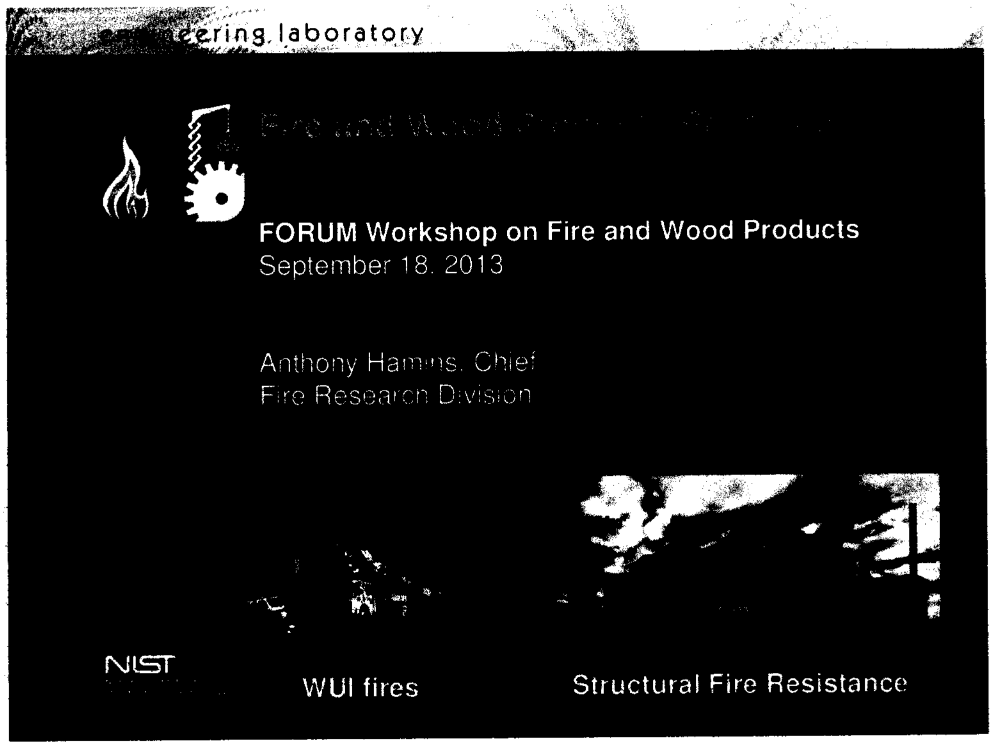
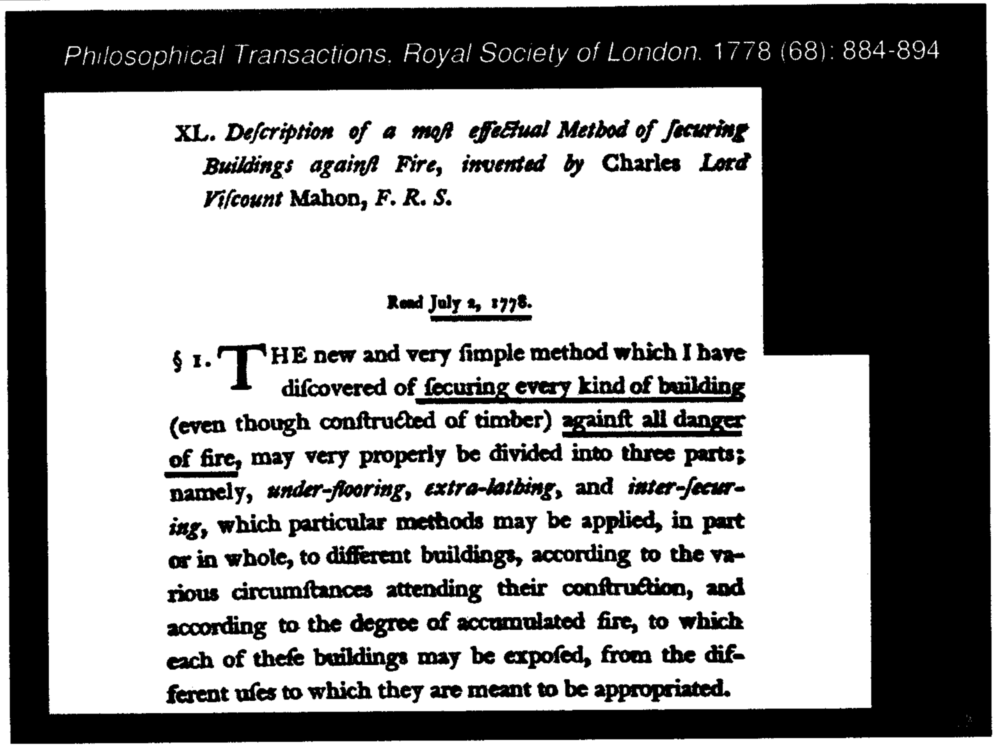
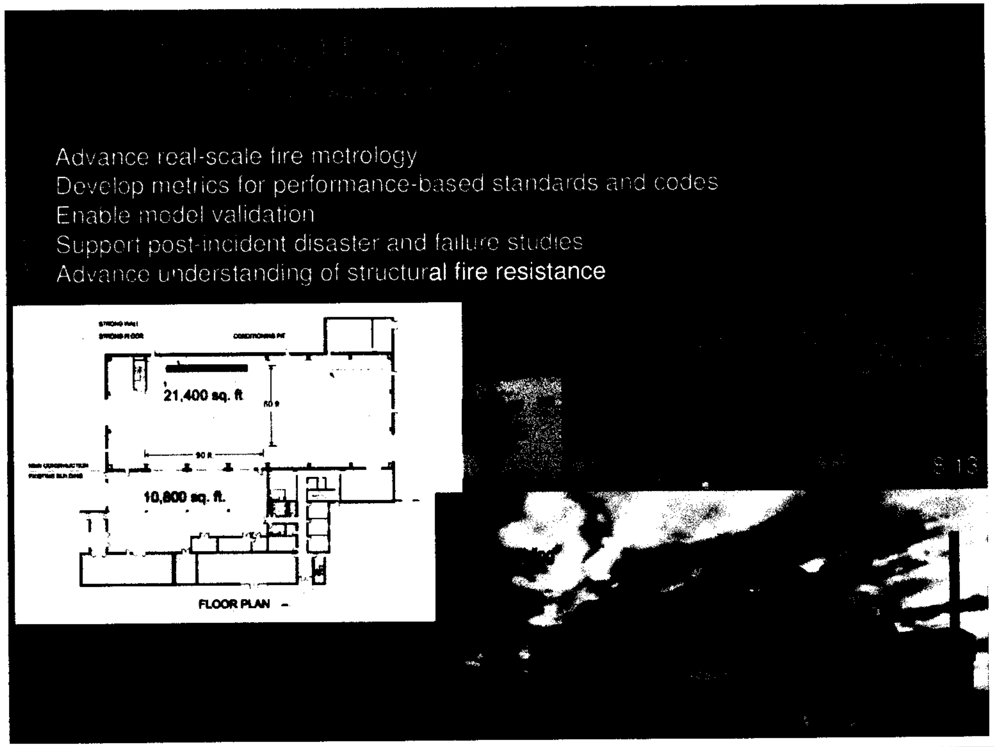


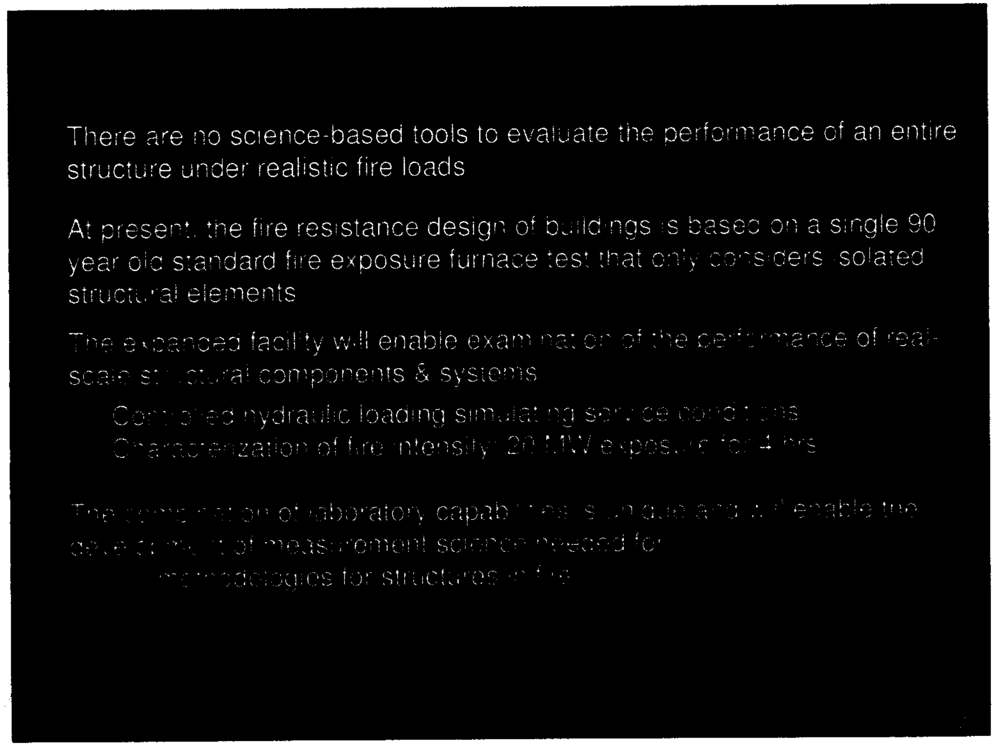


XL. *Description of a most effectual Method of securing Buildings against Fire, invented by* Charles *Lord Viscount* Mahon, F. R. S.

Read July 2, 1778.

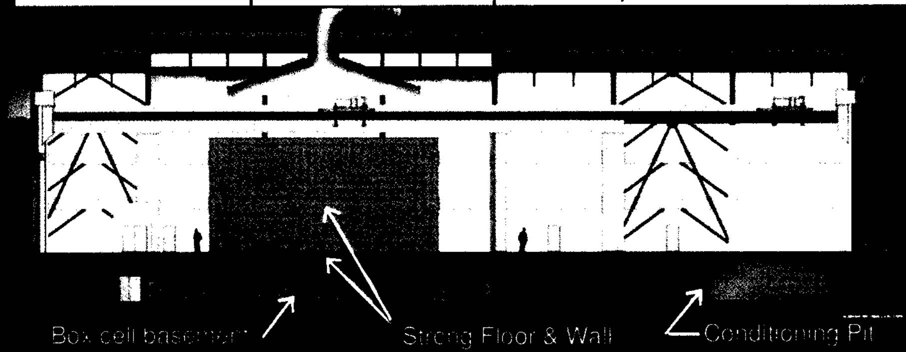
§ 1. THE new and very simple method which I have discovered of securing every kind of building (even though constructed of timber) against all danger of fire, may very properly be divided into three parts; namely, *under-flooring*, *extra-lathing*, and *inter-securing*, which particular methods may be applied, in part or in whole, to different buildings, according to the various circumstances attending their construction, and according to the degree of accumulated fire, to which each of these buildings may be exposed, from the different uses to which they are meant to be appropriated.





	NIST GCR 02 843-1	NIST IR 6890 (2002)	NIST IR 7133 (2004)	NIST SP 1061 (2006)	NIST GCR 07 910	NIST GCR 07 915	NIST GCR 12 958
Needs for test facilities							
Advanced instrumentation							
Test fires / fire scenarios							
Material constitutive models and properties							
Numerical models (Fire Structure)							
Full-scale data (connections, sub-assemblies, systems)							
Model validation							
Improvement of ASTM E119							
Development of design tools							
Development of research Plans led to performance based design							

Total Floor Area	10,800 sq. ft.	21,400 sq. ft.
Fire Capacity	1 MW (small hood) 3 MW (medium hood) 10 MW (large hood)	20 MW
Strong Floor/Strong Wall	None	60 ft. x 90 ft. x 4 ft. thick strong floor and 60 ft. x 30 ft. x 4 ft. thick strong wall.
Structural Loading	None	Reconfigurable hydraulic loading system, 55-215 kip actuators; 30 inch stroke



- Test the performance of real-scale structures under realistic fire and structural loading under controlled laboratory conditions.
- Develop an experimental database on the performance of large-scale structural connections, components, subassemblies and systems under realistic fire and loading.
- Evaluate physics-based models to predict fire resistance performance of structures.
- Provide the technical basis for performance-based standards for fire resistance design of structures and foster innovation in the building design and construction industry

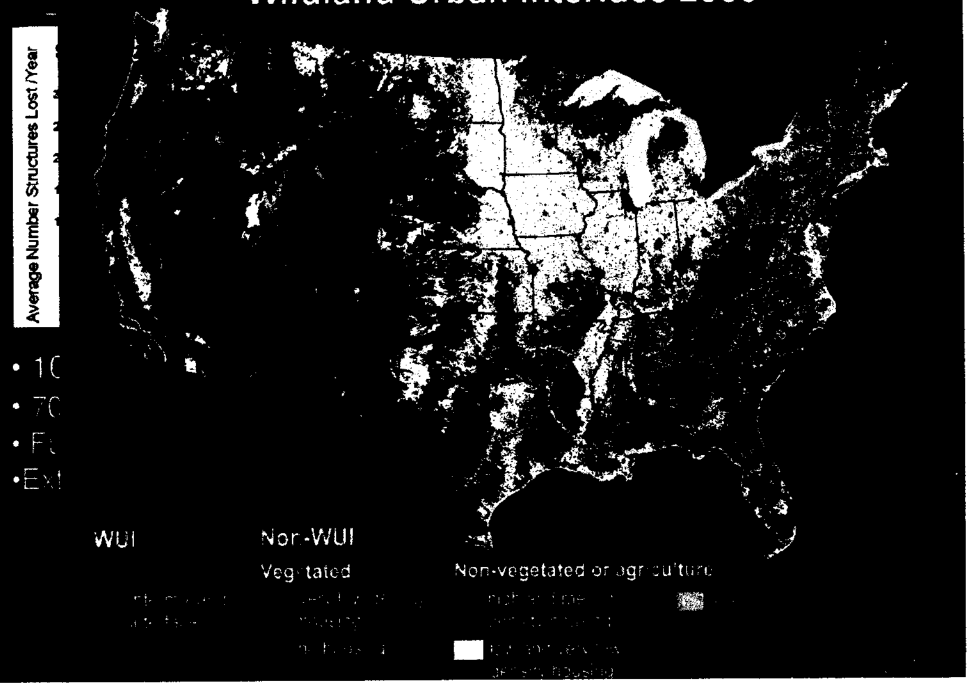
CIB NIST Fall Workshop

- Identify research and development needs for large-scale experiments on fire resistance of structures (steel, concrete, and timber) to support performance-based engineering and structure-fire model validation;
- Prioritize those needs in order of importance to performance-based engineering;
- Phase the needed research in terms of a timeline, i.e. near term (less than 3 years), medium term (3 to 6 years) and long term;
- Identify the most appropriate international laboratory facilities available to address each need
- Identify the potential collaborators and sponsors for each need.
- Identify the primary means to transfer the results from each series of tests to industry through [illegible] national and international standards, predictive tools for use in practice, and comprehensive research reports; and
- Identify the means for the coalition of international partners to review progress and exchange information on a regular basis

What can NFRL do for timber structure fire safety?

