# WOOD UTILIZATION + DESIGN INSTITUTE

ANNUAL REPORT 2023

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### Introduction

We are celebrating! It has been 10 years since the Clemson Board of Trustees approved creating our Institute. And what a decade it has been! We are here today because our state forest landowners and industry asked Clemson to help find a solution for new markets for the wood that our landowners are growing in SC. And in true Clemson Tradition, we put our backs into it to carry out once again the "Will of Thomas Green Clemson:" to be a "high seminary of learning in which the graduate of the common schools can commence, pursue and finish the course of studies terminating in thorough theoretic and practical instruction in those sciences and arts which bear directly upon agriculture, ... to always bear in mind that the benefits herein sought to be bestowed are intended to benefit agricultural and mechanical industries."

It has been a big year for all of us as we began new projects, continued existing projects and completed some old ones. In this report, we will highlight that work, share our history and our alumni who are contributing to using more wood and feature how Clemson continues to be a model University for using mass timber.





The new Clemson Alumni & Visitor Center. Photos courtesy of Stephanie Cooper, AIA, AUA, University Architect & Executive Director of Planning, Design & Construction at Clemson University.

### Mass Timber at Clemson

Clemson broke ground on construction of its new Alumni and Visitors Center on February 1. Located adjacent to the Clyde V. Madren Conference Center and John E. Walker Sr. Golf Course, the new Clemson Alumni and Visitors Center will overlook the 18th green and the shores of Lake Hartwell, standing as Clemson University's front door — inviting prospective students to explore campus and welcoming past generations back home. The approximately 100,000 square-foot facility features Southern Yellow Pine mass timber.



Rendering by Goodwyn, Mills and Cawood.

of Stephanie Cooper.



Pictured below are renderings of the new replacement building for Lehotsky Hall, which will house the Forestry and Environmental Conservation Department, at the corner of Cherry Road and Perimeter Road. The intent of the building is to display the use of wood products in construction, so many spaces will have exposed ceilings or suspended wood ceilings, and highly visible public spaces will express wood in the structure, flooring, walls and ceilings.





Renderings by Moseley Architecture.

# WU+D Happenings

### New Benefit for WU+D Members

A members-only section has been added to the WU+D website that explores the research that has taken place at Clemson since the founding of the Institute in 2013. All paying WU+D members have received an email with login instructions. If you believe that your company is a current WU+D member and you have not received the login instructions, please send an email to <u>playton@clemson.edu</u>.



### Welcome Dr. Rodrigues!



Dr. Brunela Pollastrelli Rodrigues started as an Assistant Professor in the Department of Forestry and Environmental Conservation at Clemson University in April 2023. Dr. Rodrigues is already making valuable contributions to Clemson University's FEC Department and WU+D. She co-taught Forest Products (FOR 2540) with Dr. Layton during the Summer Camp 2023 and has been preparing her Wood and Paper Products (FOR 4080/6080) courses scheduled for Spring 2024. In addition to classroom teaching, Dr. Rodrigues is serving on one graduate student advisory committee, is mentoring a visiting scholar and is organizing lab space.

Dr. Rodrigues

### WU+D Director Position Update

Clemson has a team reviewing applications for the position of the Patricia "Pat" Layton Endowed Directorship of WU+D, a position that was endowed by a \$2 million gift from Micky and Amy Scott. The Patricia "Pat" Layton Endowed Directorship is named in honor of the first full-time WU+D director, Patricia Layton.



Pat Layton and Micky Scott

## WU+D 10 Year Anniversary

The "Great Recession" of 2007-2009 was the most significant financial crisis in the United States since the Great Depression in the early 20th century. It was especially hard on the wood products industry, dropping home-building growth and forcing many sawmills out of business. Clemson University and other major universities saw significant cuts in funding. There were program closures, faculty reductions and significant changes nationwide. At Clemson, early retirement packages were common. On September 28, 2010, the University announced via press release that Clemson was implementing a PSA and college restructuring.

