Zeeland, "Rationalization of Cross-Laminated Timber Design Standards," in *15th Fire and Materials Conference*, San Francisco, CA, 2017, pp. 643-654.

4.0 DETAILED STRUCTURAL FIRE MODELING FOR STANDARD FIRE EXPOSURE

4.1 General

[1] L. Wullschleger and K. Ghazi Wakili, "Numerical Parameter Study of the Thermal Behaviour of a Gypsum Plaster Board at Fire Temperatures," *Fire and Materials,* vol. 32, pp. 103-119, 2008. doi:10.1002/fam.956

[2] A. Frangi, V. Schleifer, M. Fontana, and E. Hugi, "Experimental and Numerical Analysis of Gypsum Plasterboards in Fire," *Fire Technology,* vol. 46, pp. 149–167, 2010. doi:10.1007/s10694-009-0097-5

[3] M. Janssens, "Eurocode 5 Advanced Method Predictions of Glulam Beam Fire Test Performance," in *12th Fire and Materials Conference*, San Francisco, CA, 2011, pp. 427-439.

[4] L. Peng, G. Hadjisophocleous, J. Mehaffey, M. Mohammad, and L. Lu, "Calculating Fire Resistance of Timber Connections," in *12th Fire and Materials Conference*, San Francisco, CA, 2011, pp. 455-465.

[5] M. Audebert, D. Dhima, A. Bouchaïr, and M. Taazount, "Experimental and Numerical Analysis of the Thermo-Mechanical Behaviour of Steel-to-Timber Connections in Tension Perpendicular to the Grain," in *Structures in Fire, Seventh International Conference*, Zurch, Switzerland, 2012, pp. 367-376. doi: 10.3929/ethz-a-007050197

[6] D. Dhima, M. Audebert, A. Bouchaïr, and M. Taazount, "Experimental and Numerical Analysis of the Thermo-Mechanical Behavior of Steel-to-Timber Connections in Bending," in *Structures in Fire, Seventh International Conference*, Zurch, Switzerland, 2012, pp. 407-416. doi: 10.3929/ethz-a-007050197

[7] D. Hopkin, T. Lennon, J. El-Rimawi, and V. Silberschmidt, "A Numerical Study of Gypsum Plasterboard Behaviour under Standard and Natural Fire Conditions," *Fire and Materials,* vol. 36, pp. 107–126, 2012. doi: 10.1002/fam.1092

[8] J. O'Neill, A. Abu, D. Carradine, P. Moss, and A. Buchanan, "Modelling the Performance of Structural Timber Floors," in *Structures in Fire, Seventh International Conference*, Zurch, Switzerland, 2012, pp. 397-406. doi: 10.3929/ethz-a-007050197

[9] L. Peng, G. Hadjisophocleous, J. Mehaffey, and M. Mohammad, "Fire Performance of Timber Connections, Part 2: Thermal and Structural Modelling," *Journal of Structural Fire Engineering,* vol. 3, pp. 133-154., 2012. doi: 10.1260/2040-2317.3.2.133

[10] J. Schmid, M. Klippel, A. Just, and A. Frangi, "Comparison of the Fire Resistance of Timber Members in Tests and Calculation Models," in *International Council for Research and Innovation in Building and Construction, Working Commission W18 – Timber Structures, Meeting 46*, 2013.

[11] M. Tabaddor, "Modeling the Thermal and Structural Behavior of Wood Beams in a Fire Environment," in *13th Fire and Materials Conference*, San Francisco, CA, 2013, pp. 209-220.

[12] M. Klippel and A. Frangi, "Numerical Investigations on the Fire Behaviour of Glued-Laminated Timber Beams Taking into Account the Influence of Adhesives," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 537-544.

[13] J. O'Neill, A. Abu, D. Carradine, P. Mossand, and A. Buchanan, "Predicting the Fire Performance of Structural Timber Floors," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 585-592.

[14] M. Fragiacomo and A. Meni, "Evaluation of the Fire Resistance of Cross- Laminated Timber Floor Elements," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 54-57.

[15] M. Janssens, J. Huczek, and N. Albracht, "Performance of Gypsum-Protected CLT and NLT in Natural and Standard Fires," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 1124-1131.

[16] M. Janssens and J. Huczek, "Using CFAST and FDS to Evaluate the Response of CLT in Natural and Standard Fires," in *15th Fire and Materials Conference*, San Francisco, CA, 2017, pp. 567-578.