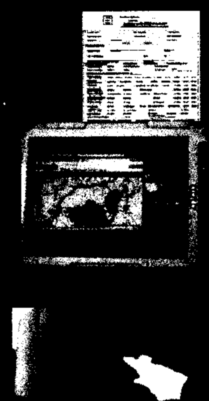
- Measurement science for timber element, sub-system and frame structure performance exposed to realistic fires (fire sizes and locations, combustibles, compartment sizes, and ventilations) and loadings
  - Timber columns and beams
  - Timber connections
  - Timber decking and floorings
  - Timber ceilings and roofs
  - Timber frame walls
  - Facades claddings
  - Fire protection (fire resistant insulation, flame retardant treatment, [illegible])
  - Two-story timber structures (system performance in fires)
  - Development of design fires
  - Timber bridge sections

Wildland Urban Interface 2000



Structure Ignition in WUI Fires

Enable standards, codes, and technologies to increase the fire resistance of WUI communities

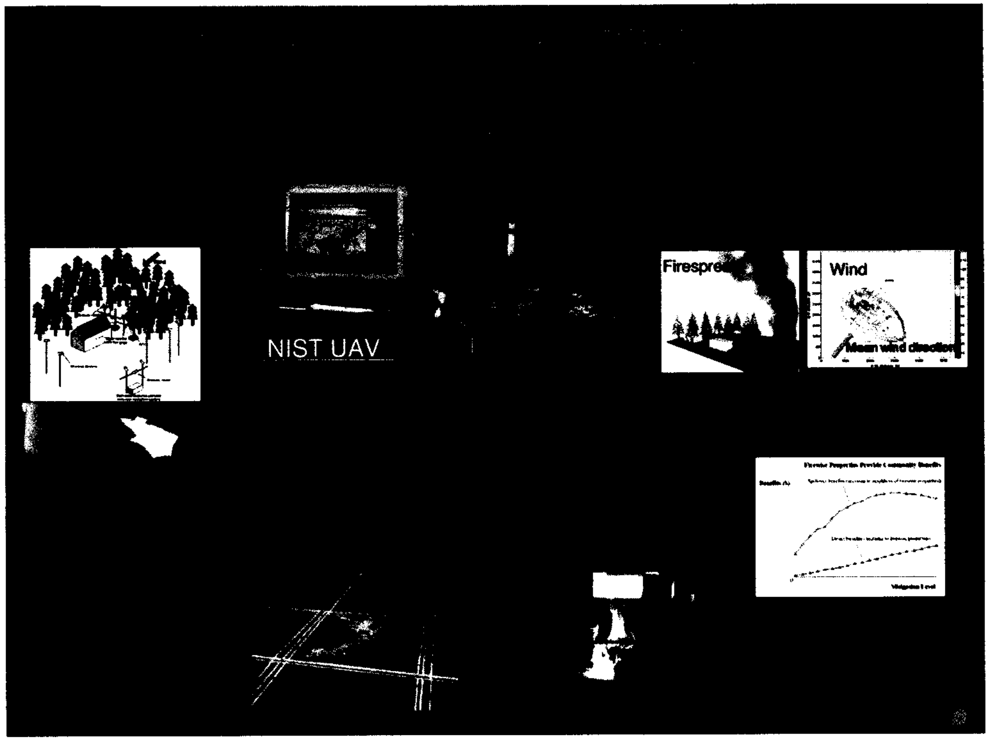


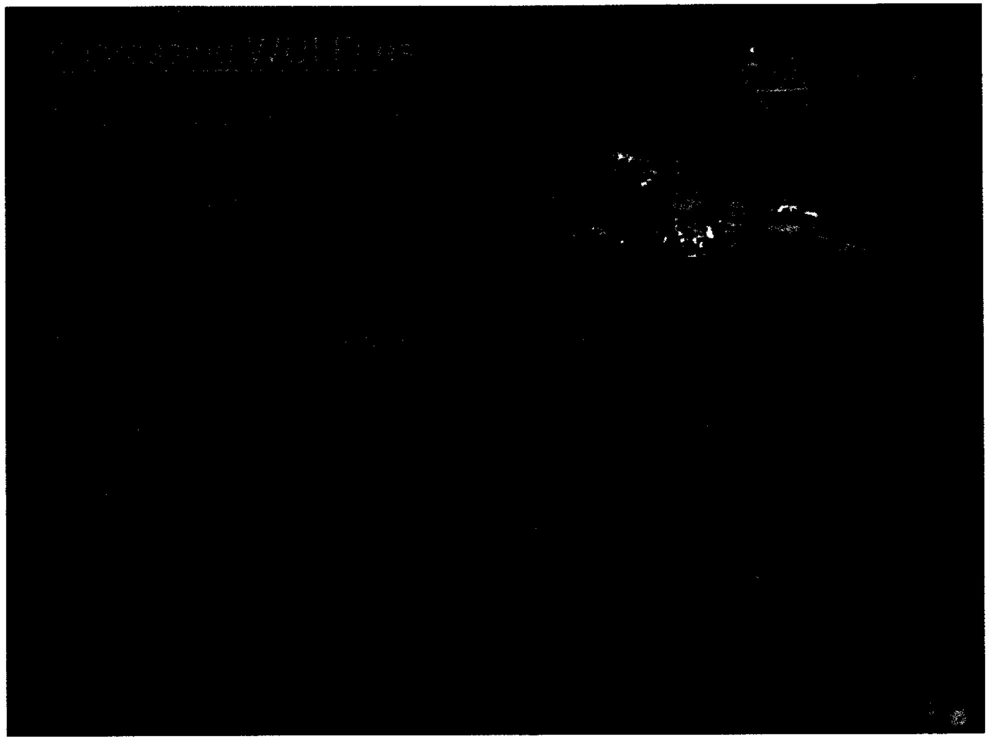
Develop standardized post-fire data collection methods, and a hazard scale to quantify the threat posed by WUI fires (including effects of thermal radiation, embers, wind, moisture, terrain)

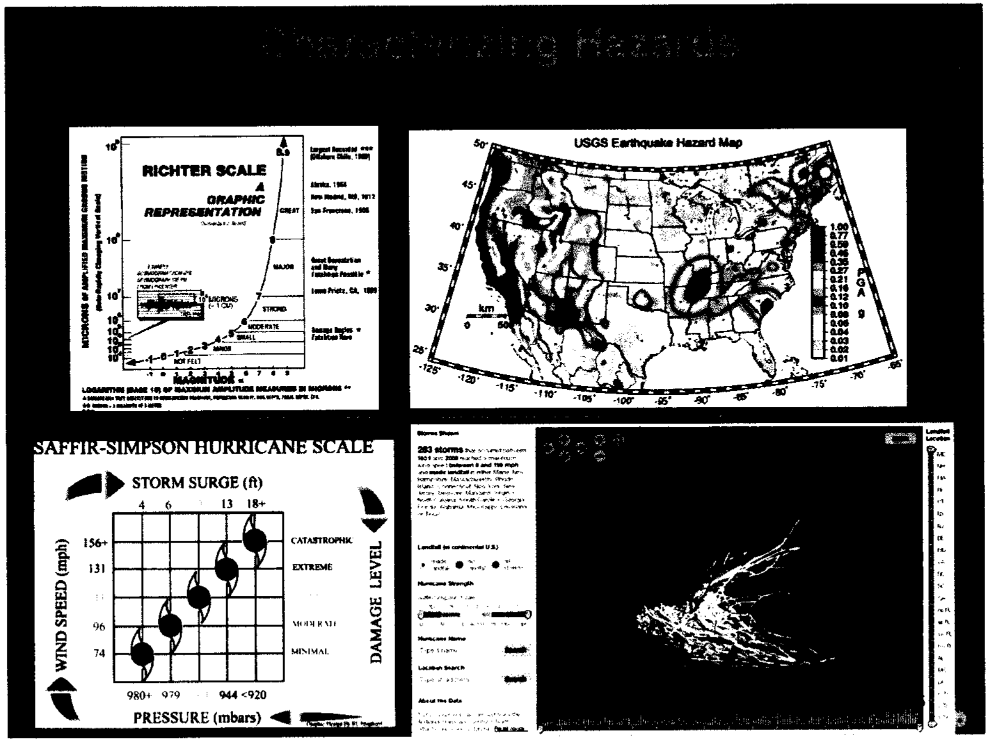
Outcomes: A hazard scale, exposure maps, and mitigation strategies will provide guidance to homeowners, community planners, fire fighters, and standards and code committees

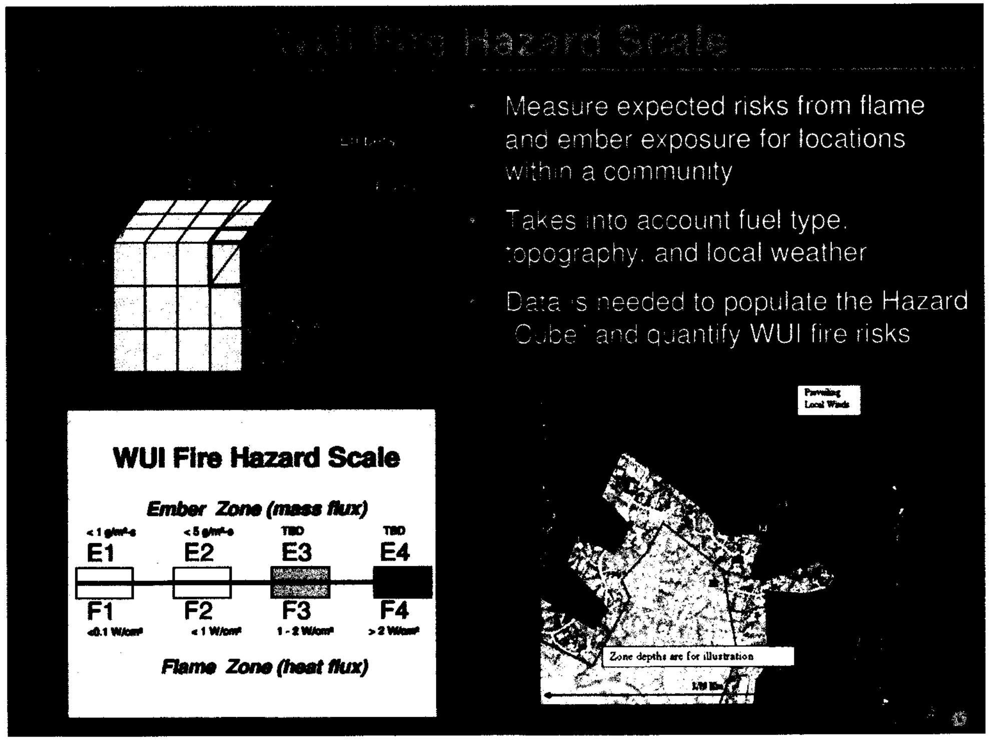
Develop science based tools and test methods to evaluate the fire resistance of materials, building components, structures, parcels, & communities during WUI fires

Evaluate cost-effective WUI fire mitigation technologies (fire resistant vegetation, coatings, wraps, foams, gels, etc.)


