CLEMSON

WOOD UTILIZATION + DESIGN INSTITUTE

2019

Annual Report

Dr. Patricia Layton

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EXECUTIVE SUMMARY

2019 has been a whirlwind year with Clemson's research with Southern yellow pine, cross-laminated timber coming full-circle — from its initial testing and research in 2013 to being utilized in the construction of the new Clemson Outdoor Recreation and Education facility. The new facility has provided an educational opportunity for officials across the Southeast to tour and learn about the utilization of a new mass timber material.

However, this was not the only major project WU+D has participated in this year. Learn more in the *Outreach Activities* section on pages 9-10.

WU+D continues to partner with Clemson's School of Architecture, department of engineering, department of construction science and forestry to teach about and promote mass timber products. We have seen many great stories come out of the collaborations this year, which you can preview below. Visit clemson.edu/wud to read more.

CLEMSON NEWSSTAND STORIES

Civil engineers see 'huge progress' in mass timber as new building opens at Clemson University
https://newsstand.clemson.edu/mediarelations/civil-engineers-see-huge-progress-in-mass-timber-as-new-building-opens-at-clemson-university/

New outdoor center will expose more recreational access for campus community
https://newsstand.clemson.edu/new-outdoor-center-will-expose-more-recreational-access-for-campus-community/

Outdoor Education Center construction reaches milestone
https://newsstand.clemson.edu/outdoor-education-center-construction-reaches-milestone/

Visit clemson.edu/wud to read more.

Mass Timber Conference 2019

REVIEW OF ACTIVITIES

ARCHITECTURE ACTIVITIES

In last year's report, we noted that the Sim[PLY] building framing system had been successfully patented in December of 2018. This light framing system, developed at Clemson, utilizes CNC pre-fabricated plywood components, and stemmed from our participation in the 2015 Solar Decathlon Competition. This marks the first patent awarded to a project from Clemson's College of Architecture, Arts and Humanities.

A demonstration of the patented Sim[PLY] building system

Building upon this momentum, 2019 has been a busy year for our work with the Sim[PLY] system. Dustin Albright and Dan Harding have partnered with the Anomura Housing Society in Victoria, British Columbia to look at Sim[PLY] as a strategy for affordable and workforce housing in that setting. Faced with high construction costs and escalating energy code requirements, among other factors, Anomura is looking to Sim[PLY] for its ease and speed of assembly, its adaptability / re-usability, and its high insulating values. In so doing, Anomura has become the first outside organization to license the Sim[PLY] technology. Albright and Harding travelled to Victoria in May to direct the fabrication and assembly of a Sim[PLY] demonstration structure measuring approximately 12ft (L) x 12ft (W) x 15ft (H). The framing components were cut by a CNC water jet cutter at the Camosun Innovates lab of Camosun College, and the construction took place nearby, in the same lab, with a small assembly crew of Camosun volunteers and Anomura board members. In total, the combined fabrication and assembly were completed in five days.

The structure has since been used as a tool for Anomura's engineers to plan out the optimal insulated wall and roof assemblies for the Victoria climate and the stepped energy codes that are being initiated. Predictive energy modeling, as well as life-cycle assessment studies are underway and are the subject of a paper submission to the 2020 World Conference of Timber Engineering.

In June of 2019, Dustin Albright was again invited to lecture on the topic of North American developments in mass timber at the Augsburg University of Applied Science in Augsburg, Germany. Albright's colleagues at Augsburg have much professional and scholarly experience in the realm of timber design and have a keen interest in building relationships with Clemson, it's WU+D Institute, and our students.

Students at various levels in the program are continuing to explore timber systems for their Studio course projects. One such project by Cameron Foster and Phil Riazzi was recognized with a prestigious COTE Top 10 student design award. This national award from AIA's Committee on the

Environment recognizes ten outstanding projects that demonstrate "moving towards carbon-neutral operation through a creative and innovative integration of design strategies." Foster and Riazzi's project, titled "Acclimate," was sited in Bremerton, Washington and featured slender residential towers of CLT built over a repurposed parking structure. A second winning team from Clemson, Michael Horan and Cole Robinson, utilized Clemson's Sim[PLY] system for the structure of their housing proposal, titled "Transfusion" and set in Tuscon, Arizona.

