Data in Brief 35 (2021) 106845

Contents lists available at ScienceDirect

Data in Brief

journal homepage: www.elsevier.com/locate/dib

Data Article

Structural health monitoring data collected during construction of a mass-timber building with a data platform for analysis

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ARTICLE INFO

Article history:
Received 7 October 2020
Revised 24 January 2021
Accepted 3 February 2021
Available online 6 February 2021

Keywords:
Big data
Cross-laminated timber
Construction monitoring
Mass plywood panel
Mass-timber
Self-centering rocking wall
Structural health monitoring
Timber monitoring

ABSTRACT

The George W. Peavy Forest Science Complex, or "Peavy Hall," is a mass-timber university building that is the subject of a structural health monitoring (SHM) program to create a comprehensive building performance dataset. The building substructure consists of cross-laminated timber (CLT)-concrete composite floors, a mass plywood panel (MPP) roof system, and the world's first application of CLT post-tensioned (PT) self-centering shear walls. This document reports on static and hygrothermal data collected during the final ten months of building construction that were used to validate a proposed methodological approach to SHM for mass-timber buildings under construction, described in *A Methodological Approach for Structural Health Monitoring of Mass-Timber Buildings Under Construction* [1]. These data, available in the repository at https://osf.io/jdz6y/, include wood moisture content of CLT, MPP, and glulam structural components, horizontal and vertical displacements of axially loaded CLT panels, tension loss of PT steel rods within CLT self-centering walls, and indoor and outdoor environmental conditions such as temperature, relative humidity, rain quantities, wind speeds, as well as wind directions. Additionally, data figures and analysis coding files are included in the repository to further define processes and allow for potential use of the analysis tools for similar projects.

DOI of original article: 10.1016/j.conbuildmat.2020.121153
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https://doi.org/10.1016/j.dib.2021.106845

Specifications Table

Subject	Civil and Structural Engineering
Specific subject area	Structural health monitoring data from a mass-timber building under construction.
Type of data	Image Graph Figure Microsoft Excel Open XML (xlsx) Files Data Platform
How data were acquired	A structural health monitoring program in the George W. Peavy Forest Science Complex at Oregon State University. Instruments: 111 wood resistance-type moisture measurement sensors (PMM) by Structural Monitoring Technology (SMT) Research Ltd., with insulated pin pairs with custom lengths. Lengths varied from 22mm to 228mm [2]. Seven MF52 thermistors by SMT Research Ltd. [3]. Three HTM2500 relative humidity gauges by SMT Research Ltd. [4]. Ten string potentiometer sensors (SPOT-00-50mm) by SMT Research Ltd [5]. Sixteen wireless data loggers with temperature and relative humidity gauges built-in by SMT Research Ltd. [6,7]. One Building Information Gateway (BIG-001) for data collection by SMT Research Ltd. [8]. One Building Information Gateway version 2.2.5 (BACnet) software by SMT Research Ltd. [9]. One Vantage Pro2 weather station by Davis Instruments [10]. Twenty-eight proprietary multi-axial strain gauge load cells by Vishay Precision Group (VPG). Jupyter Notebook with Python 3.7.
Data format	Raw Analyzed
Parameters for data collection	Considerations for monitoring included tension loss of post-tensioned (PT) steel rods in cross-laminated timber (CLT) self-centering shear walls, vertical and horizontal displacements of PT CLT self-centering shear walls, moisture performance of CLT, glulam, and mass plywood panel (MPP) components, and building indoor as well as outdoor environmental conditions during the final ten months of construction of a mass timber building.
Description of data collection	These data were collected through the implementation of a structural health monitoring program in a mass-timber building under construction using the methodological approach described in [1]. The monitoring program was carefully designed to meet research needs. Sensors were installed and commissioned following recommendations to avoid false data. Data were acquired with supplier hardware and stored in supplier software until they were transmitted to a central server to house and backup all data. These data were then analyzed and post-processed using tools developed to use data semi-automatically.
Data source location	Institution: Oregon State University City/Town/Region: Corvallis, Oregon Country: United States Latitude and longitude (and GPS coordinates) for collected samples/data: 44°33′51.0"N 123°17′08.2"W (44.564171, -123.285621)
Data accessibility	Repository name: Open Science Framework Data identification number: 10.17605/OSF.IO/JDZ6Y Direct URL to data: https://osf.io/jdz6y/

(continued on next page)

Related research article	Baas, E. J., Riggio, M., & Barbosa, A. R. (2021). A methodological approach for structural health monitoring of mass-timber buildings under construction. Construction and Building Materials, 268, 121153. https://doi.org/10.1016/j.conbuildmat.2020.121153.

Value of the Data

- These data are useful to compare with similar monitoring projects or laboratory test data related to mass-timber products and structures. Furthermore, these data can be used to provide a point of reference for the *in-situ* construction performance of mass-timber buildings as well as provide a benchmark for processing and viewing data. These data are also valuable to test the validity of various management, visualization, and real-time analyses for structural health monitoring data.
- Beneficiaries of these data include engineers, architects, contractors, wood scientists, mass-timber product manufacturers, data scientists, statisticians, computer scientists, and students interested in the construction performance of mass-timber products or dealing with big data from structural health monitoring projects.
- These data can be further used to collaborate and compare against similar monitoring or laboratory projects, as an outline of simplified procedures for data processing, to evaluate drying rates of mass-timber structural components, to validate proposed models for mass-timber products such as moisture diffusion of engineered wood products (EWPs) and investigate the construction-performance of timber post-tensioned shear walls. Additional further potential research is listed in Table 1: Descriptions of monitoring locations objectives and potential research. for the specific datasets provided.
- These are the first available datasets on immediate and short-term tension loss of *in situ* post-tensioned self-centering mass timber shear walls. These data are key to inform further design and installation procedures of this type of structural system.