NIST UAV
Firespread
Wind
Mean wind direction




Characterizing Hazards
RICHTER SCALE
A GRAPHIC REPRESENTATION
USGS Earthquake Hazard Map
PGA g
SAFFIR-SIMPSON HURRICANE SCALE
STORM SURGE (ft)
WIND SPEED (mph)
DAMAGE LEVEL
CATASTROPHIC
EXTREME
MINIMAL
PRESSURE (mbars)


WUI Fire Hazard Scale
Measure expected risks from flame and ember exposure for locations within a community
Takes into account fuel type, topography, and local weather
Data is needed to populate the Hazard 'Cube' and quantify WUI fire risks
WUI Fire Hazard Scale
Ember Zone (mass flux)
E1 E2 E3 E4
F1 F2 F3 F4
< 1 W/cm²
1 - 2 W/cm²
> 2 W/cm²
Flame Zone (heat flux)
Prevailing Local Winds
Zone depths are for illustration

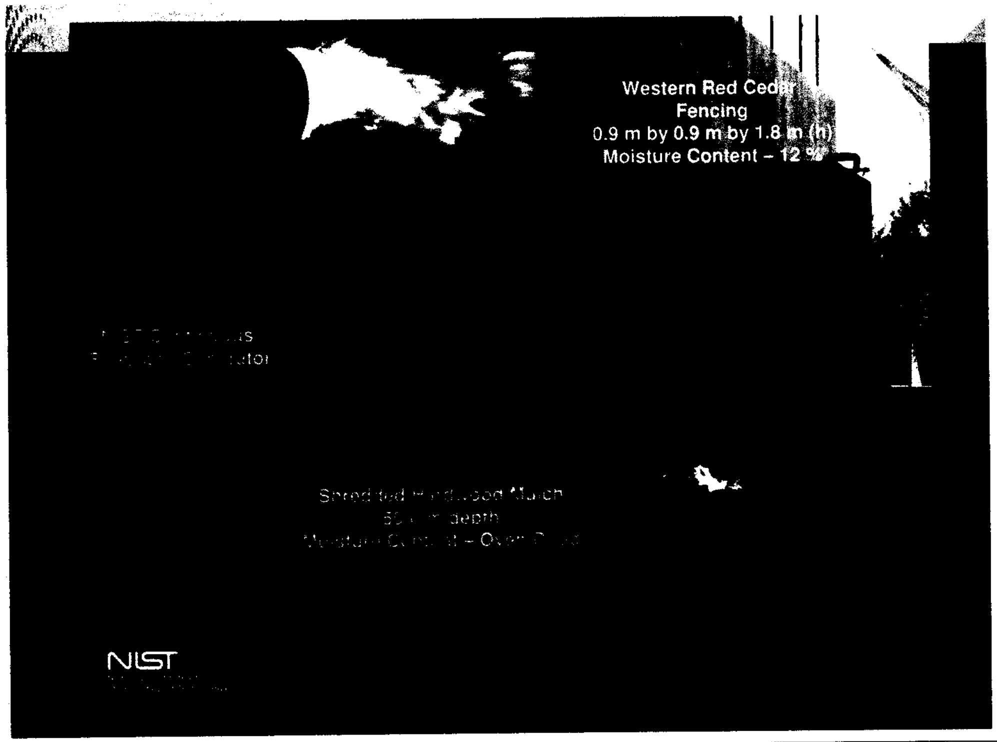
NIST Flight Profile Information

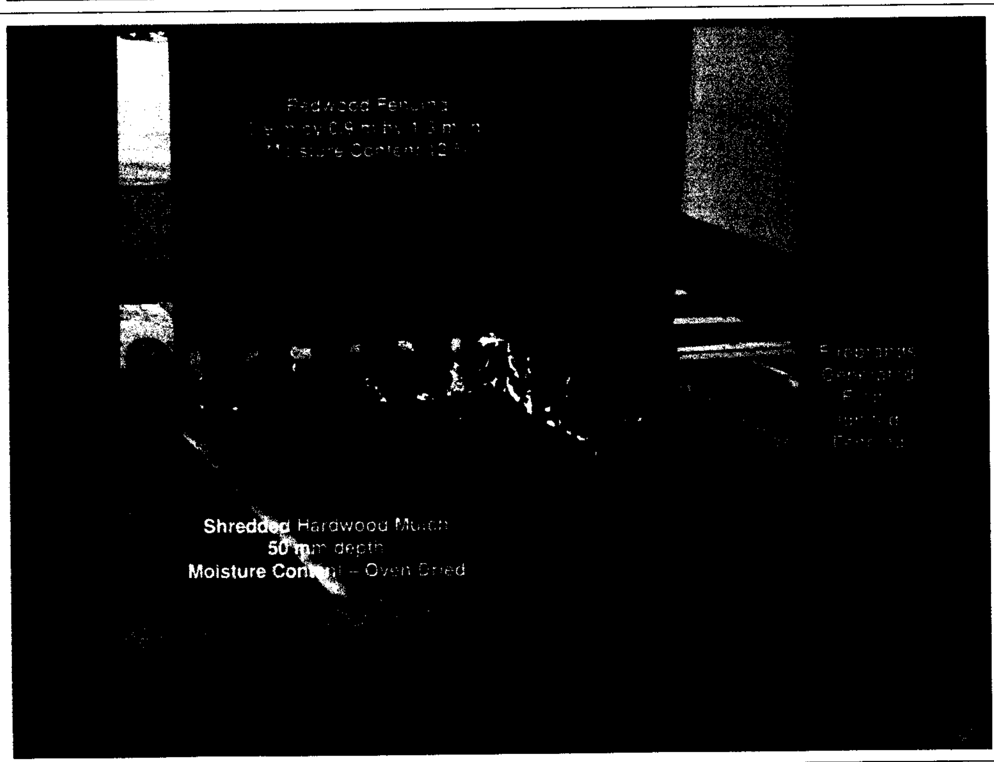
Aircraft Type	**MLB SuperBat**
Wing Span (ft)	8.5
Length (ft)	5.0
Gross Take Off Weight (lbs)	35 with payload
Propulsion	26cc internal combustion
Fuel on Board (lbs)	6.9 lbs (gas/oil mix)
Duration (typical)	10 hours/ 400 miles
Take Off Type	Catapult launch
On board electrical	3 X 5Ah Lithium Polymer
Electrical Duration (typical)	10 hours
Guidance/Avionics	Cloud Cap Piccolo II
Pilot-In-Loop/Manual Over ride	Yes
Launch Type	Catapult
Landing Type	Conventional/Skid
Failover Recovery	Parachute
Aircraft Performance	--
Max Climb (fpm)	1000
Max Descent (fpm)	800
Airspeed (max. kts)	60
Airspeed (cruise. kts)	39
Max Altitude (ft)	10,000
Active Frequencies (Transmitted)	--
Primary Command & Control Frequency	900 Mhz Spread Spectrum/Microhard
Telemetry Frequency	900 Mhz Spread Spectrum/Microhard
Secondary Frequency	N/A
Range (typical)	3-6 miles VLOS
Payload Frequency	1 watt, 2.4 Ghz (consumer)
Range (typical)	Up to 10 miles VLOS
Passive Frequencies (Received)	--
L1 (1575.42 Mhz) and L2 (1227.60 MHz)	GPS navigation

Field safety operations procedures (FSOP) contained in Certificate of Authority issued by the Federal Aviation Administration 2011-CSA-63.

IR – Multi-color

Visible



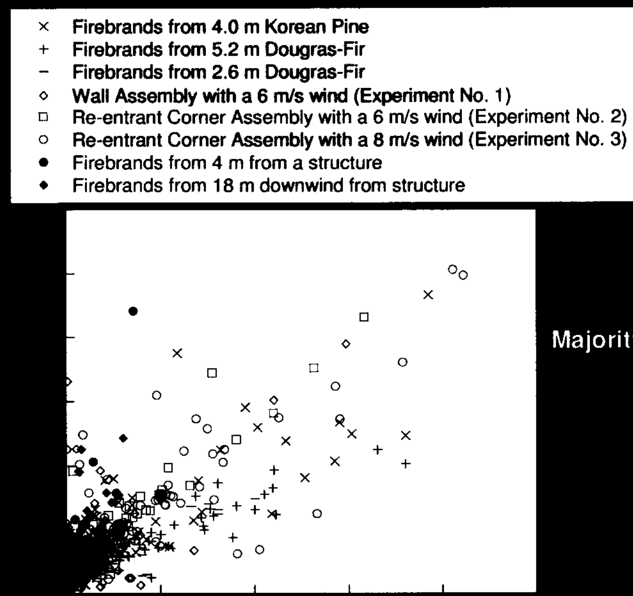


- Accumulated Firebrands Produced Ignition
- Ignition Spread to Supporting Members

Wood Type	Time to Flaming Ignition	Moisture Content (%)
Cedar	501 s [T1]; 372 s [T2]	11.6 [T1]; 11.3 [T2]
Douglas-Fir	1180 s [T1]; 688 s [T2]	8.8 [T1]; 10.8 [T2]
Redwood	356 s [T1]; 1159 s [T2]	11.2 [T1]; 9.8 [T2]

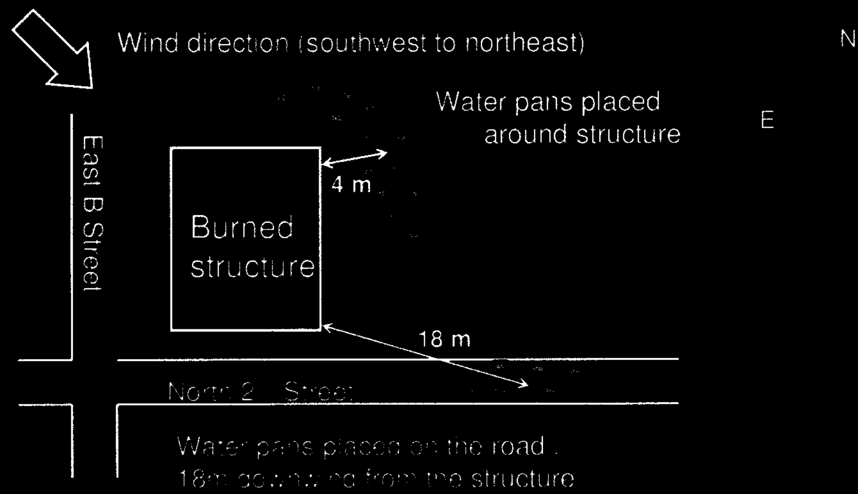
Firebrand Generation from Vegetation

- Firebrand Collection using water pan array
  - Range of crown heights: 2.4 m – 4.5 m
  - Different moisture regimes
  - Douglas-Fir and Korean Pine
- Mass loss using load cells

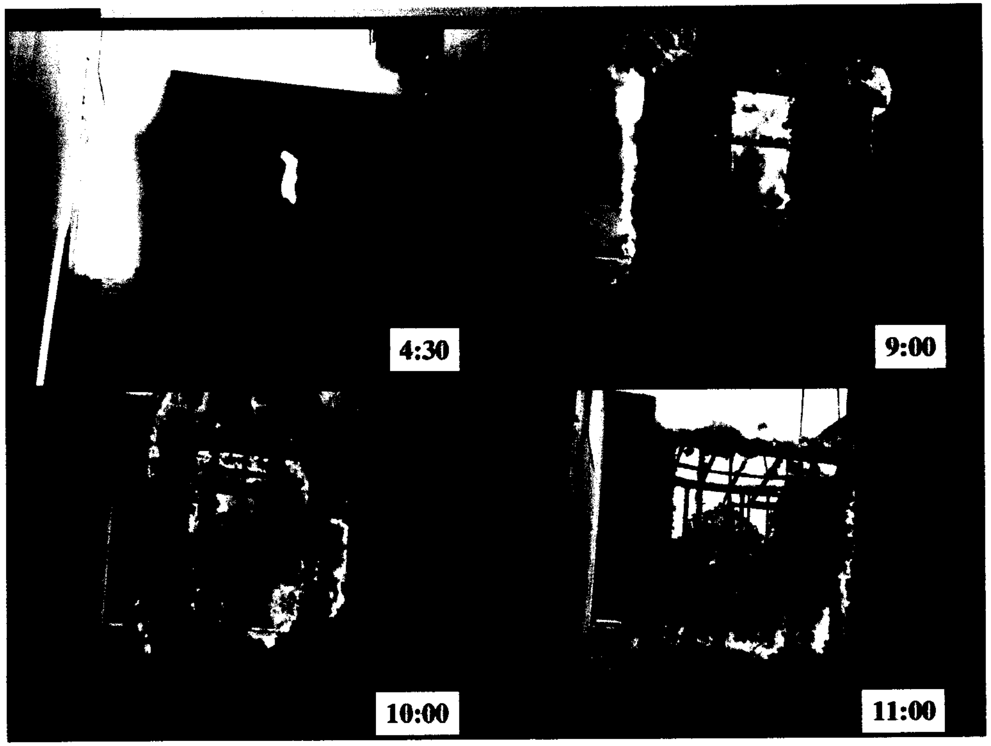


Majority of firebrands < 1g and 10 cm²

Firebrand Collection

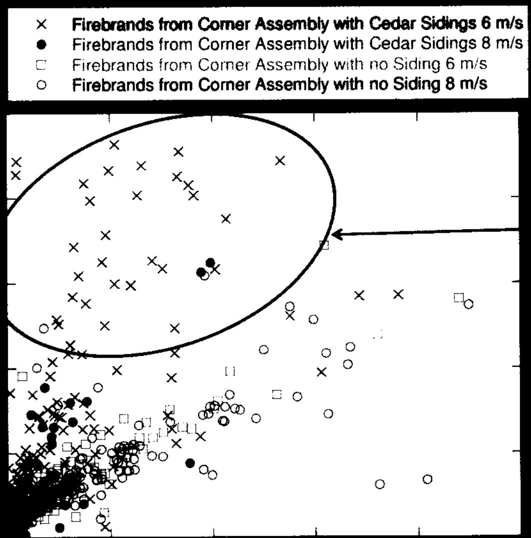


The size mass are measured after being dried



Building Components

Cedar Siding



Firebrands collected with cedar siding were larger in projected area at a given certain mass

Summary

Structural Fire Resistance

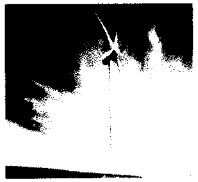
- New facility will provide new measurement capabilities
- Measurements will provide technical basis for performance-based standards for fire resistance design of structures
- CIB Fall Workshop will identify prioritize research needs