Following up on last year's retooling of Clemson's 2-Year Studio curriculum, Tim Brown and Dustin Albright and others have continued introducing the basic tenets of wood construction to the 90 sophomores in the program throughout this Fall 2019 semester. Topics included timber post and beam structures, applied through the design of a transit hub for downtown Asheville, NC.

Throughout the Fall, Albright has also been jumping into a new phase of Clemson's interdisciplinary research on Disaster Response structures. Back in April, we were awarded a grant from the USDA for our project titled "Integrated Housing Design and Logistics for Disaster Relief." The objective of this project is to study the use of prefabricated wood building systems for deployable medical units and post-disaster housing. The study partners faculty and students from Architecture and Civil Engineering, and will examine wood solutions ranging from light frame models, constructed on site with prefabricated components, to deployable modular units made from mass timber panels. The designed solutions will be able to serve as inputs for the disaster-response logistics models developed previously by our Industrial Engineering department.

RELATED PRESS RELEASE / MEDIA LINKS:

https://newsstand.clemson.edu/the-term-diy-takes-on-new-meaning-with-newly-patented-clemson-designed-technology-and-building-solution-simply/

https://academicminute.org/2019/11/dustin-albright-clemson-university-simply-system/

https://newsstand.clemson.edu/mediarelations/clemson-students-lauded-by-aia-for-sustainable-design-excellence-with-cote-awards/

https://www.npr.org/podcasts/564572329/the-academic-minute

May 2019 Sim[PLY] build with Anomura in Victoria, BC.

ENGINEERING ACTIVITIES

Graduate Student Research

DYNAMIC RESPONSE OF HIGH-RISE CLT BUILDINGS TO WIND LOADS

(Lancelot Reres)

The proposed changes to the 2021 International Building Code would allow for cross-laminated timber buildings up to 270 feet. Based on in-situ modal data of CLT buildings, and trends seen in steel and concrete construction, the dynamic response of CLT buildings above ~180 feet should be considered in the lateral design. This entails including a dynamic component when calculating drift and checking the peak acceleration. As timber structures have always been limited to heights well below this threshold, both the significance of the dynamic response and the applicability of the current design formulae need to be determined.

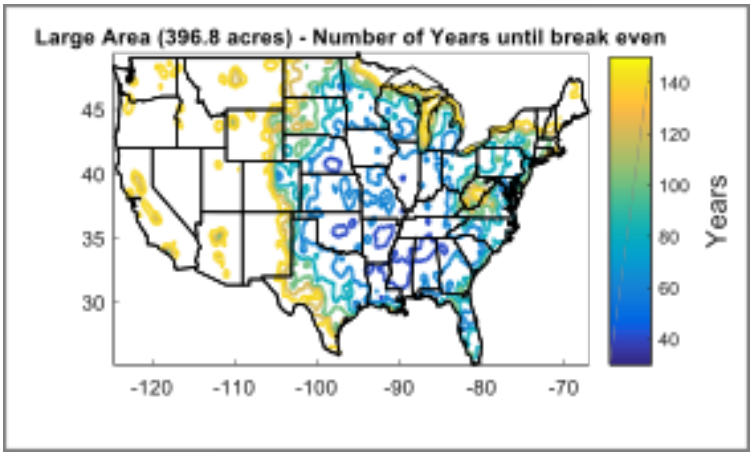
The goal of this research is to (1) assess the dynamic response of high-rise CLT structures to wind using the preliminary design methods currently in use; (2) develop numerical methods to estimate connection stiffness in order to aid in the modeling, analysis, and design of CLT buildings; and (3) perform nonlinear time-history analysis', using data obtained from wind tunnel testing to assess the performance and design of high-rise CLT buildings with regard to the ASCEs 2021 Pre-standard for Performance-Based Wind-Design.

