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

1. **Project Title**
SMART-CLT – Structural Health Monitoring and Post-Occupancy Performance of Mass Timber Buildings

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

Role	Name (Last, First)	Affiliation
Lead PI	Riggio Mariapaola	OSU-WSE
CoPI	Laleicke Paul F.	OSU-WSE
CoPI	Barbosa Andre R.	OSU-COE
CoPI	Van Den Wymelenberg Kevin	UO

3. **Project starting and ending date**

Start Date	Mar 1, 2016
End Date	Feb 28, 2018
Duration (months)	24

4. **Total Project Costs**

Year 1	Year 2	Year 3	Total
78,484	69,013	-	147,497

5. **Summary Abstract**

This project aims to establish a holistic performance-monitoring protocol for mass timber buildings. By identifying the interdependence of different performance indicators (e.g. structural efficiency and serviceability; durability and maintainability; thermal and acoustic comfort; whole building energy performance) we will gain the fundamental understanding needed to establish monitoring protocols, which can be later used to define the standard. In the proposed research, we will test several sensing techniques, and study their effectiveness in collecting information for the characterization of performance of CLT components and assemblies. This study is a fundamental step toward the definition of new frontiers for "smart" mass timber buildings. We will use feedback from the monitoring campaigns to track design outcomes and define future inputs for design iteration.
The research will be based on laboratory testing and numerical modeling. Additionally, pilot applications on mass timber buildings will be planned. For this, CLT buildings of particular interest will be identified as case studies, according to their structural and functional relevance. An envisaged outcome of the research is the identification of an optimal monitoring setup that could be implemented in the new building at the OSU-College of Forestry, to support its usefulness as a "living lab" and open resource for both the research and the professional community.
The team is formed by: M. Riggio (coordination and definition of structural efficiency, serviceability and maintainability requirements); F. Laleicke (moisture-heat mass transfer analysis, simulation of environmental conditions); A. Barbosa (structural dynamics); K. Van Den Wymelenberg (post-occupancy and energy performance monitoring).

B. Project Description

1. Introduction and justification

A diffuse and confident use of advanced timber systems, such as CLT, strongly depends on the possibility of effectively controlling and predicting their behavior and the long-term performance in a building. Reliability and predictable performance are key factors to remove barriers and foster markets, increase the confidence of code-writers, authorities, designers and end-users in the safe, durable and efficient use of emerging mass timber systems and, consequently, increase their acceptance and use.

The indoor microclimate influences the moisture content and vapor migration of wall/floor components, thus causing variations in the physical and mechanical properties of the timber panels. Microclimate is also crucial for the post-occupancy performance. The definition of a correct methodology for collecting and correlating both indoor microclimate data in a building (i.e. indoor air temperature, RH and velocity, HVAC data and occupancy pattern), material parameters in CLT panels (e.g. stiffness, vibrational-acoustic properties, thermal properties, etc.) and material/component alterations (e.g. decay, distortions/gaps, etc.) is therefore fundamental in order to define holistic performance metrics for mass timber buildings.

2. Research location and methods

The research will be performed using facilities at the Green Building Materials Laboratory (GBML) and the Engineering Lab, Oregon State University, and at the Energy Studies in Buildings Laboratories (ESBL), at the University of Oregon (Eugene and Portland).

The research will be articulated in the following working packages:

WP1: Sensor test and evaluation

The sensitivity, robustness and applicability of a number of sensors, in different layouts and applications (e.g. embedded vs. surface mounted; wired vs. wireless; wet vs. dry conditions, etc.) will be investigated in a controlled laboratory environment, on small-scale samples.

Sensing techniques will be tested after exposure cycles at different extremes of temperature and relative humidity. Existing sensors will be modified and new sensors developed specifically for CLT components. Sensor effectiveness in collecting information for the characterization of CLT components and assemblies, as well as for the identification of correlated environmental factors, will be studied. In particular, the following measurements will be considered: environment-related parameters (air temperature, humidity and velocity; wood moisture content and temperature gradients); structural parameters (panel natural frequencies and damping, deflections; crack -in the panels- and gap -between panels- opening; acoustic emissions), dependent comfort variables (assembly heat flux, thermal resistance - R-value -, airtightness, field sound transmission class -FSTC-, field impact insulation class -FIIC-, flanking sound transmission).

WP2: CLT performance simulation and monitoring

In this WP we will analyze the different types of data available from the designed multi-sensor acquisition setup. Data will be collected during a coordinated experimental campaign at the GBML and the ESBL. CLT panels with various construction layups, aspect ratios and support conditions will be monitored. Target-aimed exposure schedules will be used to test CLT assemblies in the Multi-Chamber Modular Environmental Conditioning System **(**MCMEC) at the GBML. After stages of extreme and intermediate exposure, knowledge about the anticipated changes in the assemblies will be available. Replica of the setups tested in the MCMEC, will be exposed to expected, in-door conditions, within the climatic chamber at the ESBL.