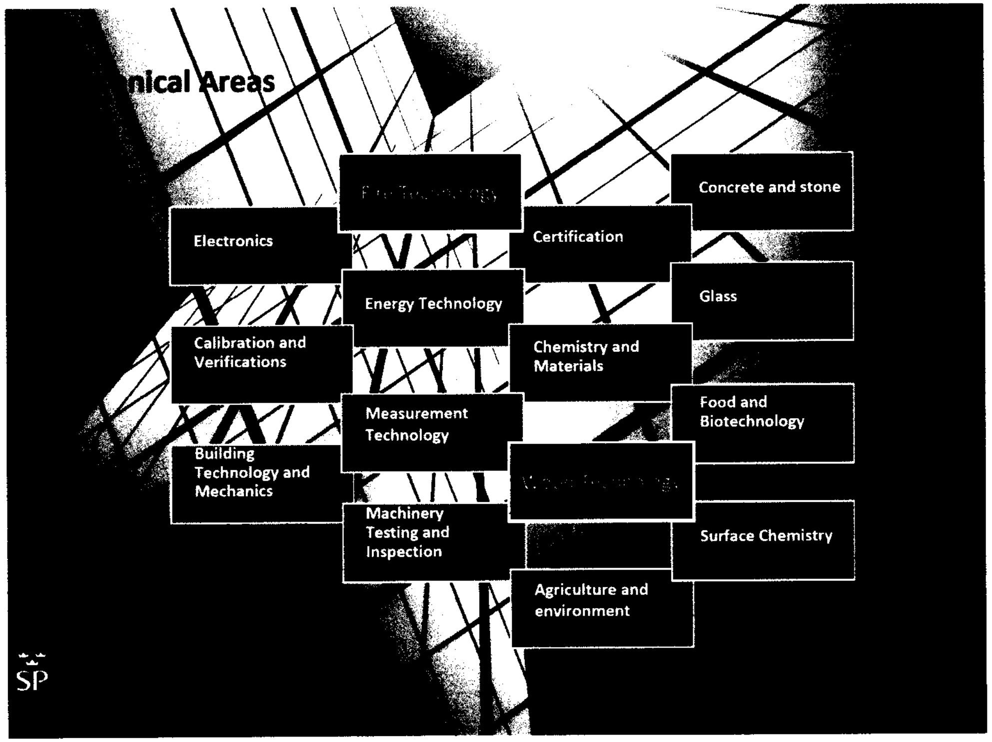
WUI Fires

- Database of fire exposure being developed
  - Structures
  - Vegetation
- Experiments conducted under a range of scales:
  - Actual house (field experiment)
  - Building components (laboratory)
  - Full scale structure (laboratory)
- Data useful for informing test method develop for new generation of WUI building codes standards

SP TECHNICAL RESEARCH INSTITUTE OF SWEDEN

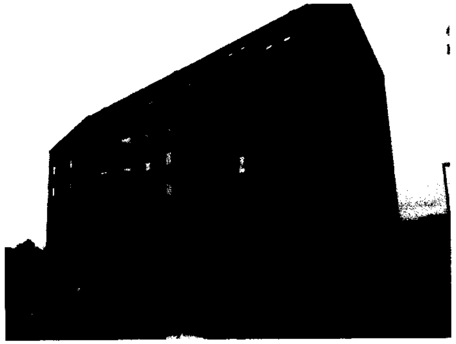
2013





Wood and Fire Research at SP Technical Research Institute of Sweden

Aiming at fire safety in timber buildings, especially higher and larger buildings



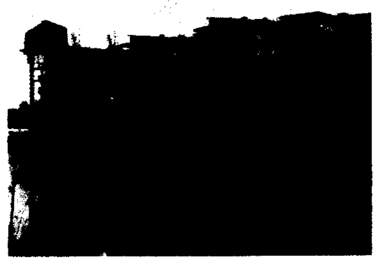
Timber buildings in more than 2 storeys allowed in Sweden from 1994

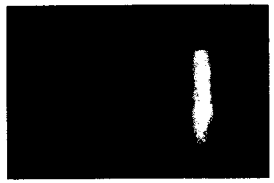
- SP Fire Technology, Borås
- SP Wood Technology, Stockholm

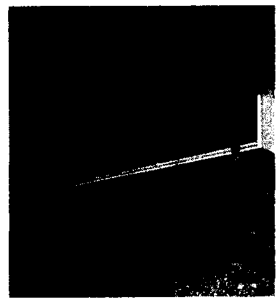
Multistorey timber buildings

Main fields:

- Structural design
- Sustainability
- Acoustics
- **Fire safety**





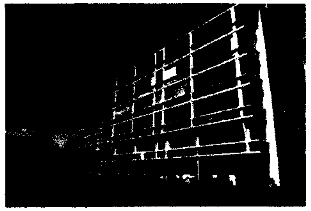


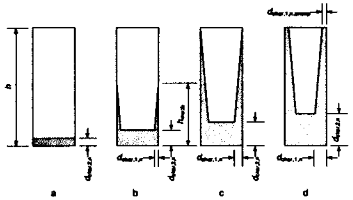
15 % of new medium rise buildings in Sweden are with timber structure (2010)

Wood and Fire Research

Core Fields

- Reaction to fire
- Fire retardant wood based products
- Fire resistance of timber members, elements and construction
- Façades
- Detailing
- Design models and simple software tools for designers
- Fire risks on construction sites





FSUW-Fire Safe Use of Wood – Key Network

European network of research and industry partners
Extending to global level (Australia, Canada, Japan, New Zealand, USA

Main contact at CSTB:
Dhionis Dhima, Département Sécurité, Structures et Feu

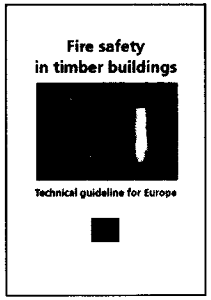
VTT · TUM Technische Universität München · ETH · CSTB le futur en construction · TreSenteret · bre · Holzforschung Austria · Resand · Innsbruck · Université Blaise Pascal · TU Technische Universität Wien Vienna University of Technology

building with wood

Fire regulations main obstacle for use of wood in buildings,

but this is changing now

1. Performance based approach
2. Trend to higher and larger buildings in wood
3. The very first European guideline on Fire safety in timber buildings – Results of a European project



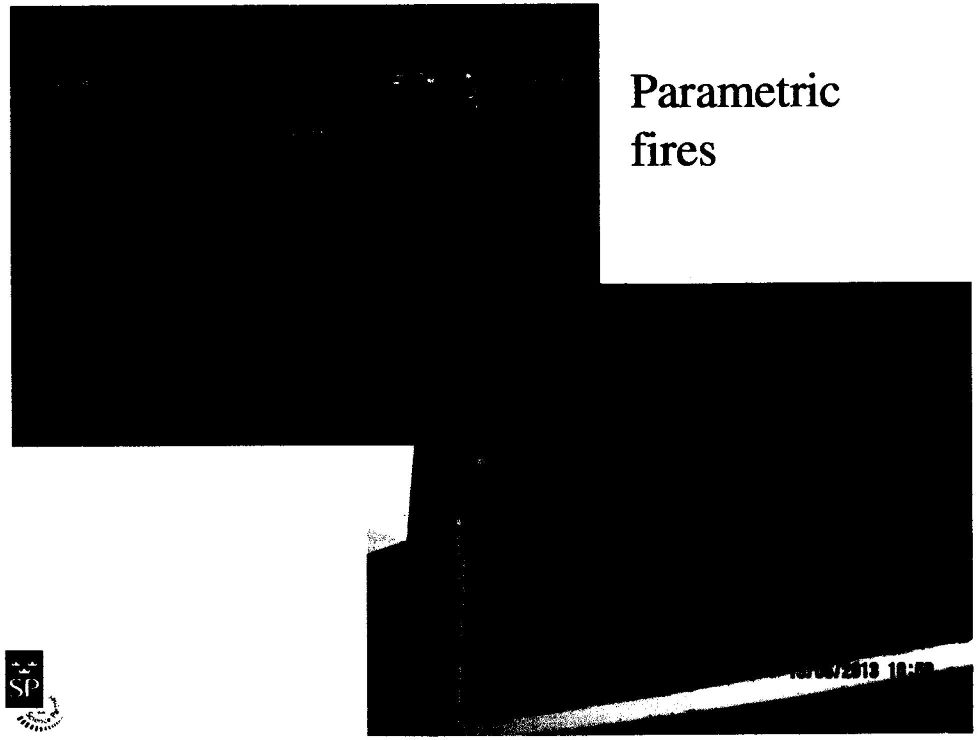
Performance based requirements

↓

Multi-storey timber buildings

Ongoing research projects on wood and fire

- Reaction to fire performance:
  - ReactaFire (EU project)
  - WoodFlareCoat (EU project)
- Fire Safety Engineeering
- Fire resistance:
  - Modelling of new types of timber elements
  - Software development
  - Testing of timber structures acc to parametric fire curves



Parametric fires

Ongoing standarisation on wood and fire

- Reaction to fire performance:
  - Longterm durability of the RtF of FRT wood products (CEN/TS 15912)
- Fire Safety Engineeering
  - Verification of fire safety design in buildings (INSTA 950, InterNordic Standards)
- Fire resistance:
  - Eurocode 5, Fire part (EN 1995-1-2)
  - Protection of timber structures (prEN 13381-7)

Contacts

Birgit Östman birgit.ostman@sp.se
(fire safety engineering, wood technology)

Joachim Schmid joachim.schmid@sp.se
(structural fire design, wood technology)

Lars Boström lars.bostrom@sp.se
(fire research and testing, fire technology)

www.sp.se/en/index/services/fireproofbuilding/Sidor/default.aspx

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Dhionis DHIMA (CSTB)

Fire behaviour of timber connections, timber walls and floors

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Summary

- ➢ **Fire behaviour of bolted and doweled connections**
- ➢ **Shear tests of wood at high temperatures**
- ➢ **Fire behaviour of timber walls**
- ➢ **Fire behaviour of timber floors**
  - ➢ Fire behaviour of three dimensional Nailing Plate connections (boîtiers & étries), Connections with Toothed-plate connectors, Nails connections and Blind Dovetail connections
  - ➢ Cross laminated timber (CLT)

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Introduction - context

1999: 1st Experimental research concerning the fire behaviour of bolted and doweled timber-to-timber and steel-to-timber connections, loaded in tension parallel to grain

2002-2012 : 2 PhDs and numerous masters devoted to fire behaviour of timber connections:

- ➢ **Experimental part** with connections loaded in:
  - *Tension parallel to grain (0°*
  - *Tension perpendicular to grain (90°)*
  - *Tension 45° to grain*
  - *Bending*
- ➢ **Numerical part** which modeled the thermo-mechanical behaviour of all types of tested connections in France, as well as, some steel-to-timber connections tested in Switzerland
- ➢ Parametric study
- ➢ Simplified formula $(t_{fi}=f(h, t_1, d))$

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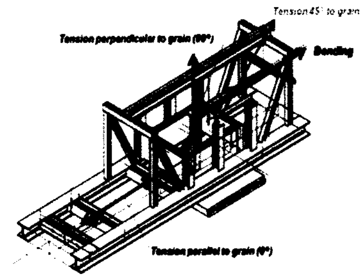
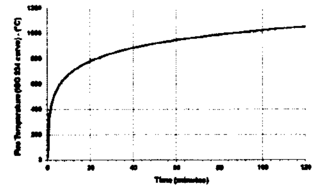
Experimental Results

- ➢ ***Specimens: Connections in double shear***
- ➢ ***Test setup: Multi purpose***
- ➢ ***Fire conditions: ISO 834 curve***



- Tension parallel to grain
  - Timber-to-timber : 19 bolted and doweled connections tested
    2 with toothed-plate and 2 with nails.
  - Steel-to-timber : 20 bolted and doweled connections tested
    6 three dimensional Nailing Plate connections
- Tension perpendicular to grain : 4 steel-to-timber connections
- Tension 45° to grain : 4 steel-to-timber connections
- Bending : 6 steel-to-timber connections

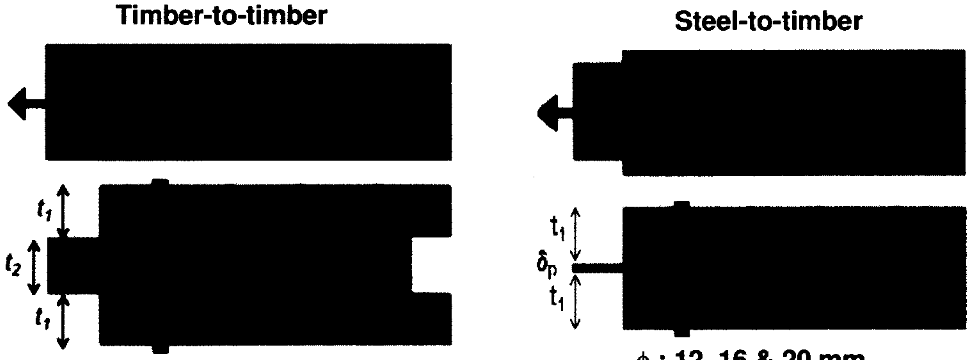


✓ Fire applied load : η = ***(10, 20 & 30%)*** N_u

✓ Cold test : N_u

Experimental Results

- Bolted and doweled connections in tension parallel to grain

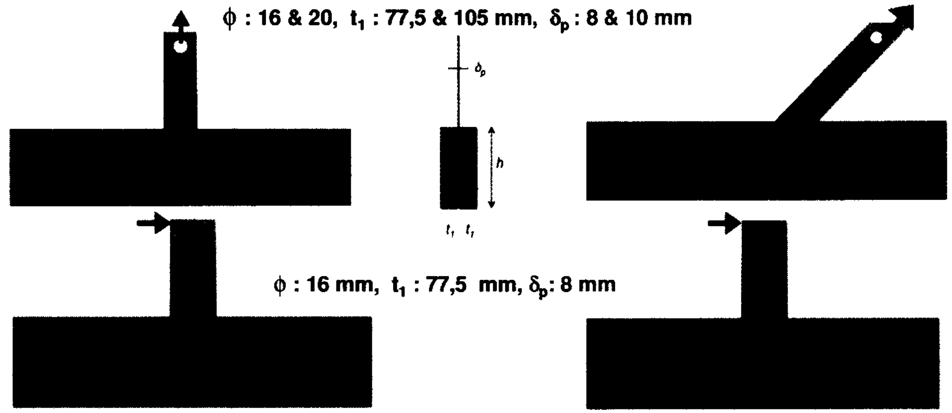


ϕ : 12, 16 & 20 mm
t_1 : 50, 60, 64 & 84 mm

ϕ : 12, 16 & 20 mm
t_1 : 50, 60, 76 & 100 mm
δ_p: 6, 8 & 10 mm

Experimental Results

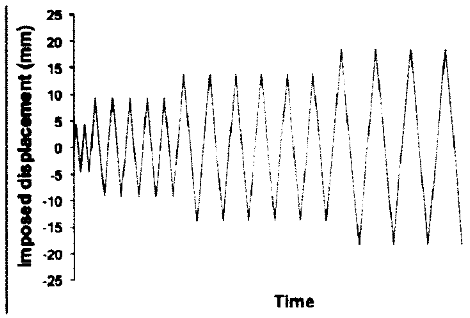
- Steel-to-timber bolted and doweled connections in tension with an angle to the grain and in bending