4.2 Material Properties

[1] O. Axenenko and G. Thorpe, "The Modelling of Dehydration and Stress Analysis of Gypsum Plasterboards Exposed to Fire," *Computational Materials Science,* vol. 6, pp. 281-294, 1996. doi:10.1016/0927-0256(96)00019-5

[2] N. Bénichou, "Thermal Properties of Components of Lightweight Wood-Framed Assemblies at Elevated Temperatures," in *7th Fire and Materials Conference*, San Francisco, CA, 2001, pp. 447-458.

[3] G. Thomas, "Thermal properties of gypsum plasterboard at high temperatures," *Fire and Materials,* vol. 26, pp. 37-45, 2002. doi:10.1002/fam.786

[4] S. Cramer, "Mechanical Properties of Gypsum Board at Elevated Temperatures," in *8th Fire and Materials Conference*, San Francisco, CA, 2003, pp. 33-42.

[5] C. N. Ang and Y. C. Wang, "The Effect of Water Movement on Specific Heat of Gypsum Plasterboard in Heat Transfer Analysis under Natural Fire Exposure," *Construction and Building Materials,* vol. 18, pp. 505-515, 2004. doi:10.1016/j.conbuildmat.2004.04.003

[6] A. Belmiloudi and G. Le Meur, "Mathematical and Numerical Analysis of Dehydratation of Gypsum Plasterboards Exposed to Fire," *Applied Mathematics and Computation,* vol. 163, pp. 1023-1041, 2005. doi:10.1016/j.amc.2004.06.013

[7] J. König, "Effective Thermal Actions and Thermal Properties of Timber Members in Natural Fires " *Fire and Materials,* vol. 30, pp. 51-63, 2006. doi:10.1002/fam.898

[8] K. Ghazi Wakili, E. Hugi, L. Wullschleger, and T. Frank, "Gypsum Board in Fire - Modeling and Experimental Validation," *Journal of Fire Sciences,* vol. 25, pp. 267-282, 2007. doi:10.1177/0734904107072883

[9] S. Craft, B. Isgor, G. Hadjisophocleous, and J. Mehaffey, "Predicting the Thermal Response of Gypsum Board Subjected to a Constant Heat Flux," *Fire and Materials,* vol. 32, pp. 333-355, 2008. doi:10.1002/fam.971

[10] L. Wullschleger and K. Ghazi Wakili, "Numerical Parameter Study of the Thermal Behaviour of a Gypsum Plaster Board at Fire Temperatures," *Fire and Materials,* vol. 32, pp. 103-119, 2008. doi:10.1002/fam.956

[11] C. N. Ang and Y. C. Wang, "Effect of Moisture Transfer on Specific Heat of Gypsum Plasterboard at High Temperatures," *Construction and Building Materials,* vol. 23, pp. 675-686, 2009. doi:10.1016/j.conbuildmat.2008.02.016

[12] K. Ghazi Wakili and E. Hugi, "Four Types of Gypsum Plaster Boards and their Thermophysical Properties Under Fire Condition," *Journal of Fire Sciences,* vol. 27, pp. 27-43, 2009. doi:10.1177/0734904108094514

[13] A. de Korte and H. Brouwers, "Calculation of Thermal Conductivity of Gypsum Plasterboards at Ambient and Elevated Temperature," *Fire and Materials,* vol. 34, pp. 55-75, 2010. doi:10.1002/fam.1009

[14] S. Park, S. Manzello, D. Bentz, and T. Mizukami, "Determining thermal properties of gypsum board at elevated temperatures," *Fire and Materials,* vol. 34, pp. 237–250, 2010. doi:10.1002/fam.1017

[15] Q. Yu and P. Shipp, "Thermophysical Characterization of Type X Special Fire Resistant Board," in *12th Fire and Materials Conference*, San Francisco, CA, 2011, pp. 417-428.