A parametric analysis was conducted using closed-form preliminary design equations considering factors such as building height, aspect-ratio, stiffness, and density. It was found that the low structural density achievable with CLT would make high-rise CLT buildings more vulnerable than steel or concrete buildings, to wind-induced drift and vibrations, if the dynamic response is not accounted and designed for. An analytical method for estimating the Modified Stewart Hysteretic (MSTEW) parameters of nailed connections was developed. The method presented utilizes design code equations and is calibrated using published MSTEW data. This method can be used for light-frame design or coupled with a connector model to assess other dowel-type connections used in CLT construction.

UTILIZATION OF CLT IN LOW- AND MID-RISE BUILDINGS FOR ENHANCED WIND PERFORMANCE (Michael Stoner)

With the goal of determining the performance of CLT in residential construction subject to tornadoes, the debris impact performance of CLT was quantified. Additional experimental research will be carried out in Spring 2020 to study the performance of CLT structures subject to the lateral loads associated with wind loading in tornadoes. This experimentation will take the form of shear wall testing of CLT used for platform construction with the presence of return walls.

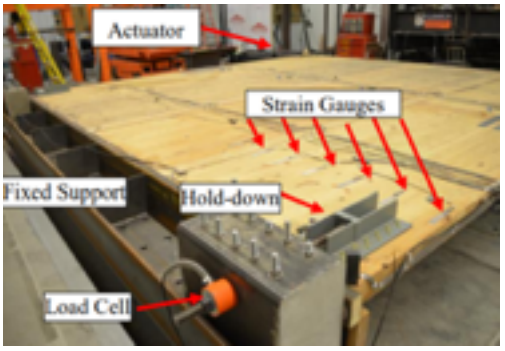
In addition to experimental studies, archetype residential structures were analyzed to determine the probability of severe failure given tornado events. Results of the study showed that structures made of CLT experienced failures due to EF-4 and EF-5 level events as compared to EF-1 and EF-2 for traditional light-frame construction. Further analysis accounting for the geographic variation in tornado hazard found that in some circumstances it would be advantageous to construct residential structures using CLT compared to light-frame over a 50-year lifespan of the structure. Quantifying the monetary benefits of a CLT residential structure subject to tornado events has proven that for some homeowners, it is an option worth considering.



EXPERIMENTAL CHARACTERIZATION OF THE IN-PLANE STIFFNESS AND STRENGTH OF A CANTILEVER CROSS-LAMINATED TIMBER (CLT) DIAPHRAGM (Bibek Bhardwaj)

A full-scale 20ft x 20ft cantilever CLT diaphragm was constructed at the Clemson Wind and Structural Engineering Research (WiSER) Facility. After a series of non-destructive tests to evaluate the initial stiffness of the diaphragm, a final destructive test was performed on October 23, 2019 using a cyclic loading protocol to simulate typical earthquake loading and to determine the ultimate capacity of the diaphragm. The preliminary test results showed that the CLT diaphragm achieved the design strength with the CLT-to CLT surface spline connections acting as the main energy dissipation mechanism.

As part of this experimental program, CLT-to-CLT and CLT-to-glulam connections were also tested both at Clemson University and Texas A&M University. The results of the connection tests are currently being utilized in a computer program to model the results of the tested cantilever diaphragm. Once the computer model is fully developed and validated, it may be used in conjunction with the connection test results to predict the stiffness and strength of CLT diaphragms of different configurations.