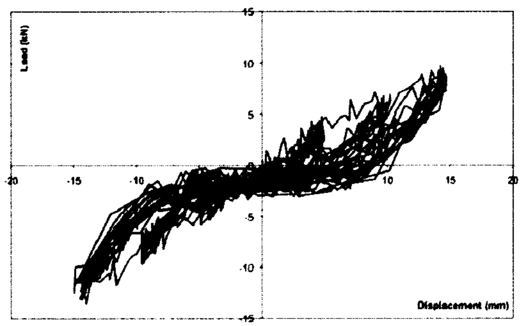


Experimental Results

> ***Cyclic tests (EN 12512): 2 connections*** *(one of each configuration)*

- Influence of clearances on the fire resistance
- Displacement applied to the plate is increased gradually until 1.7^*u_y (0.75^*u_y)





Experimental Results

Tension //

Bending

Tension ⊥

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Experimental Results - Main Results

- **Tension parallel**
  - *- Tests 1999 :* $t_{fi} \approx 10 - 38$ minutes ($\eta = 20 - 65\%$)
  - *- Tests 2003 :*
    - $-\eta = 10\%$: $t_{fi} \approx 50 - 60$ **minutes**
    - $-\eta = 30\%$: $t_{fi} \approx 35 - 45$ **minutes**
- **Tension perpendicular**
  - $-\eta = 10\%$: $t_{fi} \approx 71$ minutes
  - $-\eta = 30, 45\%$: $t_{fi} \approx 48 - 62$ minutes
- **Tension at 45°**
  - $-\eta = 10\%$: $t_{fi} \approx 69$ minutes
  - $-\eta = 30, 45\%$: $t_{fi} \approx 45 - 55$ minutes
- *Bending*
  - $-\eta = 12\%$: $t_{fi} = 88$ minutes
  - $-\eta = 38, 45\%$: $t_{fi} = 40 - 46$ minutes

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Experimental Results

➢ *Experimental Conclusions*

- ❖ **The timber member thickness** and the **load ratio** are the two main parameters influencing the fire resistance of the connections
- ❖ **The load parallel to grain appears predominant in the design of the connections in fire situation:**
  - **t_{fi} (0°) < t_{fi} (90° or 45°)**
  - **t_{fi} (0°) < t_{fi} (bending)**
- ❖ $\eta < 30\%$ *Nu* ⟶ t_{fi} : > 30 *minutes*

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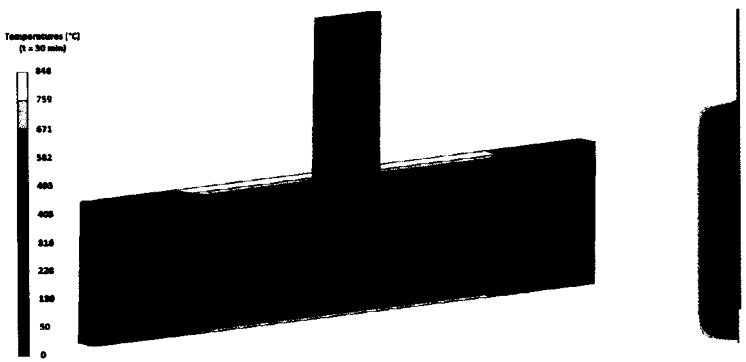
Numerical modeling – heat transfer

➢ *Thermophysical properties: $\rho(\theta)$, $\lambda(\theta)$, $c(\theta)$*

- *Steel: EC3-1.2*
- *Timber: sensitivity analysis*



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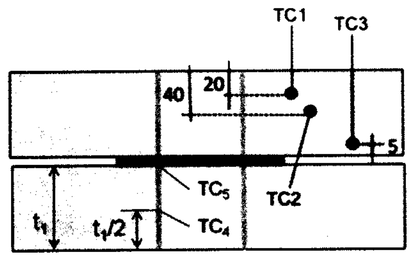
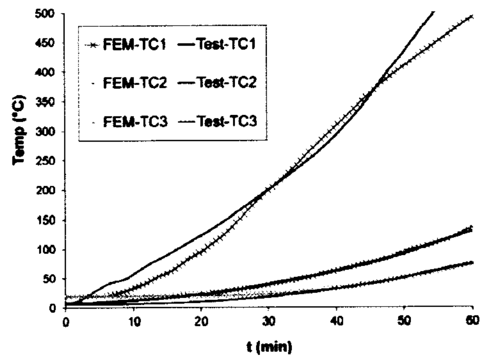
Numerical modeling – heat transfer

➢ *Validation by comparison of measured and calculated temperatures and charring rates.*



Thermocouple positions



Measured and calculated temperatures of timber members

Numerical modeling Thermomechanical behaviour

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- ➢ ***Material modeling***
  - ***Steel:*** *Isotropic elastic-plastic behaviour (Von Mises criterion)*
  - ***Timber:***
    - *Assumption of transverse isotropy*
    - *Plastic behaviour :*
      - *Hill yield criterion (symmetric criterion)*
      - *Tsaï-Wu failure criterion (asymmetry between $f_{c,90}$ and $f_{t,90}$)*
- ➢ ***Evolution of mechanical properties***
  - ***Steel:*** *reduction coefficients (EN1993-1-2)*
  - ***Timber:*** *reduction coefficients (EN1995-1-2)*
- ➢ ***Contact between different members is taken into account***
- ➢ ***Validation of the modeling by comparison of***
  - ***Evolutions of the connection slip versus the fire exposure time***
  - ***Measured and calculated durations of fire resistance***

Numerical modeling Thermomechanical behaviour

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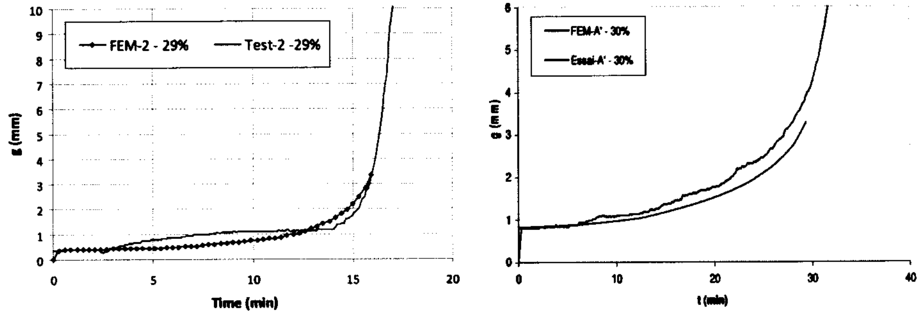
➢ **Load-displacement curves (tension // to grain)**



- ➢ ***Numerical fire resistances always lower than the experimental ones*** *(relative error of about 15%)*
- ➢ ***Consequently, the model always represents safely the fire behaviour of connections***

Numerical modeling Thermomechanical behaviour

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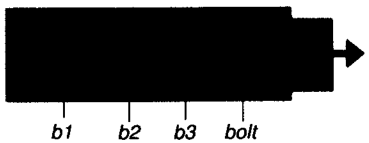
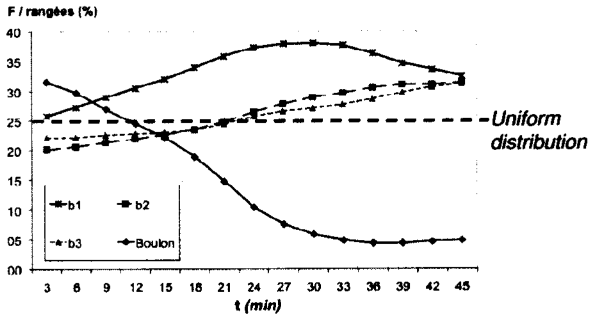
➢ **Load distribution among fasteners**

- **2 bolts**
- **6 dowels**





Numerical modeling Thermomechanical behaviour

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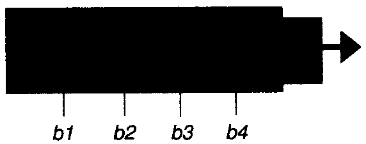
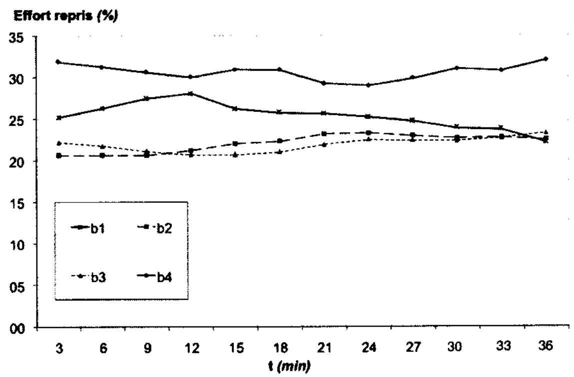
➢ **Load distribution among fasteners**

- **8 dowels**





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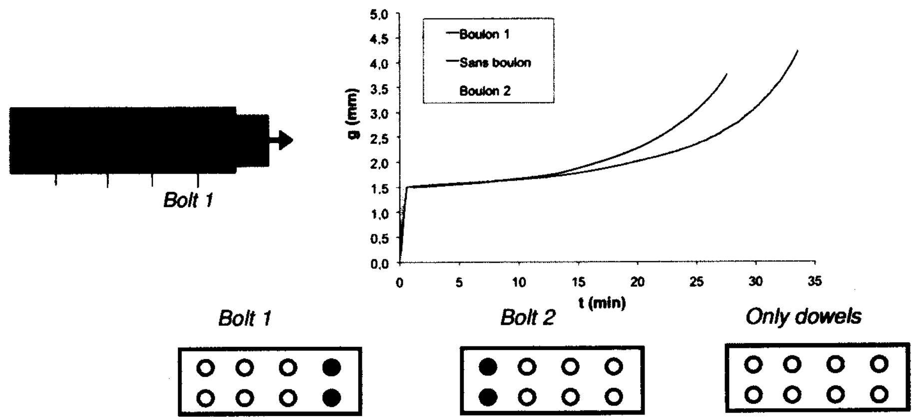
Numerical modeling Thermomechanical behaviour

- **Influence of position of the bolts/dowels**



t_{fi} = 28 minutes — t_{fi} = 24 minutes — t_{fi} = 33 minutes

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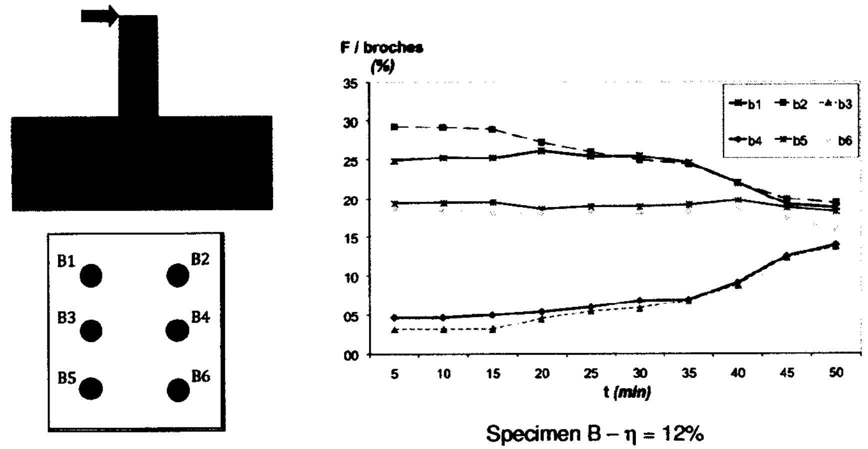
Numerical modeling Thermomechanical behaviour

- **Load distribution among fasteners**



Specimen B – η = 12%

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Design of experiments approach

- ***Studied configuration:*** *dowelled steel-to-timber connections subjected in tension parallel to grain (predominant loading case)*
- ***Factors of the numerical design:***
  - ***Load ratio: 10 and 30 % of $N_{u,EC5}$***
  - ***Timber thickness: 55 to 160 mm (6 levels)***
  - ***Diameter: 12, 16 and 20 mm***

36 simulations are necessary to realize a complete factorial design, considering the influence of each parameter

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Design of experiments approach