[16] M. Gilani and E. Hugi, "Fire Induced Desorption and Migration of Hygroscopic Moisture in Wood," in *Structures in Fire, Seventh International Conference*, Zurch, Switzerland, 2012, pp. 387-396. doi: 10.3929/ethz-a-007050197

[17] P. Collier, "The Influence of Damage to Passive Fire Protection Systems Caused by Earthquakes," in *13th Fire and Materials Conference*, San Francisco, CA, 2013, pp. 127-138.
[18] G. Semitelos, I. Mandilaras, D. Kontogeorgos, and M. Founti, "Simplified Correlations of Gypsum Board Thermal Properties for Simulation Tools," *Fire and Materials,* vol. 40, pp. 229-245, 2014. doi: 10.1002/fam.2282
[19] D. Kontogeorgos, I. Mandilaras, and M. Founti, "Fire Behavior of Regular and Latent Heat Storage Gypsum Boards," *Fire and Materials,* vol. 39, pp. 507-517, 2015. doi: 10.1002/fam.2246
[20] B. Andres and P. van Hees, "Mechanical Properties of Gypsum Plasterboard Exposed to Standard Fires," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1051-1062.
[21] M. Dodangoda, M. Mahendran, K. Poologanathan, and R. Frost, "Material Characterization and Numerical Modelling of Gypsum Plasterboards in Fire," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 1116-1123.

5.0 PERFORMANCE-BASED ASSESSMENT

5.1 Custom Furnace Tests

[1] T. Lennon, D. Hopkin, J. El-Rimawi, and V. Silberschmidt, "Large Scale Natural Fire Tests On Protected Engineered Timber Floor Systems," *Fire Safety Journal,* vol. 45., pp. 168-182, 2010. doi:10.1016/j.firesaf.2010.02.006
[2] S. Månsson, D. Ronstad, D. Lange, and L. Boström, "Mini- Furnace Testing of Timber Elements Exposed to Parametric Fires," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 93-94.
[3] S. Boadi and G. Hadjisophocleous, "Full Scale Tests on the Performance of Hybrid Timber Connections in Real Fires," in *15th Fire and Materials Conference*, San Francisco, CA, 2017, pp. 613-628.
[4] M. Janssens and J. Huczek, "Using CFAST and FDS to Evaluate the Response of CLT in Natural and Standard Fires," in *15th Fire and Materials Conference*, San Francisco, CA, 2017, pp. 567-578.

5.2 Compartment Fire Tests

[1] B. Jones, "Performance of Gypsum Plasterboard Assemblies Exposed to Real Building Fires," University of Canterbury, Christchurch, New Zealand, Fire Engineering Research Report 01/4, 2001.
[2] T. Hakkarainen, "Post-Flashover Fires in Light and Heavy Timber Construction Compartments," *Journal of Fire Sciences,* vol. 20, 2002. doi:10.1177/0734904102020002074
[3] A. Frangi and M. Fontana, "Fire Performance of Timber Structures under Natural Fire Conditions," in *Fire Safety Science, 8th International Symposium*, Beijing, China, 2005, pp. 279–290. doi: 10.3801/IAFSS.FSS.8-279
[4] A. Frangi, G. Bochicchio, A. Ceccotti, and M. Lauriola, "Natural Full-Scale Fire Test on a 3 Storey XLam Timber Building," in *World Conference on Timber Engineering* Miyazaki, Japan: Engineered Wood Products Association, Madison, WI, USA, 2008.
[5] D. Kolaitis, E. Asimakopoulou, G. Zannis, and M. Founti, "A Natural Fire Test to Assess the Behavior of Modern Timber Construction: Light Timber Frame vs. Glued Laminated Timber," in *Interflam 2013, 13th International Fire Conference*, london, England, 2013, pp. 589-592.