"Clemson University will implement a series of budget reduction and restructuring strategies to help manage state funding cuts and facilitate long-range strategic planning in its Public Service Activities (PSA) division and College of Agriculture, Forestry and Life Sciences (CAFLS).... CAFLS will have four focus areas: food and packaging systems, sustainable agriculture, human and veterinary biomedical sciences and the environment. The organizational structure will be one school – Environment and Sustainable Agriculture – and four departments: animal and veterinary sciences, biological sciences, food and packaging systems, and genetics and biochemistry."

The press release did not mention forestry, resulting in a call from the state and private leadership within the forestry community to meet with the University officials. A small "Blue Ribbon Committee" was formed, chaired by Bo Shaw. Bo invited Architect Allen Wood, Clemson Board of Trustees Emeritus, to join the committee after it became clear that working in the buildings arena was needed. The committee helped develop ideas of how Clemson could assist the state and the industry to move forward from this economic crisis. What began with this committee resulted in a faculty committee that included Scott Schiff (Professor in Civil Engineering), Dustin Albright (Lecturer in Architecture), Dan Harding (Associate Professor in Architecture) and Joel Barker (formerly with Huber Engineered Wood Products). They began regular meetings to plan an interdisciplinary research institute focusing on advanced wood design and construction. Using a Six Sigma planning approach, the groundwork was laid for the WU+D Institute. Allen and Bo believed strongly in the vision that was developed and became the first Chair and Vice Chair respectively.

During the last 13 years since the banking/financial crisis, the state's economic impact from forestry grew from about \$16 billion to \$22 billion. Significant changes in the forest products industry, public policy, funding opportunities and the greening of the built environment have affected this growth. At Clemson, this includes the development and growth of Clemson's Wood Utilization + Design Institute, which the Clemson Board of Trustees approved on July 19, 2013.

The WU+D Institute began with the idea that using sustainably managed forests to produce wood products is key to a better future and a better built environment. Let's take a look back at our work over the last decade and see our journey. This journey includes our history of research and our students. On the third page of the timeline, we feature some of the Clemson Alumni who are playing major roles in the development of the mass timber industry.

### A Timeline of WU+D Research and Growth of Mass Timber

Industry / Research WU+D / Training First hybrid mass timber resident/building built in 2009 the U.S. (Hilton Head, SC) Grants Awarded: Development of Solid and Hollow-Core Cross-2012 Laminated Timber Systems for Low- and Mid-Rise Construction (USDA) NEESR-CR: NEESsoft: Seismic Risk Reduction • for Soft Story Woodframe Buildings (NSF through Colorado State University, Co-Investigator) Clemson Wood Utilization + Design Institute formed Numerical Study of the Structural Performance of • Scott Schiff became the WU+D founding Director Large Diaphragms (FPInnovations, Canada) First mass timber-themed Graduate Comprehensive Studio: On-campus Graduate Student Housing U.S. CLT Symposium (first gathering of its kind in • U.S.) 2013 Pat Layton became Director of the WU+D • CLT Handbook published by FP Innovations First Southern Yellow Pine CLT panels fabricated in Grants Awarded: Lehotsky Hall at Clemson. Wind and Rain Resistant Design for Coastal Cross Laminated Timber Buildings (South Carolina Sea • WU+D formation secured and membership Grant) recruitment began. Founding partner funding 2014 Light-frame Performance Modeling Group – A Study • secured from Collum's Lumber. Huber of the Seismic Performance of Core-Only Versus Engineered Wood Products and Mac Rhodes. Conventional Shear Wall Design Schemes for Light-• Launched WU+D website Frame Wood Buildings (co-funded by Structural Hosted the Clemson Canada Center Event Engineers Association of California (SEAOC), The An interdisciplinary team of Clemson students Engineered Wood Association (APA), Simpson and faculty participated in the USDOE Solar Strong-Tie and Mitek) Decathlon Competition held in Irvine, CA. Effective Fastening of Structural Sheathing/ • Clemson's entry, titled the "Indigo Pine House," **Rigid Foam Insulation Panels in Light-Frame** Wood Construction to Maximize In-Plane Shear utilized an innovative light-frame structure of Resistance," Huber Engineered Woods (Huber CNC-fabricated plywood components, which Engineered Woods) came to be known as the "Sim[PLY]" system. • Participated as a member of the SC Delegation CLT first recognized within 2015 IBC • to LIGNA Grant Awarded: 2015 Expanding the Use of Wood Building Products in • First WU+D Member/Board meeting SC + Supplement (USDA) Spoke at the first International Mass Timber Conference on Cross-Laminated Timber in the Grants Awarded: Southeastern USA Wood Utilization: Pathway to Healthy Forests and • Built the SC Wood Innovation Team and hosted three Sustainable Communities (USDA) 2016 Building Sustainably with Wood in SC workshops • Utilization of Cross Laminated Timber (CLT) in Mixed "Fluid" Studio: Clemson Equine Center Low and Mid-Rise Buildings for Enhanced Wind (collaboration with John Blackburn '69) Performance (USDA FS) Provided the information needed to eliminate a state Grant Awarded: engineer's office ban on Fire Retardant Treated Full-scale Testing of Cross-Laminated Timber 2017 Wood Diaphragm In-Plane Shear and Development of a Mixed "Fluid" Studio: BICEFS Research Laboratory Design Guide for Practitioners (US Endowment for (funded service-learning project) Forests and Communities/USDA Forest Products Lab)