1. Data Description

The data repository[1] encompasses all data collected during the final ten months of construction of the George W. Peavy Forest Science Complex at Oregon State University in Corvallis, Oregon (USA). Data generated during construction are from 111 resistance-type wood moisture meters, seven thermistors, three relative humidity gauges, ten string potentiometers, twenty-eight loads cells, and 16 relative humidity and temperature readings from data acquisition units (DAQs) throughout the building. The overview of the locations of monitoring is shown in Fig. 1: Plan view of monitoring locations during the construction of the George W. Peavy Forest Science Complex. on a plan view of the structure, and Fig. 2: Depiction of materials used in the George W. Peavy Forest Science Complex shows the main structural systems used throughout the building. Table 1 expands on this figure by providing standard nomenclature for the monitoring locations used in the data repository, along with a description of monitoring, primary objectives, as well as potential for future research at each location. Fig. 3 shows all the types of sensors installed in the building. For detailed information related to quantities and precise locations of individual sensors, the data repository houses as-built location documentation, like those shown in Fig. 4, within the location folders, further described in the following paragraph. For further general information, the repository contains a folder entitled "_General Information" with four files intended to provide an overview of information of the project, summarized in

[1] https://osf.io/jdz6y/

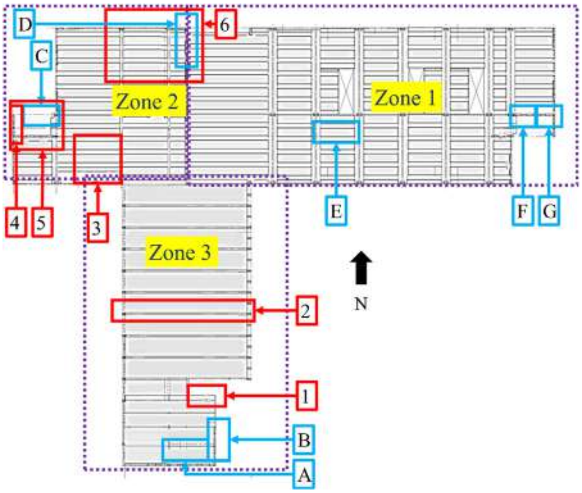

Fig. 1. Plan view of monitoring locations during the construction of the George W. Peavy Forest Science Complex. See Table 1 for information on each location based on the callout name.

Fig. 2. Depiction of materials used in the George W. Peavy Forest Science Complex.

Fig. 3. Sensors installed in the George W. Peavy Forest Science Complex.

Table 1
Descriptions of monitoring locations objectives and potential research.

Tag from Fig. 1: Plan view of monitoring locations during the construction of the George W. Peavy Forest Science Complex.	Monitoring Location Name	Primary Monitoring Interests	Potential Further Research
A	LC1 – Zone 3 – South Shearwall (Room 302)	Tension loss of all four PT steel rods; wood moisture content to compare to tension loss; indoor temperature to compare to tension loss; indoor relative humidity to compare to tension loss	Correlate wood moisture content, temperature, panel displacements, and relative humidity with tension loss; Evaluate cyclic environmental loading on shear wall performance; Validate analytical models for PT loss in time shear walls; Validate and compare creep behavior of axially loaded panels; Investigate drying rates of CLT panels; Evaluate expected environmental and static loads during construction
B	LC2 – Zone 3 – East Shearwall (Room 302)		
C	LC3 – Zone 2 – West Stairwell – South Wall		
D	LC4 – Zone 2 – Lab Space Shearwall (Room 369)		
E	LC5 – Office Shearwall (Room 314)	Tension loss of all four PT steel rods; vertical and horizontal displacement of CLT panel to compare with tension loss; wood moisture content to compare with tension loss; indoor temperature and relative humidity to compare with tension loss	
F	LC6 – East Stairwell – West Wall	Tension loss of all four PT steel rods	
G	LC7 – East Stairwell – East Wall	Tension loss of all four PT steel rods	
1	Zone 3 – NE Corner Medium Classroom (Room 302)	Determine if wetting occurs in southeast building corner; compare shear wall moisture to similar shear walls	Evaluate drying rates of CLT, MPP, and glulam; Compare drying rates based on timber exposure to sunlight; Validate moisture diffusion and transport models for EWPs; Compare data to other projects for recommendation to industry on roof and wall assemblies as well as protection during construction of timber elements; Evaluate expected environmental loading conditions during construction
2	Zone 3 – Glulam PD-PJ/P10 (Room 311D)	Determine if wetting of a ceiling glulam beam occurs near a large skylight	
3	Zone 2 – Bathroom Ceiling	Determine if wetting of roof and ceiling panels occurs as roof material thickness doubles	
4	Zone 2 – West Stairwell – West Wall	Compare shear wall moisture content to other walls	
5	Zone 2 – West Stairwell Ceiling	Determine if wetting of roof panels occurs near skylights	
6	Zone 2 – Lab Spacing Ceiling (Room 369)	Determine if wetting of roof panels and glulam ceiling members occurs where roof material thickness doubles	

detail in Table 2: Description of files in the General Information folder within the repository. Lastly, the sensor reading ranges and accuracies are displayed in Table 3.

As aforementioned, to view detailed information such as as-built drawings and raw data files, there are folders titled “00_Envionmental Conditions” and “01_Tension Loss” in the data repository. Within them are subfolders titled with the names of the standardized location from Table 1. Each folder corresponding to a location of interest has a figure with the as-built locations, plan sheets of sensors, and photos of some of the applicable sensors. These figures are entitled “*LOCATION_NAME*.tif,” where “*LOCATION_NAME*” refers to the standard location name used consistently to reference that location. An example of one of the as-built figures is

Table 2
Description of files in the General Information folder within the repository.

File Name	Description
00_Environmental Conditions Locations (.tif)	A figure displaying locations of monitoring throughout the building for wood moisture content and environmental conditions.
01_Tension Loss Locations (.tif)	A figure displaying locations of monitoring to evaluate the performance of PT CLT self-centering shear walls. For general information regarding these shear walls, the reader is referred to [11]. For information specific to the shear walls in Peavy Hall, the reader is referred to [12,13].
_Sensor Information (.xlsx)	A spreadsheet inventory of all sensors within the data repository including sensor type, identification number, ply depth of insulated pins if type is a moisture meter or embedded temperature sensor, the data acquisition unit (DAQ) number in which the sensor is installed, the channel in the DAQ in which the sensor is installed, the construction zone of installation (see Table 1), the level (1,2,3, or ceiling) in which the sensor is installed, the structural element the sensor is located on, the approximate location of the sensor on the element, and any notes regarding the sensor such as the length of a string potentiometer. This spreadsheet can be used to organize potential data of interest and sort by sensor types, locations, etc. Additionally, this file contains relevant information for sensors, such as reading ranges and tolerances, expanded in Table 3: Sensor references, general locations, measuring ranges, and tolerances from datasheets.
Sensor Appearance (.jpg)	A figure displaying the types of sensors installed in the building for an idea of how they look, simplified in Figure 3: Sensors installed in the George W. Peavy Forest Science Complex.

Table 3
Sensor references, general locations, measuring ranges, and tolerances from datasheets.