[6] C. McGregor, G. Hadjisophocleous, and S. Craft, "Contribution of Cross-Laminated Timber Panels to Room Fires," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1453-1464.
[7] A. Hevia, "Fire Resistance of Partially Protected Cross-Laminated Timber Rooms," ME Thesis, Carleton University, Ottawa, ON, Canada, 2014.
[8] D. Kolaitis, E. Asimakopoulou, and F. M., "Fire Protection of Light and Massive Timber Elements Using Gypsum Plasterboards and Wood Based Panels: A Large-Scale Compartment Fire Test.," *Construction and Building Materials,* vol. 73, pp. 163-170, 2014. doi:10.1016/j.conbuildmat.2014.09.027
[9] C. McGregor, "Contribution of Cross-Laminated Timber Panels to Room Fires. ," ME Thesis, Carleton University, Ottawa, ON, Canada, 2014.
[10] C. Dagenais, J. Su, G. Lougheed, L. Osborne, and I. Van Zeeland, "Performance of CLT Construction in Real Fire Conditions," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 47-50.
[11] K. Hox, "Branntest av Massivtre," SP Fire Research, Trondheim, Norway, SPFR-rapport A15101, 2015.
[12] M. Janssens, N. Albracht, and K. Carpenter, "Full-Scale Tests in a Furnished Living Room to Evaluate the Fire Performance of Protected Cross-Laminated and Nail Laminated Timber Construction," Southwest Research Institute, San Antonio, TX, Final Report for SwRI Project No.: 01.21428.01.001, 2015.
[13] X. Li, X. Zhang, G. Hadjisophocleous, and C. McGregor, "Experimental Study of Combustible and Non-Combustible Construction in a Natural Fire," *Fire Technology,* vol. 51, pp. 1447–1474, 2015. doi:10.1007/s10694-014-0407-4
[14] L. Osborne and C. Dagenais, "Full-Scale Mass Timber Shaft Demonstration Fire," FPInnovations, Pointe-Claire, QC, Canada, 2015.
[15] J. Su and S. Muradori, "Fire Demonstration – Cross-Laminated Timber Stair/Elevator Shaft," National Research Council Canada Ottawa, ON, Canada., Client Report: A1-004377.1, 2015.
[16] K. Hox and G. Baker, "Full-Scale Fire Test of CLT Structure Used for Student Housing," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1087-1093.
[17] M. Janssens and J. Huczek, "Using CFAST and FDS to Evaluate the Response of CLT in Natural and Standard Fires," in *15th Fire and Materials Conference*, San Francisco, CA, 2017, pp. 567-578.
[18] P. Whiting, "Behaviour of Light Timber-Framed Floors Subjected to Fire Attack From Above," Building Research Association of New Zealand, Porirua, New Zealand, Study Report No. 117, 2003.

5.3 Simplified Calculation Methods

[1] S. Ingberg, "Tests of the Severity of Building Fires," *National Fire Protection Association Quarterly,* vol. 22, pp. 43-61, 1928.
[2] M. Law, "A Relationship Between Fire Grading and Building Design and Contents," Fire Research Station, Borehamwood, England, Fire Research Note No. 877, 1971.
[3] M. Law, "Prediction of Fire Resistance," in *Symposium No. 5: Fire Resistance Requirements for Buildings - A New Approach* Fire Research Station, Borehamwood, England, 1971.
[4] P. Thomas and A. Heselden, "Fully Developed Fires in Single Compartments - A Co-Operative research Programme of the Conseil International du Bâtiment," Fire Research Station, Borehamwood, England, Fire Research Note No. 923, 1972.
[5] T. Harmathy and J. Mehaffey, "Post-Flashover Compartment Fires," *Fire and Materials,* vol. 7, pp. 49-61, 1983. doi: 10.1002/fam.810070202

[6] G. Thomas, A. Buchanan, and C. Fleischman, "Structural Fire Design: The Role of Time Equivalence," in *Fire Safety Science, 5th International Symposium*, Melbourne, Australia, 1997, pp. 607-618. doi:10.3801/IAFSS.FSS.5-607

[7] J. Nyman, "Equivalent Fire Resistance Ratings of Construction Elements Exposed to Realistic Fires," University of Canterbury, Christchurch, New Zealand, Fire Engineering Research Report 02/13, 2002.

[8] H. Gerlich, A. Buchanan, J. Nyman, and C. Wade, "Equivalent Fire Resistance of Drywall Construction Exposed to Compartment Fire," in *8th Fire and Materials Conference*, San Francisco, CA, 2003, pp. 21-32.

[9] A. Abu, H. Gerlich, and C. Wade, "Limitations of Existing Time-Equivalence Formula for Determining Fire Resistance Requirements of Buildings," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1441-1452.

[10] A. Law, J. Stern-Gottfried , and N. Butterworth, "Solving Design Challenges: Revisiting Time Equivalence," in *Interflam 2013, 13th International Fire Conference*, london, England, 2013, pp. 583-588.

[11] C. Wade, C. Fleischman, M. Spearpoint, and A. Abu, "Revisiting Normalized Heat Load and Its Application in a Computer Fire Model," in *14th Fire and Materials Conference*, San Francisco, CA, 2015, pp. 682-696.

6.0 CHARRING RATE OF MASS TIMBER

[1] R. White, "Charring Rates of Diffferent Wood Species," Ph.D. Thesis, University of Wisconsin, Madison, WI, 1988.