### Clemson Alumni Making a Mark in Mass Timber

Architecture	Engineering
Renny Logan, FAIA (M.Arch 1982) Principle and NC Design Director, Perkins & Will Thomas Corrado (M.Arch 2006) Associate Principal, Hickok Cole	2012 2011 David Impson (MS) VP, Britt, Peters & Associates
Caitlin Ranson (M.Arch)	2013 Sami Pant (MS)
Associate, Hacker	VP, Paramatric Center of Excellence, Marsh
Kendall Roberts, AIA (M.Arch) Associate Principal, Hanbury	2014 Director of Preconstruction, VP, Timberlab Ross Phillips (MS) Building Assessment Specialist, Clemson
Whitney Ranson, AIA (M.Arch) Senior Associate, Populous	2015 University Jessica Scarlett (MS) Regional Director, Woodworks
Paul Mosher, AIA (M.Arch) Owner and Architect, Patch Architecture + Design	2016
Chelsea Anderson, AIA, NCARB (M.Arch)	Eric Gu (Ph.D.)
Owner and Architect, Habitable Form	Regional Director, Woodworks
Josh Rowell (BA)	Gus Raymond (MS)
Designer, Job Captain, YBA Architects	Structural Designer, Hill Foley Rossi & Associates
Lindsey Sinisi, RA (M.Arch)	2018 Michael Stoner (Ph.D.)
Associate and Architect, Handel Architects	Lecturer, Clemson University
Aaron Autry, AIA, NCARB (M.Arch) Architect and Job Captain, Cluck Design Collaborative	2019 Engineer, 1200 Architectural Engineers 2020 Harsh Bothra (MS)
	Project Engineer, Reackon Concrete Pvt Ltd
Forestry	ZUZI
Micky Scott (1975)	Jayson Leonard (MS)
President, Collums Lumber Products LLC	Structural EIT, Britt, Peters & Associates
Pat Layton (1976)	2022 Bibek Bhardwaj (Ph.D.)
WU+D Director, Clemson University	Graduate Engineer, Walter P. Moore
Derek Ratchford (1994)	Aaron DeSantis (MS)
CEO, Smartlam	Staff Engineer, Bennett & Pless, Inc.

### **Architecture Activities**

#### Multimedia Display Wall

Dan Harding, KJ Ammon, Joseph Anaya, Hayden Duncan, Sean LaRochelle

A team led by Professor Dan Harding completed the construction and installation of the mobile multimedia display wall pictured here. This wall is used in Clemson's Lee Hall III, home to our School of Architecture, and has been frequently used for student and faculty presentations, class meetings, special events and other gatherings. The wall consists of 42 TimberStrand® LSL studs (21 pairs) from Weyerhaeuser, and arcing steel plates at top and bottom. The studs were routed to receive custom felt baffles for acoustic control – a welcomed addition in our active and noisy Lee Hall. The pair of interactive, touch-screen monitors were specially selected for the wall. We are proud of how it all turned out and we thank Weyerhaeuser, a WU+D Institute Partner organization, for its generous sponsorship of the project.