Sensor Type	Quantity	Supplier Reference	Locations	Measuring Range	Tolerance
Resistance-Type Moisture Meter with Insulated Electrode Pins	111	[2]	Near structural monitoring for correlations; Areas vulnerable to leaks; At various depths of CLT and MPP to estimate moisture gradient	9% to 30%	±1%
String Potentiometer	10	[5]	LC5 – Zone 1 - Office shearwall (Room 314)	±50 mm	0.1 mm
MF52 Thermistor	7	[3]	Near structural monitoring for correlations; At various depths of CLT for use as moisture correction	-55°C to 125°C	±1%
HTM2500 Relative Humidity Gauge	3	[4]	Near structural shear wall monitoring for correlations	1% to 99%	±3 to 5%
Proprietary Multi-Axial Strain Gauge Load Cell	28	Vishay Precision Group (VPG)	All shear wall monitoring locations	Unknown	Unknown
Davis Vantage Pro2 Weather Station	1	[10]	Atop neighboring building	Dependent on measurand, see reference or data platform files	
Data Acquisition Unit (DAQ)	16	[6,7]	Near groupings of sensors	TMP: 0°C to 40°C RH: 5% to 100%	TMP: ±1 °C RH: ±5%

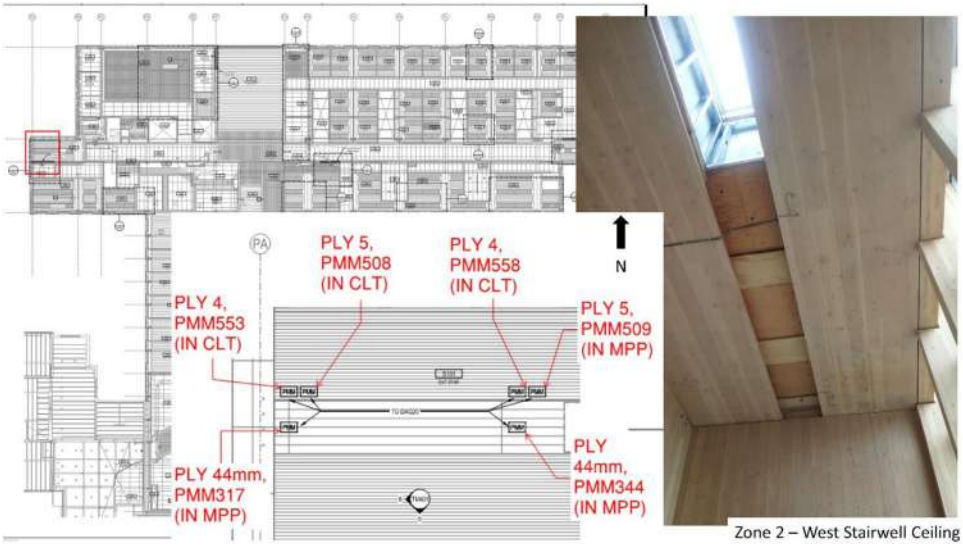

Fig. 4. Example as-built photos of Zone 2 – West Stairwell Ceiling.

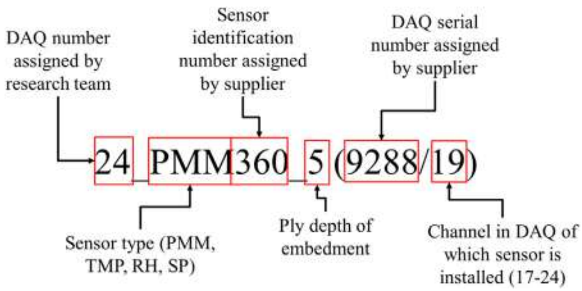

Fig. 5. Standard column header naming convention in dataset files for wood moisture content, indoor environmental, and displacement sensors.

available in Fig. 4. Also in each of these folders are Microsoft Excel Open XML Format Spreadsheet files (.xlsx) that contain raw data from the sensors. These files are grouped into measurand (e.g. moisture content, temperature, relative humidity) of interest with a standard name, described in Table 4. The headers in the raw data files are also standardized, and the descriptions of sensor header names are shown pictorially in Fig. 5 for most sensors, and Fig. 6 for sensors from a data acquisition unit (DAQ). Lastly, the rod numbering orientation for each shear wall monitoring location is standardized from right to left (Rod 1 to Rod 4), as shown in Fig. 7.

Data figures generated with standardized processing methodologies from the reference manuscript [1] are also available in the repository within the "XX_Data Figures" subfolder for each location of interest based on the standard nomenclature from Table 1. These figures include plots, subplots, and overlay plots of data applicable to the monitoring sampling criteria, and therefore not all figures described in the tables are in all location folders.

Table 5 describes figures available related to wood moisture content and environmental data from the building. As an example, Fig. 8 displays a plot of the moisture content in Zone 2 – West Stairwell Ceiling over the course of monitoring.

Table 6 describes figures available related to tension loss in PT CLT self-centering shear walls. As an example, Fig. 9 shows subplots for the tension of steel rods as well as wood moisture

Table 4
Explanation of raw dataset files in the data repository based on their standard name.

File Name	Description	Header Meanings
GE (.xlsx)	Relevant data from the local outdoor weather station, including daily rain, total rain, outdoor temperature, and outdoor relative humidity. These data were collected once per hour. "GE" is short for Global Environmental.	**DateTime:** the index date and time of sensor data. **dailyrainMM (48/12):** daily quantities of rain in millimeters. **TotalPrecipMM (48/9):** total precipitation quantities in millimeters. **TemperatureC (48/1):** outdoor temperature in degrees Celsius. **Humidity (48/7):** outdoor relative humidity in percent.
GW (.xlsx)	Wind data collected from the local weather station. These data include the wind gust speed, wind speed, and wind direction. These data were collected once per hour. "GW" is short for Global Wind.	**DateTime:** the index date and time of sensor data. **WindSpeedGustKPH (48/6):** wind gust speed in kilometers per hour. **WindDirectionDegrees (48/4):** wind direction in degrees. **WindSpeedKPH (48/5):** wind speed in kilometers per hour.
MC (.xlsx)	Wood moisture content data (in percent) from applicable resistance-type moisture meters at the location of interest. These data are corrected for wood temperature and species. These data were collected once per hour. "MC" is short for Moisture Content.	**DateTime:** the index date and time of sensor data. **##_PMM###_# (####/##):** a standard name referring to DAQ number, PMM identification number, embedded ply depth (in ply number of millimeters if installed in MPP), DAQ serial number, and channel in DAQ. For example, "24_PMM380_5 (9288/19)" refers to a PMM in DAQ 24, with identification number 380, in the fifth ply of a CLT panel, with a DAQ serial number of 9288, in channel 19 of the DAQ. See Fig. 5 for a visual of the naming convention.
RH (.xlsx)	Indoor relative humidity data (in percent) from applicable relative humidity gauges from DAQs and/or supplemental gauges installed directly on shear walls. If the gauge is supplemental, it has been corrected for the nearby temperature. These data were collected once per hour. "RH" is short for Relative Humidity.	**DateTime:** the index date and time of sensor data. **##_int_RH (####/##):** a standard name referring to an internal relative humidity gauge in a DAQ. The name includes the DAQ number, the DAQ serial number, and the input on the DAQ. For example, "24_int_RH (9288/6)" corresponds to the internal relative humidity gauge of DAQ24, with serial number 9288, from channel six in the DAQ. See Fig. 6 for a visual of the naming convention. **##_RH### (####/##):** a standard name referring to a supplemental relative humidity gauge. The name refers to the DAQ number, the RH identification number, the DAQ serial number, and the channel in the DAQ. For example, "19_RH607 (9439/21)" refers to a relative humidity gauge with identification number 607, installed in DAQ19 with serial number 9439, and is on channel 21 of the DAQ (see Fig. 5).
TMP (.xlsx)	indoor temperature data (in degrees Celsius) from applicable temperature gauges in DAQs or thermistors embedded into wood elements. These data were collected once per hour. "TMP" is short for Temperature.	**DateTime:** the index date and time of sensor data. **##_int_TMP (####/##):** a standard name referring to an internal temperature gauge in a DAQ. The name includes the DAQ number, the DAQ serial number, and the input on the DAQ. For example, "24_int_TMP (9288/5)" corresponds to the internal relative humidity gauge of DAQ24, with serial number 9288, from channel five in the DAQ (see Fig. 6). **##_TMP###_# (####/##):** a standard name referring to DAQ number, thermistor identification number, embedded ply depth (in ply number), DAQ serial number, and channel in DAQ. For example, "40_TMP335_4 (9235/20)" refers to a thermistor with identification number 335, embedded into the fourth ply of a CLT panel, installed in DAQ40 with serial number 9235, and is in channel 20 of the DAQ (see Fig. 5).