From the numerical values of fire resistance obtained with the 36 simulations, a simplified formula is defined

$$\hat{t}_{fi} = 27.32 - 1.51d + 1.07t_1 - 7.51\ln(\eta) + 0.49d\cdot\ln(\eta) - 0.24t_1\cdot\ln(\eta)$$

$$\|\varepsilon\| = \frac{\|t_{fi,sim} - \hat{t}_{fi}\|}{\|t_{fi,sim}\|} = 7.87\%$$

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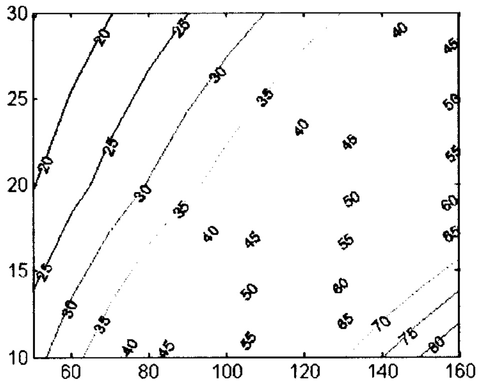
Design of experiments approach

Design abacuses for fastener ϕ=16 mm



These abacuses allow obtaining fire resistance durations closer to the experimental ones compared to current method provided by EN1995-1-2

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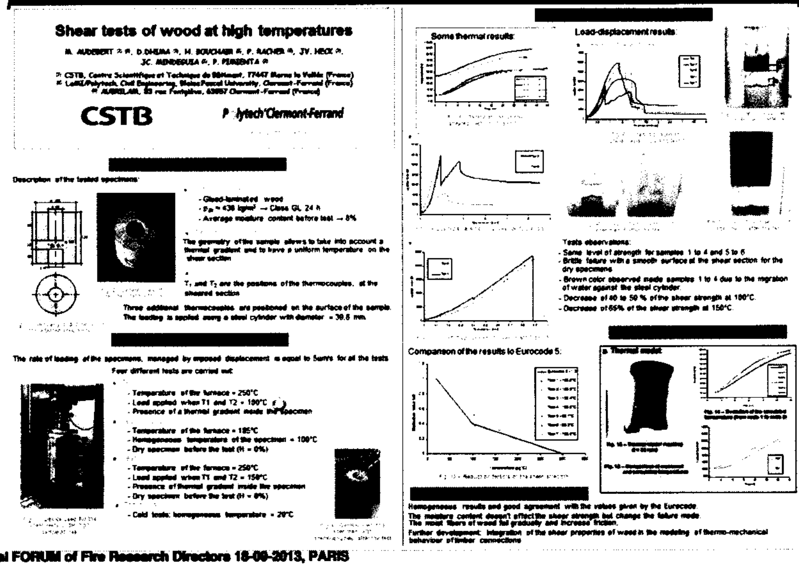
Shear tests of wood at high temperatures



CSTB le futur en construction

Timber connections - Conclusions

- ***The large experimental program conducted in France since 1999 allowed to determine the main parameters influencing the fire resistance of timber connections***
- ***The experimental results showed that tension parallel-to-grain play a predominant role in fire behaviour of timber connections***
- ***An accurate numerical model has been developed in order to provide date for a Design of Experimental Approach***
- ***The Design of Experimental Approach allows obtaining a simplified design analytical formula to calculate the fire resistance of the connection, providing more precise results than the current method of EN1995-1-2***

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Publications

1. RACHER P., LAPLANCHE K., DHIMA D., BOUCHAIR A.: "Thermo-mechanical analysis of fire performance of dowelled timber connection", Engineering Structures, Vol. 32, Issue 4, p. 1148-1157, April 2010.
2. AUDEBERT M., DHIMA D., TAAZOUNT M., BOUCHAÏR A.: "Numerical investigations on the thermo-mechanical behavior of steel-to-timber joints exposed to fire", Engineering Structures, Vol. 33, Issue 1, p. 3257–3268, January 2011.
3. AUDEBERT M., DHIMA D., TAAZOUNT M., BOUCHAÏR A.: "Behaviour of dowelled and bolted steel-to-timber connections exposed to fire", Engineering Structures, Vol. 39, p. 116-125, February 2012.
4. AUDEBERT M., DHIMA D., TAAZOUNT M BOUCHAÏR A.: "Thermo-mechanical behaviour of timber-to-timber connections exposed to fire ", Fire Safety Journal, Vol. 56, p. 52-64, February 2013.
5. RACHER P., LAPLANCHE K. and DHIMA D. and JOYEUX D.: "Fire resistance of joist hangers" – Proceedings of International Symposium on Advanced Timber and timber-Composite Elements for Buildings, Design, Construction, Manufacturing and Fire Safety, COST E29, 27-29 October 2004, Florence, Italy, p. 233-242.

<u>Accepted papers</u>:

6. AUDEBERT M., DHIMA D., TAAZOUNT M BOUCHAÏR A.: "Experimental and numerical analysis of timber connections in tension perpendicular to grain in fire", (Fire Safety Journal, p. 30).
7. DHIMA D., Audebert M., RACHER P., Bouchaïr A., Taazount M.: "Shear tests of glulam at elevated temperatures", (Fire and Materials, p. 17).
8. DHIMA D., AUDEBERT M., BOUCHAÏR A., TAAZOUNT M.: "Analysis of the thermo-mechanical behaviour of steel-to-timber connections in Bending", Journal of Structural fire Engineering, p.14 …

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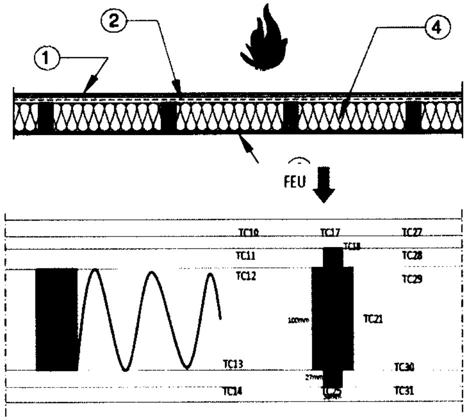
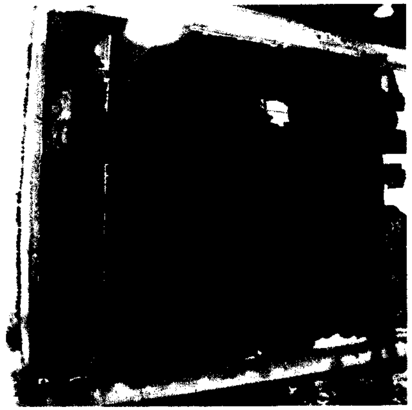
Timber walls

➢ **Configurations: 10**





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Timber walls

- **Tests 1 & 2**
  4 specimens
  1,2m x 1,2 m
  Choice of Insulation
- **Tests 3 to 12**
  Specimens
  3 m x 3 m
  Fire resistance

Test	Configurations		Fire resistance (min)		Classification (foreseen)
	Fire exposed facing (screen)	Non exposed facing	Experimental	Calculated according FIT method	
1	2BA13	2OSB(2*9mm)	49	39,5	EI30
2	1BA15F	2OSB(2*9mm)	65	35,5	EI30
3	1BA13	2OSB(2*9mm)	29	23	EI15
4	2BA13	2OSB(2*9mm)	43	38	EI30
5	2BA13	2OSB / 2plywood(2*9mm)	45	35,5	EI30
6	1BA18	2OSB(2*9mm)	43	21	EI30
7	2OSB(12+9)	2OSB(2*9mm)	28	21	EI30
8	1BA13+1OSB	MDF(15mm)	36	35	EI30
9	Timber cladding 18 mm + OSB12	BA13	71	36	EI30
10	2BA13F	2OSB / 2plywood(2*9mm)	68	55	EI60
11	1BA13+BA18	2OSB(2*9mm)	51	39	EI60
12	2BA15F	OSB(2*9mm)	84	59	EI90

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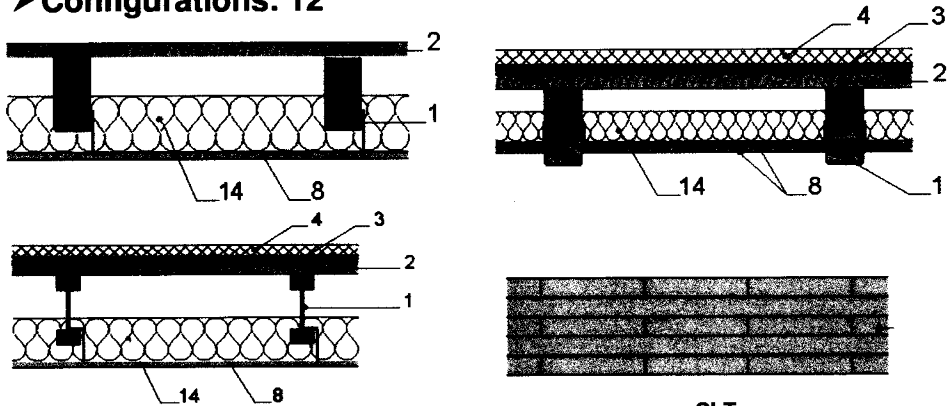
Timber Floors

➢ **Configurations: 12**



CLT

Fire resistance: REI 15, REI 30, REI 60 and REI 120.

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Timber walls

Floor configurations		
Test	Screen	Fire resistance required
1	1BA13	REI 15
2	2BA13	REI 30
3	1BA15F	REI 30
4	1BA18	REI 30
5	1x25 plywood	REI 30
6	1x22 plywood (fire retardant)	REI 30
7	2BA15F	REI 60
8	1BA25	REI60
9	1BA13+1BA18	REI 60
10	3BA15F	REI 90
11	1BA18+ABA15F	REI 90
12	CLT (17+33+17+17+27+17+17+33+17)	REI 120

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Timber walls and floors - Conclusions

- ❑ ***Analyze experimental results***
- ❑ ***Guide for the design of timber floors and walls***

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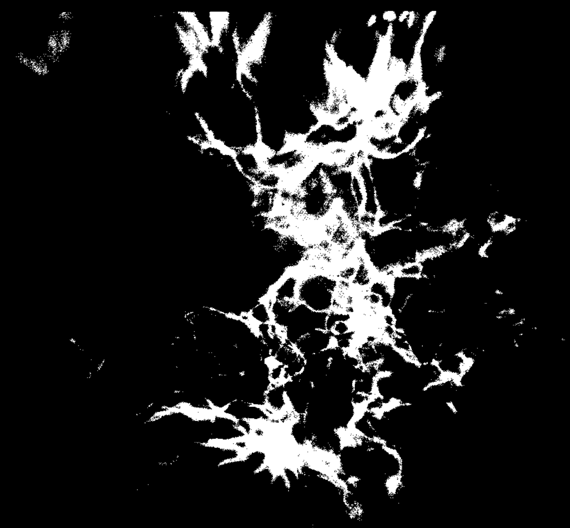
Thank you for your attention !



FM Global

FM Global

Presented by:
Lou Gritzo

Developed by:
Ben Ditch
J.C. Harrington

FM Global

New Technology

- Cross laminated timber (CLT)
- Glue laminated timber (Glulam)
- Laminated veneer lumber (LVL)
- Post-tensioned timber
- Panelized construction

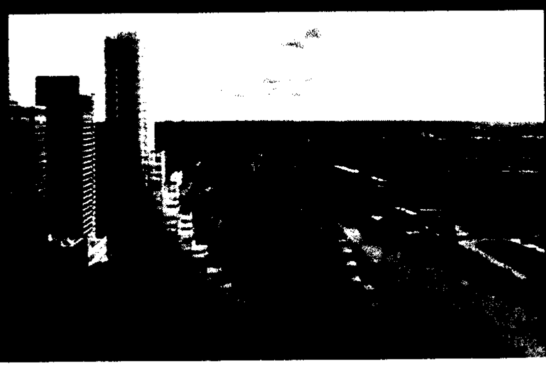
New Appl

- Green c
- Iconic b
- High rise
- Aestheti

Major Re

- Canada
- Limited

FM Global



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"Green" construction
Renewable

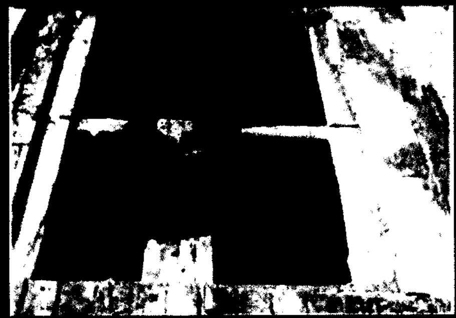
Images

Combustible construction
No clear comparison to existing buildin

FM Global

Well defined certification standards

- Component and system level
- Harmonization of evaluation criteria



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Clear cut protection requirements

- Sprinkler protection
- Passive fire barriers

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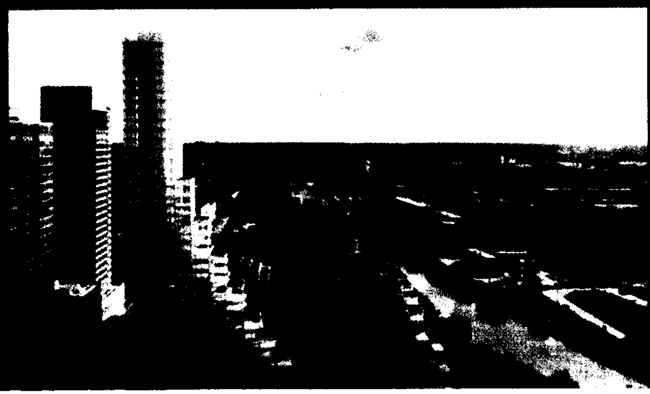
Reliable Risk Reduction

- Loss Limiting Features
  - Engineered/Certified
- Aging/Damage/Rebuild
- Cost of Risk Transfer
  - Loss History



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Canada Making Strides in Mid-Rise Wood Buildings