![](_page_9_Picture_4.jpeg)

Mobile multi-media display wall in Clemson's Lee Hall III.

#### **Post-Disaster Housing Studies**

Dustin Albright, Elly Hall (with Yongjia Song, Weichiang Pang, Michael Stoner, David Vaughn and others)

2023 marked the second year of this interdisciplinary project, which is being funded through NSF's Disaster Resilience Research Grants (DRRG) program. The project, titled "An Integrated Housing Design and Logistics Operations Modeling and Analysis Framework for Hurricane Relief," is being led by faculty members Yongjia Song (Industrial Engineering), Weichiang Pang (Civil Engineering), Michael Stoner (Civil Engineering) and Dustin Albright (Architecture), with additional support from David Vaughn (College of Engineering). The primary objective of the research is to investigate the effectiveness of different housing solutions in disaster relief and recovery by creating an integrated modeling and analysis framework for disaster housing logistics planning and operations. This framework analyzes novel, adaptable disaster housing solutions from a systematic perspective of logistics planning and operations, drawing on converging research from our different disciplines: architectural design for alternative housing solutions, natural hazard and fragility analysis and relief logistics network design and operations planning under the uncertainty of disaster housing demand caused by hurricanes.

On the architectural side, we have been identifying single-family housing case-studies, which are robust and resilient in construction, capable of rapid delivery and designed with future expansion/adaptation in mind. We are interested in a range of construction and delivery paradigms, from offsite modular units to units built with prefab wall/roof/floor assemblies, to units built from kits of smaller parts. In each case, we have primarily emphasized wood and timber solutions. Through literature review and personal correspondence, we have been gathering data on unit costs, production capacities and timelines, logistics of delivery and installation, etc. All of this will serve as inputs for the operations planning framework being developed and tested by our partners in Industrial Engineering.

The architectural studies from this project, and a related preceding project served as the basis for a paper and presentation at the Biennial Conference of the Building Technology Educators' Society, which was held in June in Scottsdale, Arizona.

![](_page_10_Picture_5.jpeg)

Cross-Section through Sim[PLY] Kit-of-Parts Core Unit (illustration by Daniel Mecca).

#### Architecture Contributions to An Entirely Wood Floor System Designed for Biogenic Carbon Storage, Adaptability and End of Life De/Re/Construction

Dustin Albright, Kylee Russell, Britton Riddle, Coly Tabberson, Sean LaRochelle, Dan Harding

2023 marked the first full year for Clemson's ongoing project titled: "An Entirely Wood Floor System Designed for Biogenic Carbon Storage, Adaptability and End of Life De/Re/Construction." The project involves faculty and students from Civil Engineering, Environmental Engineering and Architecture, plus an industry advisory panel made of diverse professionals. It is being funded through the U.S. DOE's Advanced Research Projects Agency – Energy (ARPA-E), under its HESTIA program.

One of the principle contributions from the Architecture team has been in the area of acoustic performance for the project's experimental mass timber floor system. The goal is to physically test the acoustic performance and demonstrate compliance with the requirements of the International Building Code, including the most stringent requirements which pertain to floors in hotels and multifamily housing. The project team decided to perform the testing in-house, and it will follow applicable ASTM standards, including field test methods E336 (to measure airborne NNIC) and E1007 (to measure structure borne NISR).

![](_page_11_Picture_4.jpeg)

Acoustic Testing Chamber during its construction (roof panels not shown).

An acoustic testing chamber was designed and constructed to perform this testing (and similar testing in any future project), and it consists of an upper room in which sounds are generated and a lower room in which sound transmission through the floor is measured. An 8ft x 20ft opening in the floor of the chamber will accommodate different test floor assemblies. Of note, the chamber was built in two halves, each with hinged upper walls. This was done to allow for movement between our high-bay lab space, where testing will be performed, and our low-bay lab space, where the chamber will serve as a meeting room when not being used for testing.