(*continued on next page*)

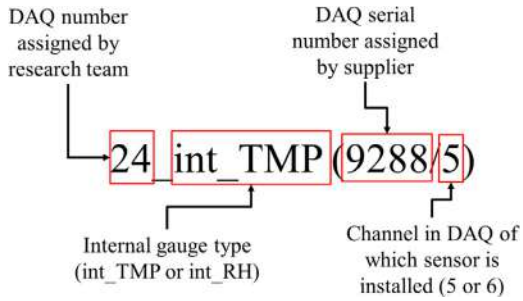

Fig. 6. Standard column header naming convention in dataset files for internal temperature and relative humidity gauges in data acquisition units.

Fig. 7. Rod numbering convention for post-tensioned shear walls in a construction access window.

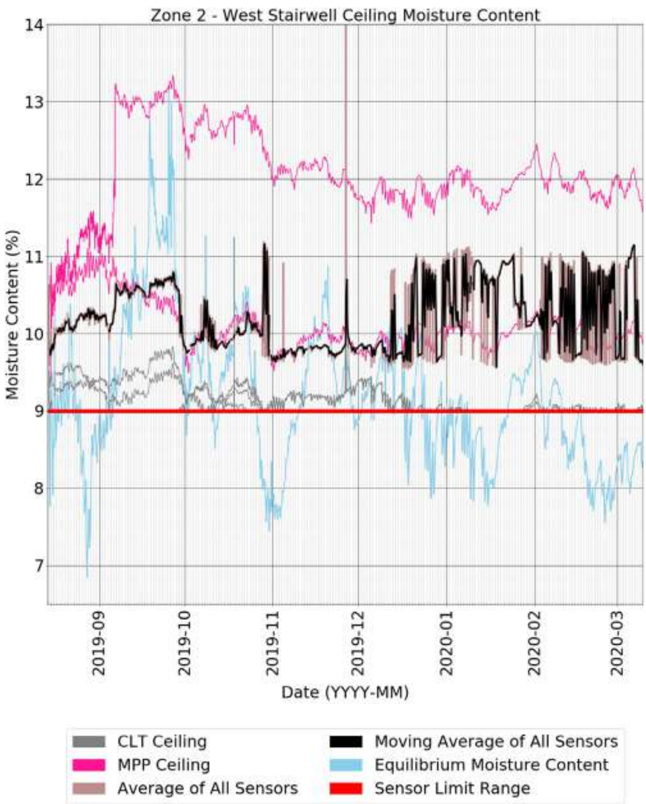

Fig. 8. Example plot of "MC.png," the wood moisture content for Zone 2 – West Stairwell Ceiling.

Table 4 (*continued*)

File Name	Description	Header Meanings
LC (.xlsx)	Tension data collected from the PT CLT shear walls. These tension data are all in pounds (1 lb = 0.00444822 kN). These files are large and may take a while to download, view, and analyze. The files are large because data were initially collected once per second during and shortly after initial tensioning, but later were modified to collect data ten times per hour.	**Date Time:** the index date and time of sensor data. **LC#:** The load cell number of interest. **Rod 1:** tension in the leftmost rod facing the construction access window. The directional orientation depends on the orthogonal direction of the wall; for LC1, Rod 1 is the east rod, for LC2, Rod 1 is the north rod, for LC3, Rod 1 is the west rod, for LC4, Rod 1 is the north rod, for LC 5, Rod 1 is the west rod, for LC6 and LC7, Rod 1 is the east rod (see Fig. 7). **Rod 2:** tension in the second rod from the left facing the construction access window. **Rod 3:** tension in the third rod from the left facing the construction access window. **Rod 4:** tension in the rightmost rod facing the construction access window.
SPH (.xlsx)	Data from horizontally oriented string potentiometers on a shear wall. These data were collected once per hour. "SPH" is short for String Pot – Horizontal.	**DateTime:** the index date and time of sensor data. **##_SP## (####/##):** a standard name referring to DAQ number, string potentiometer (SP) serial number, DAQ serial number, and channel in DAQ. For example, "11_SP57 (9271/18)" refers to string potentiometer 57, connected to DAQ 11 with serial number 9271 in channel 18 (see Fig. 5).
SPV (.xlsx)	Data from vertically oriented string potentiometers on the shear wall. These data were collected once per hour. "SPV" is short for String Pot – Vertical.	See SPH (.xlsx) and/or Fig. 5.

content and environmental conditions at LC1 - Zone 3 - South Shearwall (Room 302). Table 7 describes figures available related to displacements of axially loaded CLT panels. As an example, Fig. 10 displays an overlay of the displacement and temperature at LC5 – Zone 1 – Office Shearwall (Room 314).

It should be noted that in all cases, data outside the sensor reading range have been omitted (see Table 3 for ranges), and wood moisture content data have been corrected for wood temperature and wood species in the supplier database (see [2] for further information). Additionally, some processing, including moving averages, averaging of applicable sensors, calculation of the equilibrium moisture content (EMC) using the Hailwood and Horrobin equation [14], wavelet packet analysis, and correction for environmental effects, may be included and are noted in the legends of each figure. Lastly, data from a nearby weather station 12 km northeast of the building site may be used to fill gaps for missing local weather station data. These data are open source and available online [15].