VIBRATION CONTROL OF CROSS-LAMINATED TIMBER FLOOR WITH CONCRETE TOPPING (Ben Schwendy)

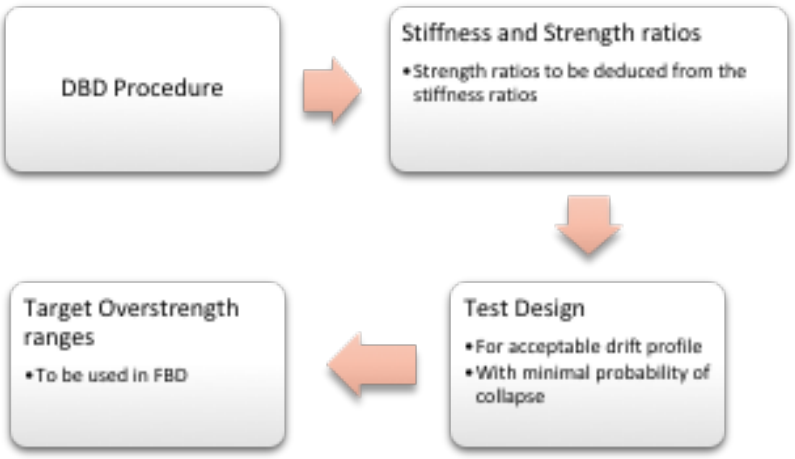

Accelerometer, in-situ

The main goals of this project are to obtain real-world data on the vibration performance of CLT with a concrete topping, and use that data to verify and potentially modify the existing methods for determining vibration controlled spans for CLT with heavy topping. If calculations on this front can be made less conservative, the cost of CLT construction will be reduced in many situations, making it a more attractive construction material. To achieve these goals, The Snow Building, which utilizes a CLT floor system with a concrete topping, has been outfitted with accelerometers, in order to monitor the vibrations caused by normal use. Once the building is fully operational, computers will be placed in the building to collect data from the sensors, allowing for continual monitoring of the structure. A more comprehensive single-panel test will also be carried out via a heel-drop test in order to get more precise data on the panel characteristics, as well as to compare the data from the accelerometers installed in the Snow Building. Once gathered, this data will provide insight into how heavy toppings and continuous spanning affect the vibration performance of CLT, allowing for potential recommendation on revisions to the current design methods if necessary.


Construction of the two-story rec center

SUPPLEMENTING FORCE-BASED DESIGN OF LIGHT-FRAME WOOD BUILDINGS BASED ON DISPLACEMENT-BASED DESIGN PROCEDURE (Bikal Shakya)

The current force-based design (FBD) method for light-frame wood buildings, though easier to implement, has its shortcomings when compared to the performance-driven displacement-based design (DBD). But the switch to DBD has been onerous because of its relative novelty and complexity. While the complete move to DBD does not seem imminent, the performance-based design criteria could be integrated into the more familiar FBD in the form of guidelines that govern design over-strength provisions and improve seismic performance. These guidelines will check upon a tendency of an engineer to arrive at a design that yields higher over-strength on the upper stories.



This study employs code-compliant archetype models based on commercial, multi-story buildings with minimal interior walls in high seismic regions to develop these guidelines. The study involves development of non-linear numerical models, execution of non-linear pushover and incremental dynamic analyses using the FEMA P-695 methodology and collapse evaluation. MATLAB scripts to carry out DBD procedure have been developed. The work in progress is refining the DBD procedure as well as integrating its results into the code-established FBD procedure. The study aims to improve the FBD method in the current building codes by using DBD as a proxy to optimize seismic performance of light-frame wood buildings.

OUTREACH ACTIVITIES (WOOD PROMOTION)

The Institute received a tremendous initial bump in our marketing and outreach effort from the 2015 Wood Innovation grant from the US Forest Service. With careful spending and a couple of extensions we are on the home stretch for completing the grant. We are using the last funds from that grant to support travel and promotional materials for marketing both within SC and going out to other southern states to promote mass timber. Several of the out-of-state presentations and tours at the Fort Jackson, SC LendLease hotel were supported by this grant. The list of tours that we have conducted at Fort Jackson and the Clemson Outdoor Recreation and Education facility at the SNOW Family Center can be found later in this report. A list of presentations that our team has completed are featured later in this report, as well.