The plan is to first gather measurements on a control floor assembly with known acoustical properties in order to calibrate equipment and validate our set-up. The testing of our experimental mass timber assembly will follow at a later date.

In addition to the acoustical considerations, the work of the Architecture team extends to the architectural layout and modeling of a three-story baseline office building. The baseline building will serve as a vehicle for a life cycle assessment (LCA) study in which a conventional steel and concrete structure is compared to a mass timber structure that utilizes our proposed floor system. Working with sizing provided by the Civil Engineering team, we have nearly completed both models and will look forward to results of the LCA study performed by the Environmental Engineering team.

### Wood and Timber in Architecture Studio Courses

Design and construction with timber continues to be a growing theme in design studio courses taught in the School of Architecture. In the Fall 2023 semester, Dustin Albright has directed an upper-level studio titled: "Poe Mill Thriving: Resilient Neighborhood Development within Greenville's Textile Crescent." The class has studied the rapid and profiteering redevelopment efforts in former textile communities across Greenville County (SC), and the gentrification and displacement which is resulting. Working then in reference to the Poe Mill neighborhood, the studio contemplated alternative, community-centric forms of reinvestment and revitalization, and developed phased master plans and programming concepts to address overarching themes of: Identity; Community Health and Well-being; Social Equity; Education; Economic Opportunity; Affordable and Sustainable Housing; Community Resilience; and more. Working from the master plans, students then divided up to design specific buildings and sites across the range of proposed programs and locations within the Poe Mill neighborhood. While referencing the mill histories and the themes of local, natural resources and industrial production, an emphasis was placed on the use of wood and engineered wood products (often hybrids) for these proposed structures.

Additionally, throughout the semester, the studio formed a unique collaboration with architecture students and faculty in the "international studio" at the Augsburg Technical University of Applied Sciences in Augsburg, Germany, which is, itself, a former textile capital in Europe, as well as a current center for timber design research and practice.

Outside of those design studio courses which make timber a central subject, we are seeing increased interest from students, in general, in these topics. For example, two out of the four nominees for the 2023 McClure Design Award (given to the top final graduate student project) featured mass timber. This included the winning project by Andrew Schick and Jerome Simiyon, titled "Murphy Ave Restorative Justice Hub." This project has gone on to win a student honor award from AIA South Carolina. Students such as these are entering the profession with a passion for ecologically-focused, low-carbon buildings and a considerable skillset in mass timber design.

![](_page_12_Picture_4.jpeg)

![](_page_12_Picture_5.jpeg)

## **Engineering Activities**

### Wood Design Class – Civil Engineering

![](_page_13_Figure_2.jpeg)

The bar chart presented here illustrates the enrollment figures for the structural wood design course from 2014 to the current academic year. In the 2023 academic year, 39 students participated in the Civil Engineering Wood Design class, comprising 29 undergraduate students and 10 graduate students. The course focuses on instructing engineering students in the design of wood buildings and structures in accordance with the National Design Specifications for Wood Construction, commonly referred to as the NDS code.

Since 2014, a total of approximately 400 students have received education in engineering wood design, with an average annual enrollment of around 44 students. Notably, the consistent sponsorship of the wood design class by Charles Ingram Lumber has significantly contributed to its popularity within the Civil Engineering Department. Charles Ingram Lumber has generously provided free NDS codes for our students over the past nine years, making the Wood Design class one of the most sought-after courses (see Figure 1). The enduring support from Charles Ingram Lumber has played a pivotal role in the success and appeal of the course, fostering a conducive learning environment for aspiring engineers in the field of wood construction.

![](_page_13_Picture_5.jpeg)

Figure 1: NDS codes sponsored by Charles Ingram Lumber and distributed to students in the Fall 2023 Civil Engineering Wood Design class.