Lastly, data platform files are available for two locations of monitoring. The data platform is defined as a place to upload, visualize, and process data. The "Zone 2 – Bathroom Ceiling" and "LC5 – Office Shearwall (Room 314)" folders in the repository contain a Python script file (ipynb) and a hypertext markup language (html) file that shows precisely how data were uploaded, cleaned, processed, plotted, and initially analyzed using open source coding language. These files encompass all the relevant data types, and so they exemplify how all data were processed and used.

[2] Note that for daily rain data, some data are shown from a nearby weather station 12 km northeast of the building [15]. These data were provided in inches but converted to millimeters for plotting (1 inch = 25.4 mm).

Table 5
Description of figures relating to wood moisture content and environmental conditions[2].

Figure Name	Description
Macroclimate subplots (.png)	A visual representation of all relevant outdoor climatic ("Global Environmental") data for the period corresponding to sensor data.
MC (.png)	All relevant moisture content sensors in the location of interest on one plot. See Fig. 8 for an example.
MC subplots (.png)	All relevant moisture content sensors in the location of interest on individual plots with associated locations and ply depths.
MC subplots with invalid data (.png)	All relevant moisture content sensors in the location of interest on individual plots with associated locations and ply depths that include data outside the sensor reading range.
MC with invalid data (.png)	All relevant moisture content sensors in the location of interest on one plot that includes data outside the sensor reading range.
RH (.png)	All relevant relative humidity gauges in the location of interest on one plot.
RH subplots (.png)	All relevant relative humidity gauges in the location of interest on one individual plot with associated locations.
TMP (.png)	All relevant temperature gauges in the location of interest on one plot.
TMP subplots (.png)	All relevant temperature gauges in the location of interest on one plot with associated locations.
Macroclimate subplots with wavelet analysis (.png)	Raw and processed outdoor environmental data using wavelet packet analysis.
MC subplots of wavelet packet analysis (.png)	Moisture content data on individual plots processed using wavelet packet analysis.
MC with wavelet analysis (.png)	Moisture content in this location on one graph, including processed data using wavelet packet analysis.
RH subplots with wavelet analysis (.png)	Relative humidity in this location on individual plots processed using wavelet packet analysis.
RH with wavelet analysis (.png)	Relative humidity in this location on one graph processed using wavelet packet analysis.
TMP subplots with wavelet analysis (.png)	Temperature in this location on individual plots processed using wavelet packet analysis.
TMP with wavelet analysis (.png)	Temperature in this location on one graph processed using wavelet packet analysis.
Actual versus calculated tension fluctuations (.png)	Calculated approximations for tension in steel rod fluctuations from environmental sensors compared to actual daily tensile changes.

2. Experimental Design, Materials and Methods

The collection of data is from sensors installed in the George W. Peavy Forest Science Complex, or "Peavy Hall," during construction. The Peavy Hall is a three-story, irregularly shaped mass-timber building intended to showcase the potential of mass-timber products by incorporating novel designs such as cross-laminated timber (CLT)-concrete composite floors, a mass plywood panel (MPP) roof system, and post-tensioned (PT) self-centering CLT shear walls. All interior structural timber is untreated Douglas-fir (*Pseudotsuga menziesii*) manufactured in Oregon, USA. The construction monitoring of the building aimed to collect hygrothermal and static data to evaluate building performance and begin to document *in-situ* mass-timber building behavior.

Construction of the Peavy Hall began in January of 2017 and was completed in March of 2020. Selected moisture monitoring with resistance-type moisture meters began in December of 2017, but these sensors were removed in November of 2018 [16,17]. Lessons learned from installation resulted in a re-evaluation of some final sensor locations. On May 8th, 2019, additional sensors were installed, and the installation of hygrothermal and static sensors continued through October of 2019. These sensors collect data until the building opening on March 10th, 2020. They will remain in place throughout the building's lifespan, with additional sensors installed for in-service monitoring, including sensors to characterize the building dynamic performance.

Table 6
Descriptions of figures relating to tension loss in post-tensioned cross-laminated timber self-centering shear walls.

Normalized tension in rods and walls (.png)	Tension data normalized to the maximum tension in the rod or wall.
Tension and environment subplots (.png)	Tension in steel rods, wall moisture content, as well as relative humidity and temperature near the wall location in the form of subplots with the same x-axis. See Fig. 9 for an example.
Tension and outdoor environment subplots (.png)	Tension in steel rods, daily rain, total rain, as well as outdoor relative humidity and temperature in the form of subplots with the same x-axis.
Tension and wind subplots (.png)	Tension in steel rods and wind gust speed, wind speed, and wind direction data in the form of subplots.
Tension and daily rain overlay (.png)	tension in steel rods and the daily rain overlaid on one graph.
Tension fluctuations due to environment (.png)	Subplots of estimated contributions of temperature and moisture content changes on the fluctuation of tension in steel rods.
Tension in rods (.png)	All tension in all steel rods on one graph.
Tension in rods and wall (.png)	Subplots of tension values (in kilonewtons) in each steel rod and the post-tensioned shear wall.
Tension MC overlay (.png)	Tension in steel rods and the average wall moisture content overlaid on one graph.
Tension outdoor RH overlay (.png)	Tension in steel rods and the outdoor relative humidity overlaid on one graph.
Tension outdoor TMP overlay (.png)	Tension in steel rods and the outdoor temperature overlaid on one graph.
Tension RH overlay (.png)	Tension in steel rods and the average indoor relative humidity near the wall of interest overlaid on one graph.
Tension TMP overlay (.png)	Tension in steel rods and the average indoor temperature near the wall of interest overlaid on one graph.
Tension total rain overlay (.png)	Tension in steel rods and the total rain overlaid on one graph.
Tension wind direction overlay (.png)	Tension in steel rods and the wind direction overlaid on one graph.
Tension wind gust speed overlay (.png)	Tension in steel rods and the wind gust speed overlaid on one graph.
Tension wind speed overlay (.png)	Tension in steel rods and the wind speed overlaid on one graph.
Actual versus calculated tension fluctuations (.png)	Calculated approximations for tension in steel rod fluctuations from environmental sensors compared to actual daily tensile changes.
Normalized tension in rods and walls (.png)	Tension data normalized to the maximum tension in the rod or wall.
Tension and environment subplots (.png)	Tension in steel rods, wall moisture content, as well as relative humidity and temperature near the wall location in the form of subplots with the same x-axis.
Tension and outdoor environment subplots (.png)	Tension in steel rods, daily rain, total rain, as well as outdoor relative humidity and temperature in the form of subplots with the same x-axis.
Tension and wind subplots (.png)	Tension in steel rods and wind gust speed, wind speed, and wind direction data in the form of subplots.
Tension and daily rain overlay (.png)	Tension in steel rods and the daily rain overlaid on one graph.
Tension fluctuations due to environment (.png)	Subplots of estimated contributions of temperature and moisture content changes on the fluctuation of tension in steel rods.
Tension in rods (.png)	Tension in all steel rods on one graph
Tension in rods and wall (.png)	Tension values (in kilonewtons) in each steel rod and the post-tensioned shear wall.
Tension in rods and wall (.png)	Tension values (in kilonewtons) in each steel rod and the post-tensioned shear wall.
Tension in rods and wall (.png)	Tension values (in kilonewtons) in each steel rod and the post-tensioned shear wall.
Tension MC overlay (.png)	Tension in steel rods and the average wall moisture content overlaid on one graph.
Tension outdoor RH overlay (.png)	Tension in steel rods and the outdoor relative humidity overlaid on one graph.
Tension outdoor TMP overlay (.png)	Tension in steel rods and the outdoor temperature overlaid on one graph.
Tension RH overlay (.png)	Tension in steel rods and the average indoor relative humidity near the wall of interest overlaid on one graph.

