Institute for Working Forest Landscapes
National Center for Advanced Wood Products Manufacturing and Design
College of Forestry, Oregon State University

A. Cover Page

1. Project Title

Fire Performance of Douglas Fir CLT Wall and Floor Assemblies Made in Oregon

2. List of principal investigators and other key personnel names and affiliations

Role	Name (Last, First)	Affiliation
Lead PI	Muszyński, Lech	WSE
Co-PI	Gupta, Rakesh	WSE
Collaborator/Consultant	James Liburdy	MIME

3. Project starting and ending date

Start Date	3/1/2016
End Date	2/28/2018
Duration (months)	24 months

4. Total Project Costs

Year 1	Year 2	Year 3	Total
$115,277	$34,703	-	$149,980

5. Summary Abstract

Historically, the fire concerns were the principal reason to introduce the 4-storey cap on wooden buildings and it are still among the commonly expressed concerns regarding the future of tall mass timber structures. Even though reliable fire performance data for CLT based mainly on European research are available in the literature the lack of US based evidential fire testing on local products is perceived as a significant barrier to approval of CLT in tall buildings in the US**.**

The aim of the project is to remove this barrier, by testing the fire performance of locally fabricated CLT wall and floor assemblies according to ASTM E119 procedure. The results will assist rational building design and will be used in education materials for the policy makers, potential investors, developers, architects, engineers and the general public on the actual fire performance of CLT assemblies "made in the USA". The analysis will include the effect of the fire event and water hosing on the structural stability of the assemblies and on local integrity of the CLT layups.

The proposal responds to the broad categories 1 and 3 in the RFP, specifically addresses crucial safety parameters needed in CLT building design and is expected to guide a further refinement of the product.
The project is expected to advance the COF/WSE long term plan to develop a comprehensive research center for all aspects related to massive timber structures, including fire safety assessments. It will constitute the first step towards building relevant expertise in WSE.

B. Project Description

1. Introduction and justification

Justification: Historically, the fire concerns had been the principal reason for introduction the 4 story cap on wooden buildings and it is still one of the most commonly expressed concerns regarding the future of tall mass timber structures. The concern has followed from the repeated experience of past catastrophic urban fires often blamed on timber structures. While this experience famously prompted development of standards for testing the fire performance of building materials and elements, it also left the general public with deep mistrust for large timber structures in dense urban environment. This mistrust, misunderstanding and often misrepresentation of fire risks persist despite the fact that wood is known to burn at a predictable rates (about 38 mm or 1.5 in per hour) and the fire resistance of a wall or floor can be estimated as the sum of the resistance of their component layers in a code-accepted procedure referred to as component additive method (CAM) [White and Dietenberger 2010]. Modern massive timber products like glulam of substantial cross sections, and cross laminated timber (CLT) have been often proven to outperform light-frame timber assemblies and even steel and concrete elements in fire events [Dagenais 2015, Barber 2015]. Barber (2015) pointed out however that lack of evidential fire testing as a "significant barrier to approval" of massive timber in tall buildings in the US. Even though CLT fire performance has been tested in EU [Frangi et al. 2009, Frangi & Fontana 2010, Schickhofer et al. 2010] and recently in Canada and in the US [Hasburgh & Bourne 2015], none of these tests included commercial CLT products actually made in the U.S.A. This is important, because the Oregon-made material is unique on the market by using Douglas fir laminations bonded with two part MUF adhesive, which is known to perform in fire better than CLT bonded with PUR offered by most manufacturers [Frangi et al. 2009, Schickhofer et al. 2010, White and Dietenberger 2010, Hasburgh & Bourne 2015].

It should also be noted that the fire event causes one-sided (asymmetric) rapid drying and thickness loss followed by the sprinkler action or fire hosing of the elements that constitute an asymmetric wetting event. Both are expected to induce substantial out-of-plane distortions: the first away, the second towards the exposed surface; potentially increasing risks of buckling of load carrying walls, or premature collapse of loaded floors [Dagenais & Osborne 2015]. The extent of the out of plane deformations has not been reported and its potential effect on the safety of the structure has not been fully evaluated.

The overall aim of the project is to remove one of the barriers for the acceptance of the CLT technology in tall buildings, by testing and standard quantification its fire performance in a way that can be incorporated in rational design and used in education of the policy makers, potential investors, developers, architects, engineers and the general public. In this sense the proposal fits in the broad categories 1 and 3 defined in the RFP. This proposal also specifically addresses the first of the themes by determination of crucial safety parameters needed in CLT building design. The outcome may also guide a further refinement of the product to improve its fire ratings.

The additional motivation is to advance the COF/WSE long term plan to develop AWP into a comprehensive one-stop research center for all things related to massive timber structures **including fire safety** assessments. This project will constitute the first step towards building relevant expertise in the WSE department.

The objective of the proposed research project is to investigate the fire performance of 5-layer Douglas fir CLT wall and floor assemblies made in Oregon. The specific objectives are:

1. Determine fire performance for unprotected and fire protected wall and floor CLT assemblies according to ASTM E119 standard.
2. Measure the out of plane deformations of wall and floor elements related to the fire and wetting events and evaluate their effect on the building stability.
3. Assess the impact of fire on the local integrity of the CLT layup.

GRA involvement and industrial collaboration: This project will be performed by a graduate research assistant in the department of Wood Science and Engineering and in collaboration with the Oregon based CLT manufacturer, DR Johnson Lumber Company, located in Riddle, OR.

This project will also support undergraduate research within the WSE department **and international summer interns** from collaborating colleges in Europe, Mexico or Chile.