#### Ongoing Research: Long-term Deflection (Creep) of Cross-Laminated Timber Panels Michael Stoner, Weichiang Pang, Aaron DeSantis, Dylan Smith

All wood products tend to deflect over time. This phenomenon is known as creep and is the subject of experimental testing which began in December 2022. A series of six cross-laminated timber (CLT) panels were loaded using a series of concrete weights and have been monitored for the increase in deflection since the tests began. The increase in deformation due to such long-term loading is described by the long-term deformation factor (creep factor). For CLT, this factor is assumed to be 2.0 by U.S. design standards and increases the deflection due to long-term loading. After nearly one year of loading, the

average measured creep factor is approximately 1.8, approaching the value defined by design standards. A large majority of the measured creep occurred in the first 100 days after loading. The test panels continued to be monitored as part of the long-term study.

![](_page_14_Picture_3.jpeg)

Long-term Deflection Test Setup.

Measured Long-term Deformation Factors.

# Ongoing Research: Mass Timber Noise Barrier and Moisture Monitoring

Michael Stoner, Weichiang Pang, Laura Redmond, Pat Layton, Dylan Smith

After the initial construction of a 3-ply CLT noise barrier constructed in 2021, the moisture in the CLT panel has been continuously monitored. The first CLT noise barrier was treated with two coatings meant to prevent UV degradation, discoloration, and promote water repellency. A second, untreated, CLT panel has been constructed and instrumented to determine any potential benefits of the coatings and to provide additional moisture data for exposed CLT products. Results from the first panel indicate that the moisture levels typically return to normal levels within 5-10 hours the peak moisture measurement.

![](_page_14_Picture_9.jpeg)

Noise Barrier - August 2021

Noise Barrier - August 2023

#### Ongoing Research: An Entirely Wood Floor System Designed for Biogenic Carbon Storage, Adaptability, and End of Life De/Re/Construction (de-constructible connection design) *Amin Nabati, Amin Nabati, Michael Stoner, Weichiang Pang, Brandon Ross*

The primary objective of this project is to employ the Design for Deconstruction (DfD) and Design for Adaptability (DfA) approaches in designing and testing a floor system. Focused on reversible connections, the emphasis is on facilitating the easy deconstruction and reconstruction of mass timber assemblies. This not only extends their lifespan but also enhances carbon storage. The proposed CLT-GLT structure addresses challenges by requiring easily reversible connections while maintaining composite action for structural integrity. Additionally, the project aims to design the floor system for adaptability, maximizing composite action and increasing the span lengths of CLT floor systems. This innovative timber floor system has the potential to significantly impact the off-site construction industry, promoting sustainability, efficiency and adaptability. It aligns with global efforts to reduce carbon emissions and encourages a shift toward a circular economy in construction for enhanced sustainability and resource efficiency, benefiting the construction industry, timber product manufacturers and society.

To achieve the project's goals, various conventional connections, including screws at different angles, have been considered. Two novel connections, (1) epoxy-coupler and (2) pipe connections, have been proposed and compared with conventional screw connections. In the epoxy-coupler connection, couplers and a bolt are used to connect CLT to GLT. For pipe connections, two pipe dimensions were tested (2 inches and 1 inch diameters). Figure 1 illustrates the fabrication process and failure modes of these two connections. Also, Figure 2 shows the de/re/construction process of epoxy-coupler connection.

Figure 1 illustrates the concept of an epoxy-coupler linking CLT and GLT, showcasing the ductile failure mode of the connection when subjected to shear loading. In this arrangement, the epoxy employs adhesive strength to secure the couplers within predrilled holes in both CLT and GLT, creating a space for the bolt to facilitate the connection or disconnection of the two pieces. In Figure 2, a pipe is utilized to connect the two sections of CLT and GLT by embedding it into the predrilled holes. The failure pattern of the pipe exemplifies the ductile characteristics of the connection.

The upcoming phase of the project involves several key tasks. Firstly, a comprehensive comparative study will be conducted to delineate distinctions between Epoxy-Coupler and pipe connections in terms of energy consumption, construction time, material usage and cost, comparing them with other conventional connections. Additionally, a broader

![](_page_15_Picture_5.jpeg)

Figure 1. (left) Test setup for CLT to GLT, (right) Test setup for CLT to CLT.

examination of de/re-constructable connections will be undertaken to validate their shear behavior, contrasting them against conventional screw connections. Furthermore, there is a plan to investigate the vibration characteristics of the proposed novel floor system. This will encompass material-level, assembly-level and systemlevel vibration tests. Given the intended use

![](_page_16_Picture_1.jpeg)

Figure 2. Isometric view for the preliminary assembly design.

for office purposes, the results will be benchmarked against existing codes and documentation to ensure compliance and effectiveness.