(*continued on next page*)

Table 6 (*continued*)

Tension TMP overlay (.png)	Tension in steel rods and the average indoor temperature near the wall of interest overlaid on one graph.
Tension total rain overlay (.png)	Tension in steel rods and the total rain overlaid on one graph.
Tension wind direction overlay (.png)	Tension in steel rods and the wind direction overlaid on one graph.
Tension wind gust speed overlay (.png)	Tension in steel rods and the wind gust speed overlaid on one graph.
Tension wind speed overlay (.png)	Tension in steel rods and the wind speed overlaid on one graph.

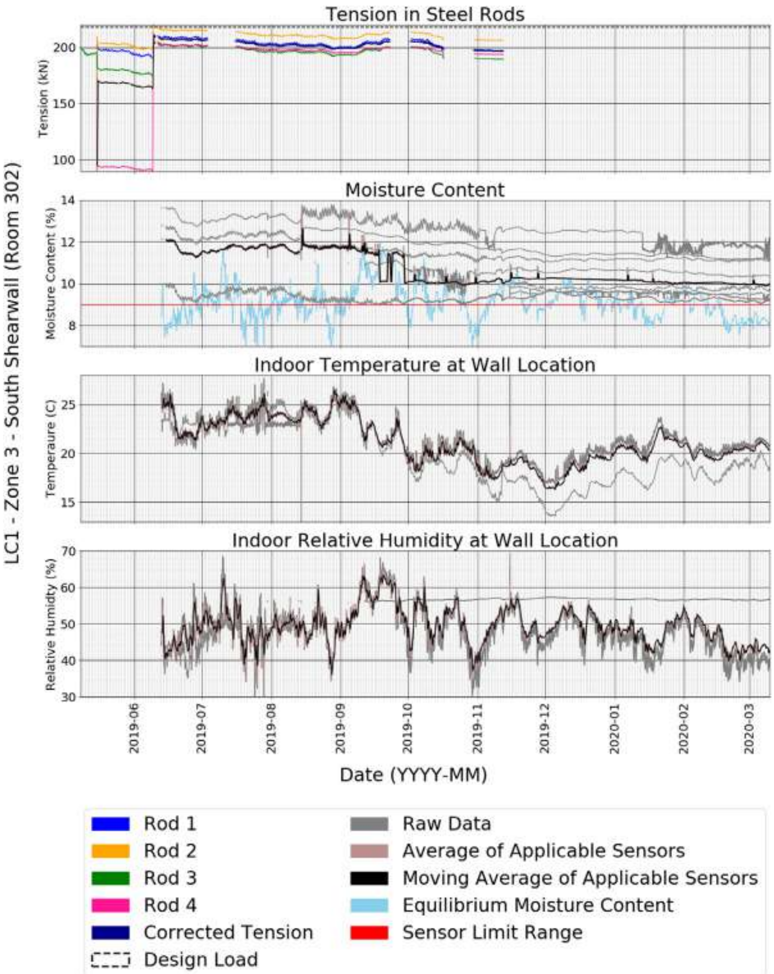

Fig. 9. Example plot of "Tension and environment subplots.png" for LC1 - Zone 3 - South Shearwall (Room 302).

For in-depth information regarding the design of the complete in-service monitoring system, the reader is referred to [12]. In-service monitoring is a topic of future research.

Data available in the repository were used to validate a methodological approach for SHM of mass-timber buildings under construction [1]. As a part of the methodology, data cleaning, processing, and visualization were to be performed, and this step was completed using a developed data platform. The data platform during construction was built with open-source programs

Table 7
Descriptions of figures relating to vertical and horizontal displacements of axially loaded cross-laminated timber panels.

Actual versus calculated horizontal displacement fluctuations (.png)	Calculated approximations for horizontal (vertical) movement fluctuations from environmental sensors compared to actual daily horizontal (vertical) movement fluctuations.
Displacement and environmental subplots (.png)	Subplots of vertical displacement, horizontal displacement, wall moisture content, as well as relative humidity and temperature near the wall.
Displacement and outdoor environmental subplots (.png)	Subplots of vertical displacement, horizontal displacement, daily rain, total rain, as well as outdoor relative humidity and outdoor temperature.
Displacement and wind subplots (.png)	Subplots of vertical displacement, horizontal displacement, wind gust speed, wind speed, and wind direction.
Displacement fluctuations due to environment (.png)	Subplots of estimated contributions of sensor components, temperature and moisture content changes on the fluctuation of displacement.
Horizontal (Vertical) displacement outdoor RH overlay (.png)	Plot of average horizontal (vertical) displacement and outdoor relative humidity overlaid on one graph.
Horizontal (Vertical) displacement daily rain overlay (.png)	Plot of average horizontal (vertical) displacement and daily rain overlaid on one graph.
Horizontal (Vertical) displacement outdoor TMP overlay (.png)	Plot of average horizontal (vertical) displacement and outdoor temperature overlaid on one graph.
Horizontal (Vertical) displacement wind direction overlay (.png)	Plot of average horizontal (vertical) displacement and wind direction overlaid on one graph.
Horizontal (Vertical) displacement wind gust speed overlay (.png)	Plot of average horizontal (vertical) displacement and wing gust speed overlaid on one graph.
Horizontal (Vertical) displacement wind speed overlay (.png)	Plot of average horizontal (vertical) displacement and wind speed overlaid on one graph.
Horizontal (Vertical) displacement MC overlay (.png)	Plot of average horizontal (vertical) displacement and average moisture content in wall overlaid on one graph.
Horizontal Vertical) displacement RH overlay (.png)	Plot of average horizontal (vertical) displacement and average indoor relative humidity near the wall overlaid on one graph.
Horizontal (Vertical) displacement TMP overlay (.png)	Plot of average horizontal (vertical) displacement and average indoor temperature near wall overlaid on one graph. See Fig. 10 for an example.
Horizontal (Vertical) displacement total rain overlay (.png)	Plot of average horizontal (vertical) displacement and total rain overlaid on one graph.
Tension and displacement subplots (.png)	Subplots of tension in steel rods, vertical displacement, and horizontal displacement.
Tension horizontal (vertical) displacement overlay (.png)	Plot of tension in rods and horizontal (vertical) displacement overlaid on one graph.