[2] W. Gardner and D. Syme, "Charring of Glued-Laminated Beams of Eight Australian-Grown Timber Species and the Effect of 13 mm Gypsum Plasterboard Protection on their Charring," N.S.W. Timber Advisory Council, Sydney, Australia, Technical Report No. 5, ODC 843.4-015, 1991.

[3] P. Collier, "Charring Rates of Timber," Building Research Association of New Zealand, Judgeford, New Zealand, Study Report No. 42, 1992.

[4] R. White and E. Nordheim, "Charring Rate of Wood for ASTM E 119 Exposure," *Fire Technology,* vol. 28, pp. 5–30, 1992. doi: 10.1007/BF01858049

[5] P. Lau, I. Van Zeeland, and R. White, "Modeling the Char Behavior of Structural Timber," in *5th Fire and Materials Conference*, San Antonio, TX, 1998, pp. 123-135.

[6] A. Frangi and M. Fontana, "Charring Rates and Temperature Profiles of Wood Sections," *Fire and Materials,* vol. 27, pp. 91–102, 2003. doi: 10.1002/fam.819

[7] S. Inaba, Y. Hasemi, S. Tsuchiya, N. Yasui, M. Yoshida, and N. Kawamura, "Prediction of Fire Exposure and Characteristic Rate of the Burning Behavior of Wood for the Design of a Heavy Timber "Fire-Proof" Building under Localized Fire Scenario," in *10th Fire and Materials Conference*, San Francisco, CA, 2007, pp. 47-48.

[8] T. Yang, S. Wang, M. Tsai, and C. Lin, "The Charring Depth and Charring Rate of Glued Laminated Timber After a Standard Fire Exposure Test," *Building and Environment,* vol. 44, pp. 231-236, 2009. doi: 10.1016/j.buildenv.2008.02.010

[9] K. Friquin, "Experimental Charring Rates for Cross-Laminated Timber Panels Compared to Calculated Charring Rates," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1659-1664.

[10] K. Tsai, "Charring Rates for Different Cross Sections of Laminated Veneer Lumber (LVL)," University of Canterbury, Christchurch, New Zealand, Fire Engineering Research Report 10/5, 2010.

[11] A. Frangi and J. König, "Effect of Increased Charring on the Narrow Side of Rectangular Timber Cross-Sections Exposed to Fire on Three or Four Sides," *Fire and Materials,* vol. 35, pp. 593–605, 2011. doi: 10.1002/fam.1078
[12] K. Friquin, "Material Properties and External Factors Influencing the Charring Rate of Solid Wood and Glue- Laminated Timber," *Fire and Materials,* vol. 35, pp. 303-327, 2011. doi: 10.1002/fam.1055
[13] K. Tsai, D. Carradine, P. Moss, and A. Buchanan, "Charring Rates for Double Beams Made from Laminated Veneer Lumber (LVL)," *Fire and Materials,* vol. 37, pp. 58–74, 2012. doi: 10.1002/fam.2112
[14] D. Lange, L. Boström, J. Schmid, and J. Albrektsson, "Charring Rate of Timber In Natural Fires," in *Structures in Fire, Eighth International Conference*, Shanghai, China, 2014, pp. 521-528.
[15] A. Bartlett, R. Hadden, L. Bisby, and A. Law, "Analysis of Cross-Laminated Timber Charring Rates Upon Exposure to Non-Standard Heating Conditions," in *14th Fire and Materials Conference*, San Francisco, CA, 2015, pp. 667-680.
[16] K. Pandtle, "Evaluation of Differences Between the Determination of the Charring Rate Following the DIN and EN Standard Using Comparable Experimental Setups," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 89-90.
[17] M. Tiso, J. Schmid, and M. Fragiacomo, "Charring Behaviour of Cross Laminated Timber with Respect to the Fire Protection, Comparison Of Different Methods," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 58-61.
[18] C. Mindeguia, G. Cueff, V. Drean, and G. Auguin, "Simulation of Charring Depth of Wood-Based Products when Exposed to Non-Standardized Fire Curves," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 675-683.
[19] J. Schmid, D. Brandon, A. Santomaso, U. Wickström, and A. Frangi, "Timber under Real Fire Conditions - The Influence of Oxygen Content and Gas Veloicity on the Charring Behavior," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 692-699.
[20] N. Werther, "External and Internal Factors Influencing the Charring of Timber - an Experimental Study with Respect to Natural Fires and Moisture Conditions," in *Structures in Fire, Ninth International Conference*, Princeton, NJ, USA, 2016, pp. 650-658.