Joseph Su
Fire Safety
National Research Council Canada

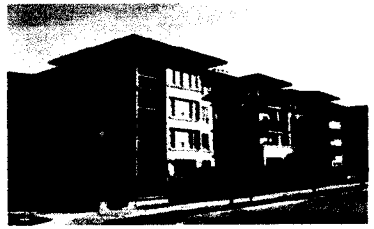
FORUM Workshop
September 18, 2013

National Building Code of Canada (NBCC)

Objective-based code (since 2005)

- Acceptable solutions

  Height and area limits for sprinklered wood buildings
  - 4 storeys for CE/D with floor area ≤ 1800/3600 m^2
  - 2 storeys for A2 with floor area ≤ 2400 m^2



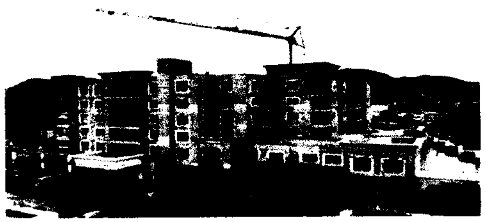
- Alternative solutions

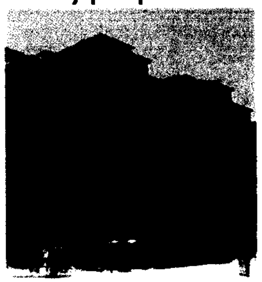
  Allowing higher and larger
  - But burden of proof

Changing Building Codes

To allow 5-6 storey wood frame construction

- British Columbia Building Code amended in 2009
- Quebec Building Code to be amended by end of 2013
- National Building Code of Canada (NBCC) proposed to change in 2015





Changing Building Codes

Proposed changes in *Acceptable Solutions*

- 6 storeys Groups C/D with floor area ≤ 1500/3000 m^2
  - 18 m to uppermost floor; 25 m to highest point on roof
  - Facing 1 street if ≥25% of perimeter within 15 m of street
  - Occupancy combinations (some require higher FRR)
- Compensatory measures
  - NFPA 13 sprinklers + in concealed space and on balconies
  - Improved fire blocking
  - Improved safety/security and firefighter access at construction and demolition sites

R&D for Midrise and Taller Wood Buildings

Funders

- Natural Resources Canada
- Governments of Ontario, Quebec and British Columbia

Collaborators

- National Research Council of Canada
- Canadian Wood Council
- FPInnovations
- Network for Engineered Wood-based Building Systems

Providing technical info and innovative solutions to

- Support code changes to allow mid-rise wood buildings
- Facilitate use of wood structure in mid-rise buildings
- Develop performance based requirements
- Support design and construction of demo buildings

Mid-Rise Wood R&D Project

Goals

- Short-term: inform decisions on changes for NBCC 2015
- Longer-term: develop performance-based criteria and solutions

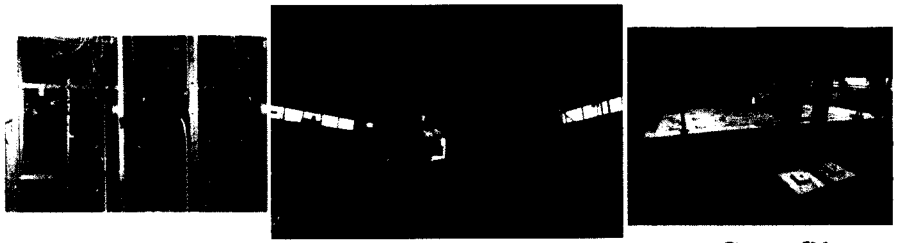
Areas:

- Structure, fire, acoustics and building envelope

Mid-Rise Wood Project Activities

Develop solutions for:

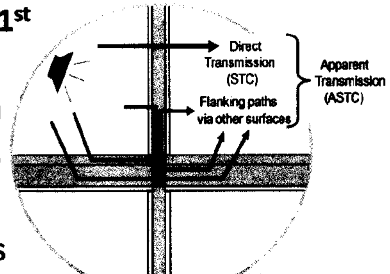
- **Encapsulation of wood structures** – fire performance
- **Wood structural members and systems** – fire resistance and acoustic performance
- **Wood-based exterior walls** – fire and building envelope

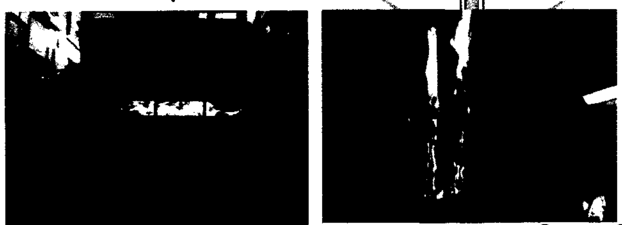


Solution: Wall and Floor Assemblies

New stronger assemblies for 1st and 2nd storeys meet

- Acoustic requirements (STC)
- Other acoustic performance (ASTC as well as impact)
- Fire resistance requirements (FRR)





FRR of Light-Weight Wood-Frame Walls

- Staggered studs with glass fiber insulation
- Double layer of 12.7 mm Type X gypsum board (with/without shear layer or resilient channels)

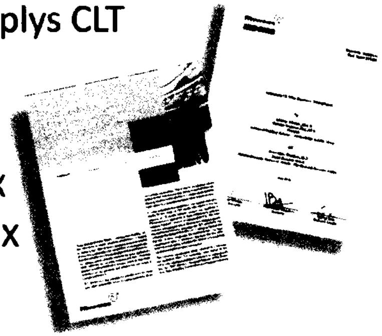
LWF Test Assembly	Stud size (mm x mm)	Spacing (mm)	Header* Footer End Studs	Shear Layer	Resilient Channels
[redacted]	38 x 89 S	400	38 x 140	OSB	-
[redacted]	38 x 89 T	400	38 x 140	-	one side
[redacted]	38 x 89 S	100	38 x 140	-	one side
[redacted]	38 x 89 S	400	38 x 140	-	-
[redacted]	38 x 140 S	400	38 x 190	OSB	-

S – single, T – triple, *double

Fire Resistance of CLT Assemblies

Full-scale fire resistance tests

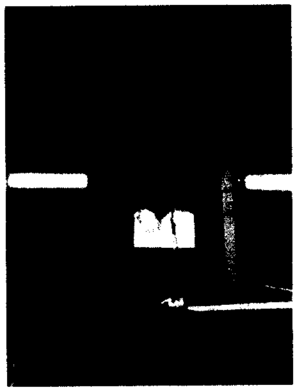
- FPInnovation/NRC report and TechNote
- Specimens: 3-, 5- and 7-plys CLT
- Adhesive: Polyurethane
- Gypsum Board:
  - 1 layer of 15,9 mm Type X
  - 2 layers of 12,7 mm Type X



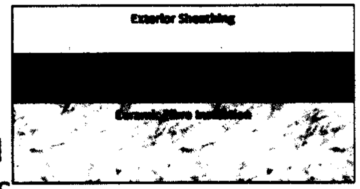
Solution: Exterior Wall Assemblies

Wood-based assemblies (LWF, CLT)

- Limit fire spread on exterior
- Meet hygrothermal performance



Material Screening for Exterior Wall Assemblies



Screening tests

- Spray polyurethane foam (SPF)
- Polystyrene (PS)
- Gypsum sheathing with plywood
- Gypsum sheathing with SPF or PS
- Fire-retardant-treated (FRT) plywood
- FRT plywood with SPF or PS
- Vapour permeable membrane

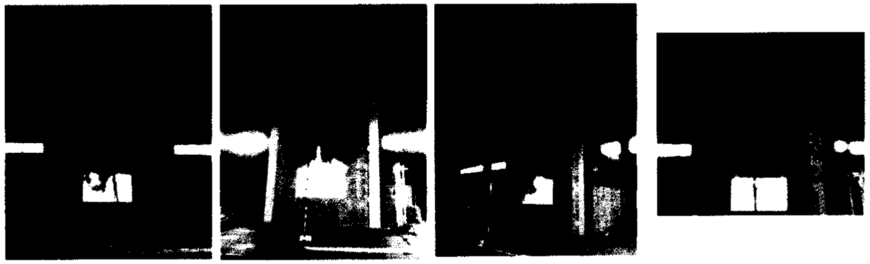
Selection for generic exterior wall systems

- Materials with highest heat output

Fire Tests of Exterior Wall Assemblies

LWF assemblies with spray polyurethane foam

CLT assemblies with outboard polystyrene insulation



- Sheathing: gypsum or fire-retardant treated plywood

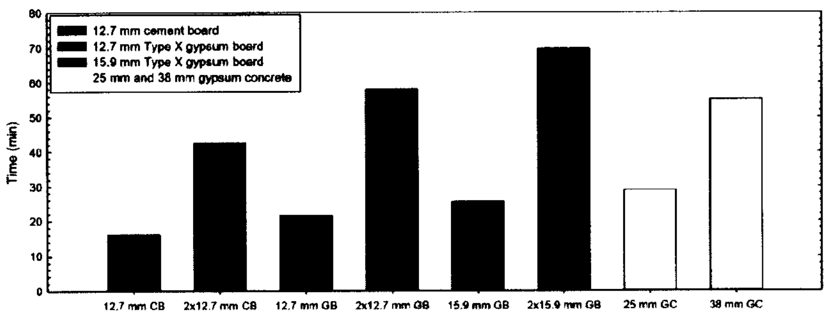
Solution: Encapsulation of Wood Structure

Delay ignition and limit contribution of wood structural elements to fire using thermal barrier materials

- Type X gypsum board
- Cement board with fibreglass
- Gypsum concrete

Encapsulation Material Characterization bench- and intermediate-scale tests

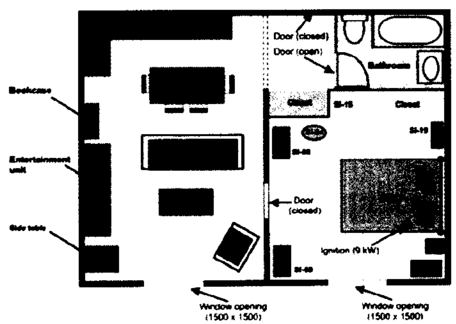
- Encapsulation time
- Ignition time
- Ignition temperature of plywood substrate

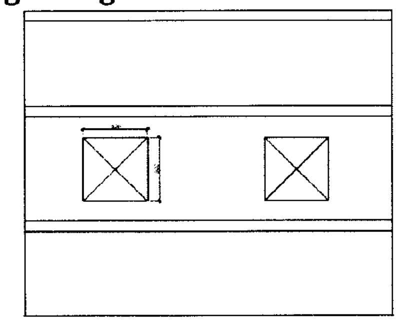


Encapsulation: Apartment Tests

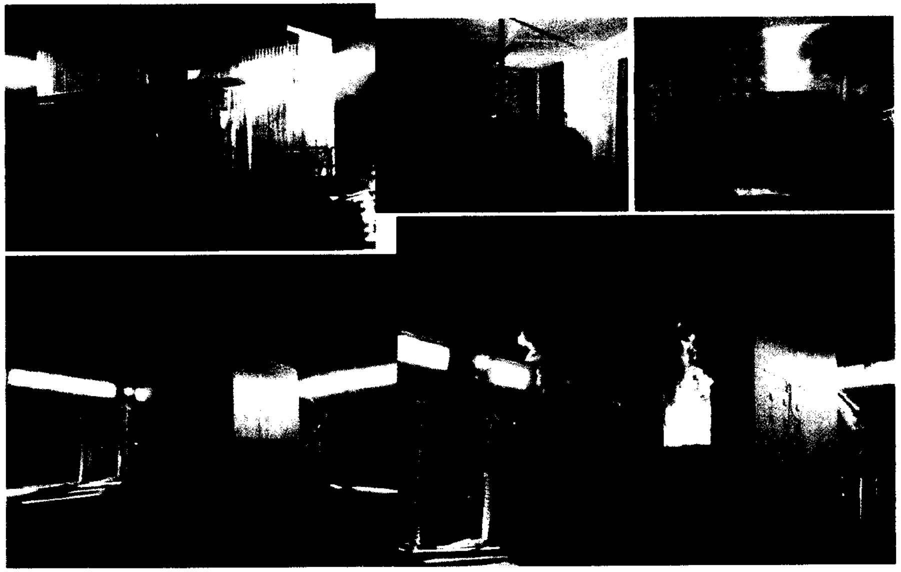
To demonstrate similar fire severity between:

- Encapsulated wood structure – LWF and CLT
- Noncombustible structure lightweight steel frame

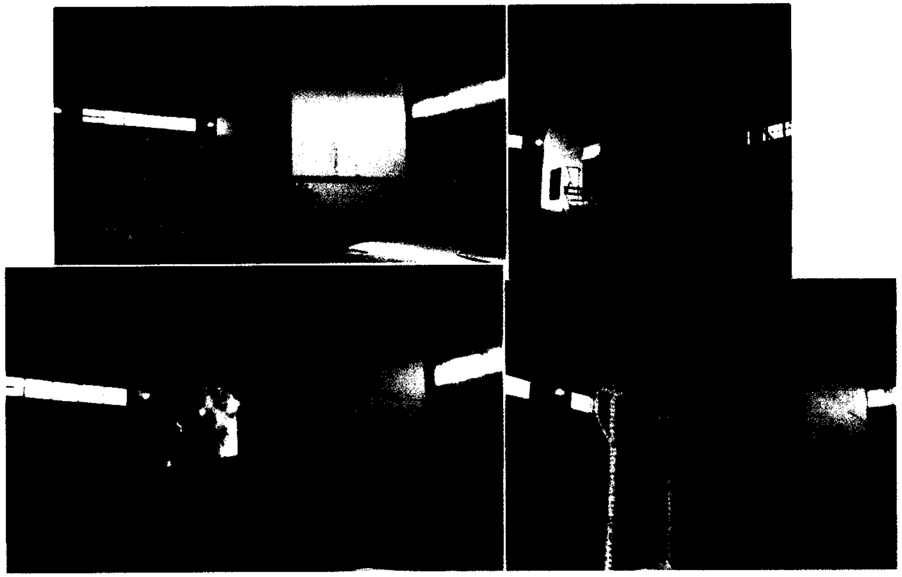




LWF Apartment Test



CLT Apartment Test



Summary

Canada is moving towards expanding the use of wood-based structural materials in mid-rise buildings.