incorporating notes for users not familiar with the coding language. The data platform includes instructions on how to use them, notes about general processes, and troubleshooting advice for common errors. Two data platforms are available in the repository, one related to location "Zone 2 – Bathroom Ceiling", and one related to "LC5 – Zone 1 – Office Shearwall (Room 314)" as discussed in the previous section. The general outline for processing, analyzing, and visualization protocols are shown in Fig. 11, with in-depth processing described in further detail below. For additional information regarding the used calculations used for processing, the reader is referred to the manuscript [1] or the data platform files.

The platform available for "Zone 2 – Bathroom Ceiling" is typical for the locations associated with "00_Environmental Conditions," consisting of wood moisture content as well as indoor and outdoor environmental conditions processing. The steps taken this analysis are as follows:

1. Import functions necessary to complete analysis in the Python script file. These may need to be installed on the computer used for analysis by using the "pip install" command in the computer command prompt. This process is detailed in the data platform files in the repository.
2. Apply standard unit conversion names for moving between U.S. imperial and International System (S.I.) units.

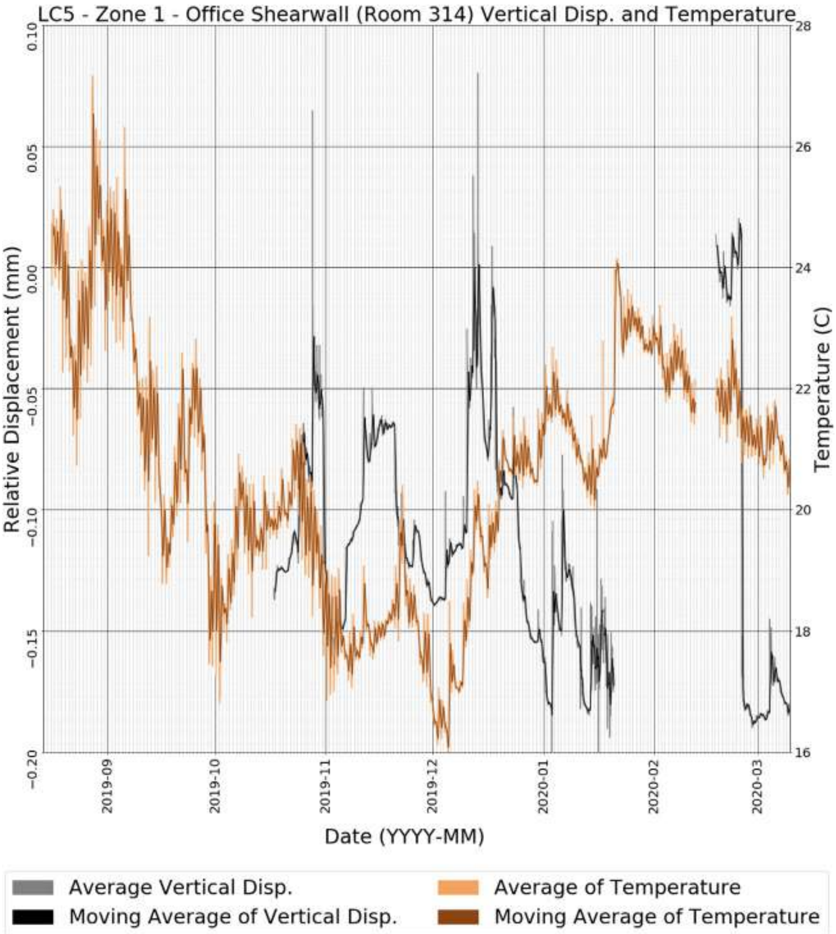

Fig. 10. Example of "Vertical displacement TMP overlay.png," the vertical displacement of a CLT panel and nearby temperature overlaid on one plot for LC5 – Zone 1 – Office Shearwall (Room 314).

3. Import data in a way that reads multiple sheets such that if data cannot fit on one Microsoft Excel Open XML (.xlsx) sheet (>1,048,576 data points), it can still be accommodated.
4. Convert date and time index to an understandable format in the coding language.
5. Plot invalid data (data outside sensor reading range) for moisture content if the user desires on one graph and subplots of individual sensors with daily rain, including sensor location and ply depth in plot titles.
   a. These plots include condition warnings through scaffolding lines for data outside of the sensor limit range, wet according to by the National Design Specification (NDS) for Wood Construction standard, and where there is potential for decay [18,19]. Automated e-mails can also be sent to appropriate personnel when these limits are exceeded for a certain number of days.
6. Replace null values, values outside of sensor limit ranges, and values prior to sensor connection in the building with "NaN" or "not a number" to signify an invalid point while conserving a gap in data rather than interpolating between missing points.
7. Create subsets of individual sensor data.
8. Calculate the moving average of each data stream from a sensor with a period of 12 hours.

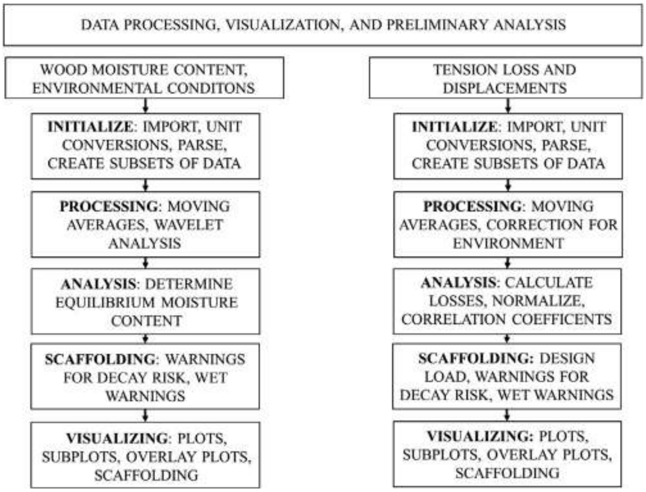

Fig. 11. General outline of the data processing, visualization, and preliminary analysis incorporated into the data platforms.