7.0 CONTRIBUTION OF EXPOSED WOOD

7.1 CLT

[1] A. Frangi, G. Bochicchio, A. Ceccotti, and M. Lauriola, "Natural Full-Scale Fire Test on a 3 Storey XLam Timber Building," in *World Conference on Timber Engineering* Miyazaki, Japan: Engineered Wood Products Association, Madison, WI, USA, 2008.
[2] C. McGregor, G. Hadjisophocleous, and S. Craft, "Contribution of Cross-Laminated Timber Panels to Room Fires," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 1453-1464.
[3] C. McGregor, "Contribution of Cross-Laminated Timber Panels to Room Fires. ," ME Thesis, Carleton University, Ottawa, ON, Canada, 2014.
[4] C. Dagenais, J. Su, G. Lougheed, L. Osborne, and I. Van Zeeland, "Performance of CLT Construction in Real Fire Conditions," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 47-50.

[5] X. Li, X. Zhang, G. Hadjisophocleous, and C. McGregor, "Experimental Study of Combustible and Non-Combustible Construction in a Natural Fire," *Fire Technology,* vol. 51, pp. 1447–1474, 2015. doi:10.1007/s10694-014-0407-4
[6] L. Osborne and C. Dagenais, "Full-Scale Mass Timber Shaft Demonstration Fire," FPInnovations, Pointe-Claire, QC, Canada, 2015.
[7] J. Su and S. Muradori, "Fire Demonstration – Cross-Laminated Timber Stair/Elevator Shaft," National Research Council Canada Ottawa, ON, Canada., Client Report: A1-004377.1, 2015.
[8] K. Hox and G. Baker, "Full-Scale Fire Test of CLT Structure Used for Student Housing," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1087-1093.

7.2 Façade Fires

[1] J. Carlsson and B. Karlsson, "Using CFD Models to Calculate Flame Spread and Fire Growth on Practical Building Façade Materials," in *5th Fire and Materials Conference*, San Francisco, CA, 2001, pp. 147-158.
[2] B. Östman, "Wooden Façades in Multi-Storey Buildings," in *7th Fire and Materials Conference*, San Francisco, CA, 2001, pp. 185-196.
[3] T. Hakkarainen and T. Oksanen, "Fire Safety Assessment of Wooden Façades," *Fire and Materials,* vol. 26, pp. 7-27, 2002. doi:10.1002/fam.780
[4] S. Colwell, J. Bregulla, and R. Cullman, "Fire Safety of External Timber Wall Façades," in *Interflam 2007, 11th International Fire Conference* London, England: Interscience Communications, London, England, 2007, pp. 771-777.
[5] J. Anderson and R. Jansson, "Fire Dynamics in Façade Fire Tests: Measurement and Modelling," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 93-104.
[6] M. Giraldo, A. Lacasta, and J. Avellaneda, "CFD Simulation Study on Fire Propagation in Wooden Façades and the Influence of Façade's Geometry," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 36-39.
[7] J. Anderson, L. Boström, and R. Jansson, "Experimental Assessment of Repeatability in Façade Fire Testing," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 653-658.
[8] J. Anderson, L. Boström, and R. Jansson, "Modeling of Fire Exposure in Façade Fire Testing," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1115-1125.
[9] S. Koo, "A Probabilistic and Time Dependent Approach to External Fire Spread and Building Separation Distance," in *Interflam 2016, 14th International Fire Conference* London, England: Interscience Communications, London, England, 2016, pp. 677-682.
[10] M. Nilsson, A. Mossberg, B. Husted, and J. Anderson, "Protection Against External Fire Spread - Horizontal Projections or Spandrels?," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1163-1174.
[11] K. Park, M. Smolka, Y. Yoo, and H. Yoshioka, "Development of the Advanced Technical Method and Test Standard for the Purpose of the Fire Safety of Façade Materials in Buildings," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 1103-1114.
[12] M. Smolka, B. Messerschmidt, L. Boström, T. Crimi, V. Dowloing, K. Park, and H. Yoshioka, "Principles of Testing and Regulating Fire Safety of Façades," in *Interflam 2016, 14th International Fire Conference*, London, England, 2016, pp. 659-664.

7.3 Fire Spread to Adjacent Structures

[1] E. Janse and P. van de Leur, "Fire Safe Building Separation Distances in the Netherlands," in *Interflam 2001, 9th International Fire Conference*, Edinburgh, Scotland, 2001, pp. 1281-1286.