2. Research location and methods

The approach is to perform standard ASTM E119 fire tests on CLT wall and floor elements and assemblies at Western Fire Center in Kelso, WA. The fire performance "defined as the period of resistance to standard exposure elapsing before the first critical point in behavior [that is an integrity or structural failure] is observed" will be determined on unloaded and loaded wall and floor assemblies. Testing of the unprotected wall and floor assemblies will allow an assessment of a benchmark fire performance of the structural CLT elements alone. In actual structures CLT assemblies are typically protected by a variety of treatments or external protective cladding. For instance, a high degree of fire containment may be added to wall and floor assemblies through use of gypsum board as the interior finish [White and Dietenberge 2010, nationalgypsum.com]. Fire rating of standard cladding systems are published in product catalogues, however their actual performance depends on the substrate to which they are attached (ASTM E119). While testing all possible protective combinations is outside the scope of this project, it is important to determine how application of a simple protective cladding modifies the fire performance of the Oregon made CLT assemblies. Therefore we propose to test one wall and one floor assembly protected with a standard type X 5/8" gypsum wallboard cladding.

The tested matrix will include:

Test element/assembly	Dimensions & construction	Fire protection	Loading	# tests
CLT wall	9' x 12', 5 layers, DF	Unprotected	unloaded	1
CLT wall	9' x 12', 5 layers, DF	Unprotected	loaded	1
CLT wall assembly	9' x 12', 5 layers, DF	protected*	unloaded	1
CLT floor	14' x 18', 5 layers, DF	unprotected	unloaded	1
CLT floor	14' x 18', 5 layers, DF	unprotected	loaded	1
CLT floor	14' x 18', 5 layers, DF	protected*	unloaded	1

*) standard type X 5/8" gypsum wallboard

Non-contact optical measurement method based on digital image correlation (DIC) principle will be employed in order to measure the changes in the element geometry during the fire test and during the subsequent water hosing of the burned side of the assembly. The effect of these additional deformations on the structural stability of the assemblies will be evaluated. All tests will also be video-recorded for further analysis.

We will also measure the dynamics of the temperature profiles throughout the depth of the assemblies in various locations across their plane area. Finally, the average charring rate variations across the plane area of the barriers will be determined and confirmed. The standard test procedure includes the measurement of the temperature of the opposite surfaces of the test assembly. This is not sufficient to measure the unsteady heat flow and non-linear temperature profile through the thickness of the assemblies as it develops in course of the tests. Therefore in addition to the standard instrumentation additional thermocouples will be embedded in a number of strategic points through their thickness. The surface temperature of the assemblies will be also monitored with thermal cameras in order to evaluate the effect of localized flaws (longitudinal joints in the floor assemblies, knots, finger-joints etc.).

Following the tests the charred specimens will be moved to WSE labs in Corvallis in order to map the charring depth throughout the barrier area, measure and describe localized phenomena (residual bond integrity in the vicinity of the charred layer, evidence of delaminations, performance of finger joints and knotted areas). The measured charring rates will be compared with published charring rate models for Douglas fir and similar CLT assemblies [White & Nordheim 1992, Frangi et al. 2009, Schickhofer et al. 2010, White & Dietenberger 2010].

3. Anticipated outcomes

The tests will allow us to assess the fire rating of the 5-layer CLT wall and floor assemblies produced in Oregon per ASTM E119. These standard ratings, temperature profiles and the measured charring rates will be compared with data published for other CLT materials (fabricated with different layup species, different adhesive systems).
The analysis of the localized effects of fire on CLT layups is expected to provide additional clues and guidelines for the manufacturers on fabrication techniques that may have impact on fire performance of CLT products.

Deliverables: The outcomes will be communicated in form of a) raw fire test reports covering the standard ASTM E119 measurements, b) one M.S. thesis covering all aspects of the project, c) conference presentation(s)/poster(s) presenting the conceptual framework and preliminary outcomes of the project, d) a publication in Forest Products Journal or the Wood and Fiber Science summarizing the complete scientific outcomes of the project e) technical publications in trade journals and presentations at trade shows and workshops aimed at changing the perception of the performance of massive timber products in fire events f) educational material with visuals and videos recorded during the tests will be published on the WSE webpages.

4. Timeline

The following table summarizes a timeline of research tasks and major milestones and outreach activities.

Task	**Location**	**Year 1**				**Year 2**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
1. Construction of the CLT boards	DRJL, Riddle, O	■	■						
2. Construction of wall & floor assemblies	DRJL, Riddle, OR		■						
3. Transportation of assemblies to WFC				■					
4. Instrumentation of assemblies/DIC setup	WFC, Kelso, WA			■					
5. ASTM E119 Tests	WFC, Kelso, WA			■					
6. Transportation of assemblies to OSU					■				
7. Analysis of localized effects	OSU, Corvallis				■	■	■		
8. Reporting & communication of results	OSU, 2017 conference venues				■		■	■	■

5. Partner linkages and support

This project will be conducted in collaboration with the Oregon based CLT manufacturer, DR Johnson Lumber Company, located in Riddle, OR. The tests will be performed at the Western Fire Center in Kelso, WA.

Thermo-vision measurements will be conducted in collaboration with the Thermal Fluid Sciences Lab in the OSU School of Mechanical, Industrial and Manufacturing Engineering (MIME) in the College of Engineering. Our MIME partner will be Prof. James Liburdy who agreed to assign and supervise a technical consultant to operate the thermal cameras.

C. Bibliography

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