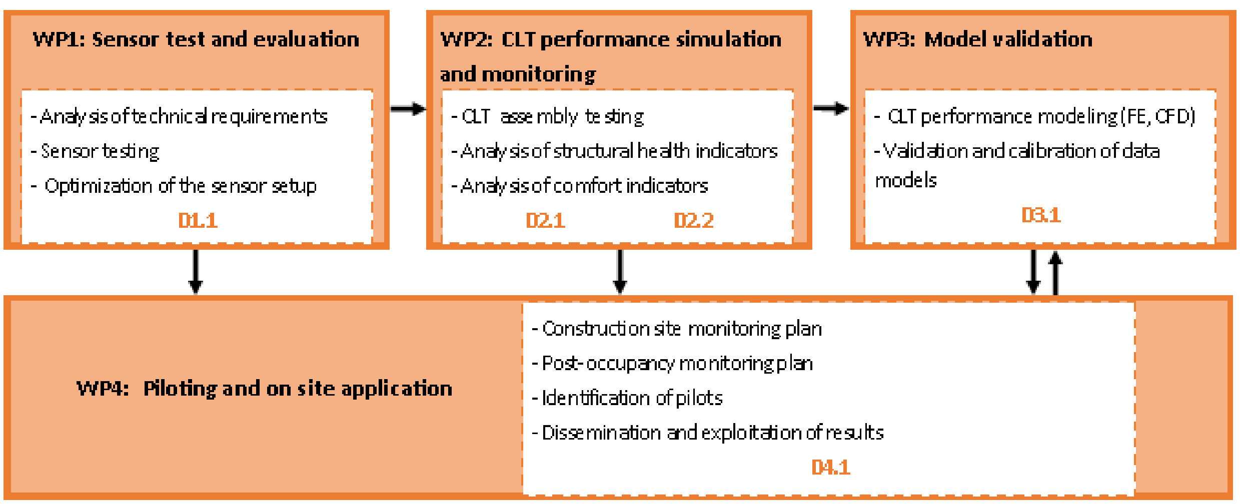
Optimal pre-processing techniques and consequent data fusion methods will be chosen, to effectively combine all the information collected. Multivariate analysis methods will be used for evaluating the combined effect of multiple variables on the investigated system. In particular, the correlations between investigated environmental parameters and material/system properties will be studied

WP3: Model validation

In order to implement a measurement campaign on a real case scenario, it is important to consider scale effects (from the mockup to the real building system), boundary conditions (both structural and functional), and the expected thermal and mechanical loadings. For this purpose, available state of the art models (e.g. of material, microclimate, dose-response, etc.) will be identified, and the possible interaction among actual measures, models and analysis tools will be analyzed. Examples of analysis tools and methods to be considered include, CFD, FE, building dynamic simulation, and building energy performance simulation.
The optimal location and distribution of measurements, and the most effective measurement frequency rates will be identified, considering differing design scenarios (e.g. building layouts, use, exposure, etc.).

WP4: Piloting and on site application

One or more testing campaigns on mass timber buildings will be planned as final outcome of the project and for further development of the research. The pilot case studies will be identified in collaboration with interested stakeholders (e.g. architects/engineers, contractors, etc.). Possible applications could be the new Peavy Hall - COF, the “Framework” building, west-coast winner of the “U.S. tall wood building prize competition” by LEVER Architects, or the Modular CLT Classroom project (in design with SRG Partnership). Specific monitoring activities will be planned on a construction site, to gain fundamental knowledge on: the influence of weather exposure during construction; the role of the different components (i.e. main load bearing structure, complementary structures, etc.) in the building global behavior. In particular, low-amplitude forced dynamic tests as well as ambient vibration testing at different construction stages, aim to evaluate the influence of specific components (e.g. the structure, the composition of separating walls and floors, panel-to-panel /wall-to-wall/wall-to-floor joint solutions) on the structural-dynamic performance and the sound transmission.
Depending on the type of pilot available within the project timeframe (i.e. already built and under use), the possibility of carrying out continuous measurements, additional to those performed in the lab, (e.g. occupancy data, HVAC data) will be considered.



3. Anticipated outcomes

The outcomes of the project will be reported in the following deliverables:
D1.1: Technical requirements report and sensor test results (including functional, data, usability and performance testing)
D2.1: Test report on measurements of structural health indicators
D2.2: Test report on measurements of comfort indicators
D3.1: Data models validation and calibration (report)
D4.1: Recommendations for full scale monitoring (report)

The team (PIs and involved students) will be actively engaged to produce sound scientific publications and present the research in the most relevant research conferences, nationally and internationally. The team will also actively participate in and promote workshops and demonstrations, to ensure follow up on results by the industry and professional community via established relationships with the American Institute of Architects, the Association of General Contractors, the US Green Building Council, and other organizations such as FPInnovations, the Binational Softwood Lumber Council, the USFPL, American Wood Council, APA and U.S. WoodWorks.
The active participation of the team members in technical committees interacting with standardization bodies (e.g. RILEM, IES) will be one of the strategies, to contribute to the revision and new formulation of building codes.
The application of the research outcomes on mid- and long-term monitoring will provide information needed for the development of best practice guides, recommendations, and standards.
The possibility of applying the research on buildings that are "iconic" *per se* will magnify the dissemination and impact of the project results.
We seek to leverage this pilot research into other federal funding proposals (USDA, DOE, DOD) to promote the research agenda of the Institute for Working Forest Landscapes and the National Center for Advanced Wood Products Manufacturing and Design.

4. Timeline

Activity	Q2-16	Q3-16	Q4-16	Q1-17	Q2-17	Q3-17	Q4-17	Q1-18
WP1			D1.1					
WP2				D2.1			D2.2	
WP3								D3.1
WP4								D4.1

5. Partner linkages and support

The multidisciplinary character of the proposed research is the ideal field for a synergistic collaboration. The project will take advantage of the complementary expertise of the PIs in the team, including two architects (OSU-WSE and UO), an engineer (COE) and a wood scientist (UO).
Two graduate students, at OSU and UO, will jointly work on this project; exposure to such an interdisciplinary milieu will play a significant role in student success.
Experimental activities will be carried out using state-of-the-art facilities at OSU and UO and involving industrial partners and professionals (e.g. Dr Johnson, Modern Building Systems, LEVER Architects, SRG Partnership), interested in validating their products and design concepts. Partnership with Skidmore, Owens, and Merrill is envisaged as a further development of the on-going research carried out at COE (PI A. Barbosa) on experimental testing of CLT floor systems.

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