[2] R. Chitty and S. Kumar, "Building Separation Calcluations Revisited using Advanced Fire Models," in *Interflam 2004, 10th International Fire Conference*, Edinburgh, Scotland, 2004, pp. 447-458.

[3] P. W., L. Hu, R. Yang, Q. LV, F. Tang, Y. Xu, and L. Wang, "Full Scale Test on Fire Spread and Control of Wooden Buildings," *Procedia Engineering,* vol. 11, pp. 355-359, 2011. doi:10.1016/j.proeng.2011.04.669

[4] A. Steen- Hansen, K. Storesund, R. Fjellgaard Mikalsen, J. Stensaas, A. Gagnat Bøe, and K. Hox, "Fire Safety in Towns with Wooden Buildings. Experience from Investigation of Large Fires," in *1st European Workshop "Fire Safety of Green Buildings" of the COST Action FP 1404 "Fire Safe Use of Bio-Based Building Products"* Berlin, Germany, 2015, pp. 111-115.

[5] S. Koo, "A Probabilistic and Time Dependent Approach to External Fire Spread and Building Separation Distance," in *Interflam 2016, 14th International Fire Conference* London, England: Interscience Communications, London, England, 2016, pp. 677-682.

8.0 FIRE RISK ASSESSMENT

[1] D. Yung, G. Hadjisophocleous, and H. Takeda, "Comparative Risk Assessments of 3-Storey Wood-Frame and Masonry Construction Appartment Buildings," in *Interflam 1993, 6th International Fire Conference*, Oxford, England, 1993, pp. 499-508.

[2] N. Bénichou, D. Yung, and G. Hadjisophocleous, "Impact of Fire Department Response and Mandatory Sprinkler Protection on Life Risks in Residential Communities," in *Interflam 1999, 8th International Fire Conference*, Edinburgh, Scotland, 1999, pp. 521-532.

[3] B. Karlsson and B. Tómasson, "A Fire-Risk Index Method for Multi-Storey Apartment Buildings," in *Interflam 2001, 9th International Fire Conference*, Edinburgh, Scotland, 2001, pp. 221-232.

[4] A. Barowy, K. Notarianni, and L. Moore-Merrell, "Community Risk Assessment Modeling: Results of Residential Fireground Field Experiments," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1875-1886.

[5] D. Berry, "The Provision of a Risk Information System for the English Fire and Rescue Service," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1493-1498.

[6] C. English and S. Bennett, "Fire Compartment Sizes and the Benefit of Sprinklers - A Risk Based Approach Using Monte Carlo Simulations," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1007-1018.

[7] S. Raue, C. Johnson, D. Bouchlaghem, and S. Konucku, "Supporting Integrated Risk Management Planning for the UK Fire and Rescue Services: Evaluation of Prevention and Protection Activities of Commercial, Public and Heritage Buildings," in *Interflam 2010, 12th International Fire Conference*, Nottingham, England, 2010, pp. 1523-1529.

[8] D. Charters and C. Sherwood, "Quantitative Analysis of Fire Risks in Tall Buildings," in *Interflam 2013, 13th International Fire Conference* London, England: Interscience Communications, London, England, 2013, pp. 451-454.

[9] X. Li, P. Rao, X. Zhang, and G. Hadjisophocleous, "A Case Study on the Effect of Building Construction Type, Height, and Area on the Building Fire Risk Using the Fire Risk Assessment Model CURISK," in *14th Fire and Materials Conference*, San Francisco, CA, 2015.

[10] S. Koo, "A Probabilistic and Time Dependent Approach to External Fire Spread and Building Separation Distance," in *Interflam 2016, 14th International Fire Conference* London, England: Interscience Communications, London, England, 2016, pp. 677-682.

9.0 DETAILING

[1] M. Teibinger, "Fire Stops and Fire-Resistant Sealing in Timber Construction," in *Interflam 2013, 13th International Fire Conference*, London, England, 2013, pp. 723-734.

[2] N. Werther, J. Denzler, R. Stein, and S. Winter, "Detailing of CLT with Respect to Fire Resistance," in *Joint Conference of COST Actions FP1402 and FP1404: Cross Laminated Timber – A Competitive Wood Product for Visionary and Fire Safe Buildings* Stockholm, Sweden, 2016.