The Clemson Outdoor Recreation and Education center (CORE) has been the centerpiece for many of our promotional and marketing activities and materials this year. We have had numerous stories in the news and on social media that feature the building. Our partners in the construction, engineering and design of the CORE building have supported these outreach efforts. We expect this building, and Clemson's Cadden Chapel (glulam and CLT) to contribute to our continued efforts to promote wood buildings. Meanwhile, the team that brought the CORE building to life are expanding their efforts to design, engineer and build with mass timber. For example, Sherman Construction will be erecting the Wofford Environmental Sciences building in 2020 and Cooper Carry is designing a new building at Auburn University using some mass timber.

Late last winter, we developed a section on our website to promote Innovative Wood Buildings in SC. We populated it in part with former Wood Design Award Winners selected by the Wood Products Council from SC. We promoted this new web feature through email and social media and received several new suggested additions. We will continue to annually promote this new online feature to bring new buildings to the map and let others know about the impact in SC. Our goal is to let others know that wood building is not just a northwest USA phenomena.

In 2019 we were approached by many associations, businesses and individuals across the U.S. and event abroad to interact with them about what we have done and our efforts in wood products promotion. The list of presentations, research and teaching efforts in this report all reflect the growing appreciation of our efforts and the recognition that we have built as a collaborative team at Clemson. Clemson University is making a difference in moving wood and mass timber products into new markets.

We received funding this fall from the U.S. Forest Service to begin work on innovating new Mass Timber Noise Barriers. We plan to establish a nationwide Mass Timber Noise Barriers Advisory Team (MTNBAT) that will 1) develop a list of states that have bans or regulations on using wood materials in noise barriers and seek to remove these, 2) develop initial designs for mass timber barriers, 3) seek state or federal Department of Transportation (DOT) agencies that will allow barrier tests, 4) develop designs with state engineers for the manufacture of test barriers, 5) seek and support installers willing to work with wood barriers (especially those for test locations), 6) collect cost and performance data after installation and 7) develop best practice materials and case studies to expand the use of mass timber noise barriers. This work is just getting started.

Mass Timber Tours

FORT JACKSON, SC

- **March 14, 2019:** AWC tour Paul Coats and Andrew Dodson
  This tour also included meeting with Senate staff about changing Building codes to a six-year
  time frame, which did not go through the Senate.

- **March 28, 2019:** Various engineers and Architects along with staff from Natural Resources

- **May 6, 2019:** State Engineer, John White, and three others including Macmillan Pazden Smith

- **July 2, 2019:** State Building code employees, with Paul Coats

- **July 24, 2019:** SCFC, GAFC and USFS, Region 8

- **Aug 15, 2019:** SC Foresters Council

CLEMSON SNOW CENTER

- **April 24, 2019:** Phil Landreth

- **May 17, 2019:** Interfor

- **May 23, 2019:** Georgia Pacific

- **July 1, 2019:** Katerra and others after diaphragm test

- **July 9, 2019:** MiTek

- **July 16, 2019:** Boise Cascade

- **July 27, 2019:** Brian Fehr and Dan Wurth

- **August 1, 2019:** Todd Everett, Cress Development, Josh Sorrell (contractor) and Sam Everett

- **August 14, 2019:** Lexington Technology School

- **October 9, 2019:** Huber Engineered Wood Products

- **October 23, 2019:** Wood Works/Wood Products Council

Lunch & Learns, Other Educational Events

- **August 23, 2019:** LS3P Charlotte, NC

- **September 2019:** Mass Timber and Conventional Wood Frame Construction: Building Code Update (Sponsored by Huber Engineered Woods, American Wood Council and Clemson Wood Utilization + Design Institute. Dallas, Austin, TX)