9. Calculate averages and moving averages for each data stream (with a period of 12 hours) for all sensor types.
10. Plot all relevant moisture content sensor data on one graph with scaffolding lines, average, and a moving average of all sensors.
    a. The user can specify to calculate and plot the equilibrium moisture content (EMC) derived from the Hailwood and Horrobin equation [14].
11. Plot all relevant indoor temperature data on one graph with average (if the number of sensors is >1) and the moving average of temperature for all sensors. Repeat for relative humidity data.
12. Plot subplots of individual moisture content sensors and daily rain with scaffolding lines and moving averages. Plot titles include pertinent information such as sensor location and ply depth of electrode pins.
13. Plot subplots of individual indoor temperature sensors and outdoor temperature with moving averages. Plot titles include pertinent information such as sensor location and embedded ply depth (if applicable). Repeat with indoor and outdoor relative humidity.
14. Plot subplots of outdoor weather conditions, including daily rain, total rain, outdoor relative humidity, and outdoor temperature.
15. Begin wavelet packet analysis by interpolating between gaps in data, as wavelets require no missing data.
16. Define a dictionary of mother wavelets to test. In the data platform, all Daubechies and Symlet mother wavelets were tested.
17. Undergo a wavelet packet analysis to denoise data for all applicable sensors and averages of data. This includes finding the maximum level of decomposition with standardized code, decomposing the signal, applying a statistical multi-level threshold, reconstructing the signal, and calculating the l^P-Norm cost function to determine optimal wavelet. This is done in a loop of all wavelets previously defined automatically.
18. Redefine the index to re-associate the correct date and time of data collection.
19. Create similar plots previously mentioned but include wavelet packet analysis results in addition to moving average results.

The platform for “LC5 - Zone 1 – Office Shearwall (Room 314)” is typical for the locations associated with “01_Tension Loss,” and includes vertical and horizontal displacement data as this was the only location that monitored this phenomenon. The steps taken for analysis with this data platform are as follows:

1. Steps 1-3 from the wood moisture content and environmental conditions.
2. Calibrate load cells based on ten data points prior to tensioning to zero the sensor.
3. Convert date and time index to an understandable format in the coding language.
4. Split the data set between tensioning times (initial tension and re-tensioning).
5. Identify the maximum tension and final tension before re-tensioning.
6. Calculate the tension loss in individual rods, the wall, and deviation from the engineering design value during the initial tensioning.
7. Identify the maximum tension and final tension since re-tensioning.
8. Calculate the tension loss in individual rods, the wall, and deviation from the engineering design value since re-tensioning.
9. Replace data prior to tensioning to “NaN” or not a number.
10. Ask the user if they would like to analyze and plot historical data (data from first tensioning).
11. Ask the user if they would like to group data by the hour.
12. Plot invalid moisture content data (data outside sensor reading range) if the user desires, on one graph and subplots of individual sensors and daily rain with information related to sensor location and ply depth with similar scaffolding lines as in the “00_Environemntal Conditions” data platform.
13. Replace null values, values outside of sensor limit ranges, and values prior to sensor connection in the building with “NaN” or “not a number” to signify an invalid point while conserving a gap in data rather than interpolating between missing points for moisture and environmental sensors.
14. Create subsets of individual sensors for ease of calling them.
15. Calculate the moving average of each sensor with a period of 12 hours.
16. Calculate averages and moving averages (with a period of 12 hours) of all sensor types.
17. Isolate effects of moisture content and temperature on tension fluctuations in steel rods using analytical equations from stress and strain. When using a surface temperature reading, it was adjusted by 0.95 to approximate internal wood temperature estimated from experienced differences in other locations throughout the building.
18. Plot subplots of isolated contributions of environmental conditions on tension fluctuations.
19. Plot actual fluctuations from the sensor with those calculated on a single plot.
20. Correct tension data with analytical stress-strain equations for environmental conditions.
21. Plot subplots of tension in individual rods and tension in the wall of interest.
22. Plot normalized tension of individual rods and tension in the wall of interest.
23. Plot tension in individual rods, their average, and their moving average on one graph.
24. Plot subplots of tension in rods, the moisture content in the wall, as well as indoor temperature and relative humidity near the wall with the same x-axis.
25. Plot overlays of tension in rods and average moisture content, average indoor temperature, and average indoor relative humidity.
26. Calculate Pearson’s correlation coefficients between average tension in rods, the average moisture content in the wall, the average temperature near the wall, and average relative humidity near the wall.
27. Calculate Pearson’s correlation coefficients between individual load cell, moisture content, indoor temperature, and indoor relative humidity sensors.
28. Plot subplots and overlay plots of tension in steel rods, daily rain, total rain, outdoor relative humidity, and outdoor temperature.
29. Calculate Pearson’s correlation coefficients for average and individual rod tension with daily rain, total rain, outdoor temperature, and outdoor relative humidity.
30. Plot subplots and overlay plots of tension in steel rods, wind gust speed, wind speed, and wind direction.
31. Calculate Pearson’s correlation coefficients for average and individual rod tension with wind gust speed, wind speed, and wind direction.

32. Isolate environmental and sensor component effects on string potentiometer data using analytical stress-strain equations and plot.
33. Correct string potentiometer data for environmental conditions.
34. Perform similar analysis described in previous steps for vertical and horizontal displacement, including plotting, visualization, and calculation of Pearson's correlation coefficients with tension data, indoor environmental data, and outdoor environmental and wind data.

Once these steps are completed using the data platforms, the data can be visualized to determine where interesting pieces of data may lie. Furthermore, the data are better prepared for use to validate models, test further methodologies, and perform additional analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this article.

Acknowledgments

The authors would like to thank those who helped with data collection, hardware and software programming, and sensor verification in the building of which this project would not have been successful without, including Brad Huffman, Sean SanRomani, and Emily Davis. Thank you to Ryan Longman for testing the data platforms, and Emily Davis for her feedback on the repository organization. Thank you to Gabriele Granello and Evan Schmidt for their valuable technical guidance. Thank you to those who provided in-kind contributions to this project, including SMT Research Ltd., Vishay Precision Group (VPG), and Trimble Navigation. The authors would also like to thank Anderson Construction for providing access to the building throughout the project. Thank you to the College of Forestry at Oregon State University for supporting this project, and the School of Civil and Construction Engineering at Oregon State University for supporting graduate students on this project.

Funding

This work is supported by the "Living Lab @ Peavy Hall" conducted through the TallWood Design Institute with funding by the U.S. Department of Agriculture's Agricultural Research Service (USDA ARS) [Agreement No. 58-0202-5-001]; the "Design, construction and maintenance of mass-timber PT shear walls: data, models and recommendations" conducted through the TallWood Design Institute with funding by the U.S. Department of Agriculture's Agricultural Research Service (USDA ARS) [Agreement No. 58-0204-9-165]; the National Institute of Food and Agriculture, U.S. Department of Agriculture, McIntire Stennis project [grant number 1009740].

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