Ongoing Canadian research projects develop performance based solutions to help

- Remove technical and regulatory barriers
- Facilitate the design and demonstration of mid-rise and taller wood buildings

NRC CNRC

Canada Making Strides in Mid-Rise Wood Buildings

Questions?

Thank You!

Fire Research: Highlights of 2012-13

CWC/FPI/NRC Mid-Rise Consortium (NRCan, QC, BC & ON)

- Support CWC's Code changes to allow greater use of wood
- Full-scale 3-storeys apartment fire tests
  1. Light-frame wood assemblies (completed)
  2. CLT assemblies (completed)
  3. Light-weight steel assemblies (± Nov. 2013) (min. "acceptable solutions")

- Fire-resistance tests (5) – (≥ 1-hr and STC ≥ 50)
  - Structural wall assemblies (typ. in the lower portions of mid-rise buildings)
- FPI contributed significantly to the design of the various test buildings & assemblies

FPInnovations

Fire Research: Highlights of 2012-13

Code & Standard Activities

- Participate in various C&S committees (CSA, ULC, ASTM, ISO)
  - Provide scientific data to committees and help in developing standards, namely in fire safety engineering and testing
    - CLT now accepted as Type IV in the next 2015 IBC
    - Development of fire-resistance calculation models
      - > Fire-resistance calculation method for mass timber elements (Canada)
      - > Fire-resistance calculation method for CLT assemblies (US & Canada)
- Support Canada Wood to facilitate & ensure market access
  - Assistance to JAS standard development on CLT in Japan
  - Revision of the National Timber and Fire Codes in China

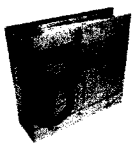
FPInnovations

Fire Research: Highlights of 2012-13

Support to AHJs and Design Community

- Developed a design guide to allow mid-rise residential wood construction in Quebec

- Development of fire-resistance models
  - US calculation method now published in US CLT Handbook
  - Updated version of Chapter 8 (fire) from the Canadian CLT Handbook (enhanced method) (under peer-review)
  - Finite element models (structural & heat transfer)



- Development of a road map for implementing performance-based fire design (i.e. alternative solutions)

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Fire Research: Focus for 2013-14

Fire Testing

- Flame Spread Rating of Massive Timber Elements
  - CLT E1-grade, PSL, LVL and LSL evaluated per ULC S102. Report available.
    - CLT V2-grade to be tested soon.
- Fire-Resistance
  - CLT V1-grade (Douglas-Fir)
  - CLT with thin laminates (less than 35 mm)
  - CLT panel-to-panel joints (other than half-lapped)
  - Hybrid concrete-timber floor assemblies
- Combustion properties of SCL
  - PSL, LVL and LSL to be evaluated per ULC S135 (Cone calorimeter)

FPInnovations

FPInnovations Fire Research Program 2013-14

Activity report for the 2013 Annual Meeting of the
Fire Design Subcommittee of the American Wood Council
July 23-24, 2013 – Leesburg, VA

Advanced wood building systems form a significant market opportunity for wood in taller (greater than 4 storeys) and larger buildings. However, current building codes set prescriptive limits on the use of wood products in such buildings type due mainly to potential fire hazard. There is a need to rationalize those prescriptive limits through a performance-based/engineering approach that will help in the development of alternative solutions and eventually, pave the way towards a performance-based building code or updated prescriptive solutions.

The general objective of this year projects is to develop a performance-based road map for designing larger and taller buildings with respect to fire safety, structural, building envelope and sustainability. Assessment and identification of performance criteria are the initial and fundamental steps towards achievement of the general objective.

Performance-based fire design

Continue to explore possibilities in improving, or developing, performance-based fire design tools for allowing more flexibility for designing fire-safe taller and larger wood building systems.

1. Review current Code limitations, objectives, functional statements and performance levels.
2. Investigate fire performance of hybrid concrete-CLT floors and hybrid steel-wood assemblies.
3. Investigate charring rate of CLT made from Douglas fir lumber.
4. Investigate charring rate of CLT made with thin laminates (less than 1⅜ in.).
5. Assess flame spread rating of massive timber assemblies (LVL, PSL, LSL, CLT). Report is completed and is available upon request.
6. Determine combustion properties of Structural composite lumber from Cone calorimeter tests.
7. Develop a fire-risk index method for wood-framed constructions.

Fire-resistance calculation methods

A mechanics-based calculation method has been developed and is similar to that found in both the NDS and the Eurocode 5 – Design of Timber Structures, Part 1-2: General rules – Structural fire design.

The calculation method is applicable to heavy timber, glue-laminated timber and structural composite lumber. It does not include the fire-resistance of cross-laminated timber (may be added later). The new design methodology has been submitted at the CSA O86 main Technical Committee for consideration in the next 2014 edition of the standard.

Lastly, further to the publication of the US edition of the CLT Handbook, the Canadian version will be updated for addressing integrity and insulation criteria, but also in regards to one-dimensional charring rate as a function of the thickness of laminates.

Support to Carleton Univ. Industrial Research Chair in Fire Safety Engineering

FPInnovations provide support to the Industrial Research Chair in Fire Safety Engineering at Carleton University in the following ways:

- FPInnovations co-supervise students completing Masters and PhD thesis.
- FPInnovations co-supervise research projects under the Theme III of the NEWBuildS program.
- FPInnovations, along with NSERC, also fund the Industrial Research Chair.

Collaboration on the CWC/FPI/NRC Consortium on Mid-Rise Combustible Construction

The existing prescriptive requirements in building codes limiting the use of combustible materials for structural elements based on prescriptive height and area requirements, which are dependent on the occupancy classification of the building, are a soft barrier to the use of wood-based structural assemblies.

There have been submissions to the Canadian Commission on Building and Fire Codes (CCBFC) for changes to the 2015 National Building Code of Canada (NBCC) to allow for the increased use of wood structural elements in buildings presently required to use noncombustible structural systems. A collaborative research project has been undertaken to develop the data needed to support industry-initiated proposals to the CCBFC to incorporate requirements into the NBC to permit the use of wood products in mid-rise buildings and to facilitate the implementation of demonstration projects.

Three real 3-storey building fire tests are being investigated as a joint project with FPInnovations, Canadian Wood Council & NRC. To date, the light-frame and CLT buildings have been complete and the light-gauge steel building (minimum Code compliance) is scheduled for end of summer. Reports from NRC will be available shortly after this time.

Five full-scale fire-resistance tests have also been conducted on structural wall assemblies that would typically be found in the lower portions of mid-rise buildings and required to achieve at least 1-hr fire-resistance rating and sound transmission class of 50. Reports from NRC will be available later this summer.

Codes and Standards Activities

FPInnovations' fire scientists continue to participate in many codes and standards committees such as ULC S100a on fire tests, ISO TC92/SC4 on fire safety engineering, CSA A257 Technical Committee on Engineering Design in Wood and Truss Plates, CSA A370 Technical Committee on Solid and Engineered Wood Products, Standing Committee on Housing & Small Buildings (Part 9) from the Canadian Commission on Building and Fire Codes (CCBFC), the ANSI/APA Performance standard on Cross-Laminated Timber and the JAS/BEC Technical Committee on Japanese standards and Building Experts Committee.

Support to Building Designers and AHJs

FPInnovations' fire scientists play an increasing role in providing support to fire protection engineer consultants seeking approval from AHJs for performance-based designs using wood structures that do not fall under the prescriptive requirements in the National Building Code of Canada.

Work is being conducted in the province of Quebec and BC to better implement a road map and design procedures for performance-based fire design.

A design guide written by FPInnovations (in French only) has been recently published for supporting a provincial Code change allowing mid-rise residential buildings in Quebec. It is expected that Quebec's minister will officially announce the "green light" for building for mid-rise in Quebec during this month of July.

Ontario has also showed some interest for future collaboration.

Submitted by Christian Dagenais
July 2nd, 2013

THE INTERNATIONAL FORUM
OF FIRE RESEARCH DIRECTORS

FORUM

FIRE SAFETY CHALLENGES OF TALL WOOD BUILDINGS

ANNUAL MEETING

17 – 20 SEPTEMBER 2013   PARIS, FRANCE

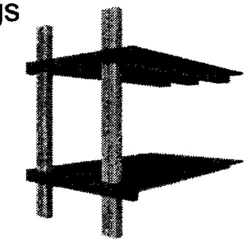
Casey C. Grant, Research Director
Fire Protection Research Foundation
Quincy, Massachusetts USA

THE FIRE PROTECTION RESEARCH FOUNDATION

Fire Safety Challenges of Tall Wood Structures – Phase 1

BACKGROUND

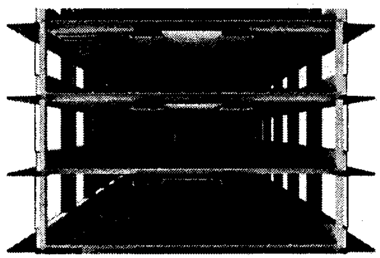
- Recent architectural trends include design and construction of increasingly tall buildings with structural components
- Using components of laminated wood referred to by names such as:
  - cross laminated timber (CLT),
  - laminated strand lumber (LSL)
  - glued laminated timber (Glulam)
- Construction currently underway on buildings up to 30 stories in Australia, Austria, Canada and Norway
- Motivation includes sustainability and green approach (use of renewable construction materials)
- Questions on claims of safety exceeding steel construction



Fire Safety Challenges of Tall Wood Structures – Phase 1

ORIGIN AND DEVELOPMENT

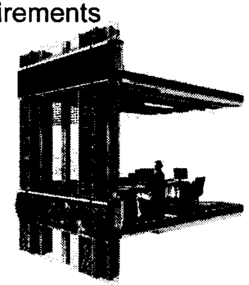
- Need exists to clarify building performance under credible fire scenarios.
- Questions on characteristics (e.g., fire service operations, interior/exterior flame spread, structural stability, fire exposure hazard, etc)
- Project funded by PIRG – Property Insurance Research Group
- Project contractor is Arup
- Project started earlier in 2013
- Scheduled to be completed by November 2013



Fire Safety Challenges of Tall Wood Structures – Phase 1

SCOPE AND TASKS

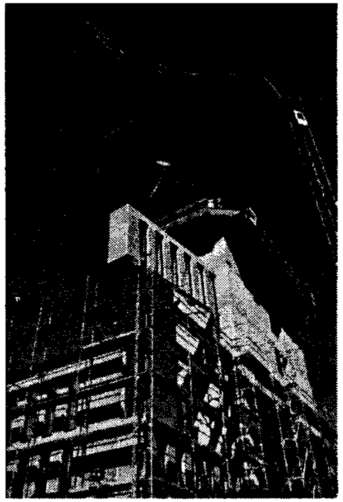
- Focus on buildings 6 stories and greater
- Intent is to consider fire protection features that are functioning, or are partially or fully impaired
- Objectives:
  - Characterize the fire performance of tall wooden structures.
  - Define the necessary design and material requirements to achieve a level of safety and property protection equal to or above steel structures.
  - Communicate the results to serve as a guide for architects, engineers, and code officials.
- Phase 1 Task 1: Literature Review
- Phase 1 Task 2: Gap Analysis

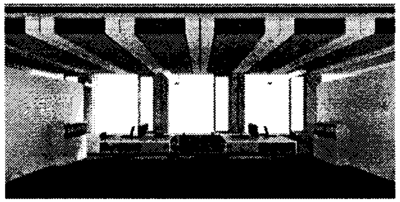


Fire Safety Challenges of Tall Wood Structures – Phase 1

PHASE 1: INTRODUCTION

- 1.1) Phase 1 of the Fire Safety Study
- 1.2) Background
- 1.3) Context: Visions of Tall Timber
- 1.4) Principles of Fire Safety
- 1.5) Timber Building Fundamentals
- 1.6) Timber Fire Fundamentals

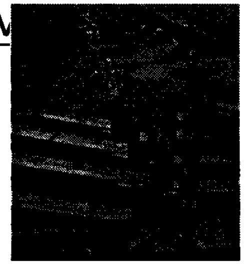


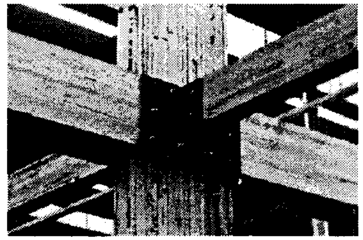


Fire Safety Challenges of Tall Wood Structures – Phase 1

PHASE 1: TASK 1 LITERATURE REV

- 2.1) Overview
- 2.2) Testing Data on Timber Structural Components in Fire
- 2.3) Ongoing Research Studies
- 2.4) Review of Fire Incidents in Timber Structures
- 2.5) Review of Existing Design Guidelines
- 2.6) Global Case Studies of High-Rise / Tall Timber Framed Buildings





Fire Safety Challenges of Tall Wood Structures – Phase 1

PHASE 1: TASK 2 GAP ANALYSIS

- 3.1) Summary of Literature Review - Purpose of Gap Analysis
- 3.2) Structural Component and Sub-System Fire Tests
- 3.3) Engineered Fire Safety
- 3.4) Social Impact
- 3.5) Societal Impact