- **November 16, 2019:** Clemson President's Leadership Institute

Clemson President's Leadership Institute at CORE

GRANTS & CONTRACTS

AWARDS

FY'20

Patricia A. Layton. Development and Promotion of Mass Timber Noise Barriers for Highway (U.S. Forest Service Wood Innovations Grant)

Weichiang Pang. Enable the Use of Mass Timber Products for Non-Residential Buildings in High Velocity Hurricane Zone (U.S. Forest Service Wood Innovations Grant)

Patricia A. Layton. Integrated Housing Design and Logistics for Disaster Relief (USDA, Forest Service Forest Products Laboratory)

FY'19

Brandon E. Ross. Collaborative Research: Tessellated Structural-Architectural Systems for Rapid Construction, Repair, and Disassembly

Weichiang Pang. NSF Graduate Fellowship - Michael Stoner

Weichiang Pang. Enhancement of Advanced Blast Analytics and Development of Performance-Based Blast Damage Assessment of Buildings

Mark C. Thies. REU: AIR-TT: Ultrapure Lignins Recovered from Paper-Mill Black Liquors as Renewable Biopolymers

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PUBLICATIONS & PRESENTATIONS

Scott May, LS3P **- Jared Coffin,** Hanbury **- Allen Wood,** Retired **- Bo Shaw,** Retired

FY'20

Layton, P., Villegas, A. (moderator), Heagy, J., de St. Aubin, B., Mitchell, J. 2019. Panel discussion on mass timber as an emerging sustainable building product Georgia Forestry Foundation Event at Greenbuild. Atlanta, GA. November 21, 2019.

Layton P. 2019. Mass Timber: Why, What, Who, Where and When. Presented to the Abbeville County Landowners Association, Abbeville, SC. November 18, 2019

Layton, P. and Fiocchi, C. 2019. The Clemson Outdoor Recreation and Educational Building. Presented to the Clemson Presidential Leadership Institute, November 14, 2019.

Layton, P. 2019. Mass Timber: Why, What, Who, Where and When. Presented to Texas Forest Service and Guests at Texas A&M University. College Station, TX. November 8, 2019

Layton, P. 2019 Popcorn and Policy - New Innovations. A Panel discussion at the SAF National Convention. Louisville, KY November 1, 2019

Layton, P. and Cantrell, R. 2019. No Markets, No Money, No Management, No Conservation! Presented at the SAF National Convention. Louisville, KY. November 1, 2019.

Layton, P. 2019. Mass Timber: The Role of Foresters. Invited Presentation to the Alabama Society of American Foresters annual meeting. Birmingham, AL. September 20, 2019.

Layton, P. 2019. Mass Timber Building Codes in 2021. Presented at workshops in Dallas and Austin, TX. September 10-11, 2019.

Stoner, M., Raymond, A., and Pang, W. 2019. "Utilization of Cross-laminated Timber in Residential Construction to Resist Tornado Hazards," The 15th International Conference on Wind Engineering (ICWE15), Beijing, China. September 1-6, 2019.

Layton, P. 2019. Update on the Wood Utilization & Design Institute. Presented at the Timberland Legacy Committee meeting, Columbia, SC. August 9, 2019.

Layton, P. 2019. Panel presentation on protecting heirs' property and promoting the sustainable use of land to provide increased economic benefit to historically under-served landowners. Center for heirs Property. 4th Annual SC Rural and Limited Resources Landowner Symposium. Charleston, SC. August 2, 2019.

FY'19

FUTURE PLANS

Albright, D. 2019. “Timber Design and Construction in North America”. Invited Presentation at Augsburg University of Applied Science. Augsburg, Germany. June, 2019.

Layton, P. 2019. No Markets, No Management, No Conservation. Presented to the International Conference on Forest Resource Cultivation and Protection and the 2nd China Forest Resource Forum 2019. Nanchang China. June 15, 2019.

Pang, W., Albright, D. and Layton, P. 2019. Wood Research and Teaching. Invited presentation at the Chinese Academy of Forestry, Beijing China, June 12, 2019.

Albright, D. 2019. “Timber Design and Construction in North America”. Invited Presentation at Augsburg University of Applied Science. Augsburg, Germany. June, 2019.

Layton, P. 2019. Wood Quality: Looking to our Past to Guide 21st Century Tree Breeding. Invited Presentation to the Western Gulf Forest Tree Improvement Program. College Station, TX. May 15, 2019.

Safiey, A., Pang, W., Ziaei, E., Majdalaweyh, S., Rokneddin, K., and Javanbarg, M. 2019. “Rethinking Treatment of Irreparability in the Context of Performance-based Earthquake Engineering,” Structures Congress, ASCE, Orlando, FL, April 25-27, 2019.

Stoner, M., and Pang, W. 2019. ”Mass Timber Performance Against High Wind Hazards and Debris Impact Loads," International Mass Timber Conference, Portland, Oregon, March 19-21. 2019.

Stoner, M., and Pang, W. 2019. “Development of a Windborne Debris Impact Fragility Curve for Cross-Laminated Timber using Experimental Testing,” Journal of Wind Engineering and Industrial Aerodynamics, 190: 143-150. 2019.

Fan, F., and Pang, W. 2019. “Stochastic Track Model for Tornado Risk Assessment in the U.S.,” Frontiers in Built Environment Wind Engineering and Science, A Special Issue on Tornado Interactions with the Built Environment. 2019.

Harding, D. 2018. At Hand: Leveraging Technology to Incite Participatory Construction. Invited lecturer/presenter at Montana State University School of Architecture Fall lecture Series. November, 2018.

Harding, D. 2018. Design+Build and Research Initiatives-Clemson University. Invited lecturer/presenter at research centric design+build symposium at California Polytechnic School of Architecture. October, 2018.

Albright, D. and Harding, D. 2018. “Sim[PLY] Building Framing System”. Invited exhibit at *Future Shock* event of the Discovery Place Museum. Charlotte, NC. September, 2018.

Stoner, M. and Pang, W. 2018. “Experimental Testing and Numerical Validation of Cross-laminated Timber under Debris Impact Loading,” World Conference on Timber Engineering (WCTE), Seoul, Korea. August, 2018.

Layton, P. 2018. Mass timber comes of age: Code consideration, evolving supply chain promises new options for tall wood buildings. Building Design + Construction. Op-ed. July, 2018.

Albright, D. 2018. “Innovations in Wood and Timber Design: An Architect’s Perspective”. Presented at the Forest Products Laboratory Industry Needs Assessment. Starkville, MS. July, 2018.

Teaching:

We are very excited to have received a grant from Weyerhaeuser for Ph.D. student, Michael Stoner, to teach the wood engineering course for civil engineering students at Clemson in 2020.

WU+D will continue to utilize the new Clemson Outdoor Recreation and Education facility as an opportunity to teach about mass timber products and construction alongside our partners on the project.

Research:

Institute fellows will continue to submit proposals for research grants as graduate students continue to perform research operations. As mass timber comes into more use industry-wide, we will be seeking out contracts with individual companies to perform product testing research.

See *Engineering Activities* starting on page 5 to learn about continued student research.

Outreach:

Dr. Layton and team will once again attend and exhibit at the Mass Timber Conference in 2020 and Dr. Layton will also be serving on the Industrialized Wood-Based Construction Conference Program Committee.

Dr. Layton has also been elected to serve on the Sustainable Forestry Initiative (SFI) Board of Directors starting in 2020.

Institute Operations:

The Institute will continue to work on its strategic plan for future development, to aid the University's administration in understanding how WU+D can grow and support the mission of PSA and Clemson University. This is especially important as University-level administration continues to evolve.

We'll continue to look for support and donations to outfit the Clemson Built Environment Laboratory (BEL) in Pendleton.

We are strategically seeking out new members and industry partners who will participate actively in our research, teaching and outreach initiatives so that all parties find significant value in the future.