### Ongoing Research: Enable the Use of Mass Timber Products for Non-Residential Buildings in High-Velocity Hurricane Zone

Sovanroth Ou, Michael Stoner, Weichiang Pang

In the High-Velocity Hurricane Zone (HVHZ) in Florida, the Florida Building Code (FBC) governs the wind design requirements. While several construction assemblies are deemed to comply with these requirements, Cross-Laminated Timber (CLT) is not among the list of qualified materials. This research aims to enable the use of CLT in HVHZ through experimental testing including windborne debris impact and cyclic wind pressure tests. The experimental results show that 3-ply CLT satisfactorily passed all tests conducted with very little damage indicating that CLT is suitable for applications in HVHZ. The research team has conducted a large missile test for a specimen (Figure 1). The 2 x 4 missiles impacted the specimen twice at the corner and center of the CLT panel. The indentation depths were measured to be 0.25 in and 0.50 in at the center and corner respectively.

![](_page_16_Picture_7.jpeg)

Figure 1: Missile indentation depth of large missile test.

The research team has also conducted the wind pressure cyclic test on the same specimen per building envelope and glazing standards. The maximum deflection for the building envelope standards was measured to be 0.112 in with a permanent deformation of 0.027 in while the maximum deflection for the glazing standards was 0.62 in with a permanent deformation of 0.005 in. No crack or opening formed during or after both experimental tests.

Note that the research team has completed the test following the loading protocol for glazing. Additional 3-ply CLT panels have been ordered and these panels will be tested following the loading protocol for walls.

## Ongoing Research: Housing Demand Prediction, Damage and Loss Estimation due to Hurricane Hazard

Adish Deep Shakya, Susmita Bhowmik, Weichiang Pang, Michael Stoner, Yongjia Song, Dustin Albright, Sheng Yin Chen, Elly Hall

Hurricanes threaten coastal communities of the United States on annual basis, causing significant damage and financial losses, and displacing hundreds of thousands of people. The societal and economic resilience in the aftermath of a hurricane hinges significantly on the resilience of individual households and residential buildings. In the U.S., the majority of residential buildings are light-frame wood construction. Mere fortification of the wind resistance of economic drivers such as commercial infrastructures and manufacturing plants may not ensure disaster resilience. The reason lies in the interdependency between these facilities, economic activities cannot resume if the homes of workers are destroyed in a hurricane event. A critical factor for expeditious economic recovery post-hurricane is the provision of disaster relief housing for the affected population. In the US, the Federal Emergency Management Agency (FEMA) plays a crucial role by offering financial and direct services to eligible individuals and households facing uninsured or under-insured expenses and severe needs, such as housing.

The objectives of this research are (1) to develop a framework for estimating disaster housing needs, and (2) to develop new options for disaster relief housing. Figure 1 shows the outline of the hurricane damage, loss and displaced household estimations framework. The estimation process commences by constructing a study domain utilizing the housing data from the National Structure Inventory and demographic data from the US Census, organized into Census Tracts. Next, a hurricane track is selected, and a parametric wind field model is used to calculate peak wind speeds at each Census Tract. Employing computed peak winds, building fragility curves and loss functions are utilized to determine damage states and losses inflicted by the hurricane. Demographic data, including household income, and owner's age, combined with determined losses, facilitate estimating short-term and long-term displaced households, with a subset being eligible for FEMA assistance. Figure 2 shows an example output for the estimation of displaced households due to a re-occurrence of the 1989 Hurricane Hugo.

![](_page_17_Figure_4.jpeg)

Figure 1: Damage and loss estimation framework.

![](_page_17_Figure_6.jpeg)

Figure 2: Displaced households due to Hugo.

### Outreach

In 2023, the faculty fellows in the WU+D Institute continued their amazing outreach, bringing mass timber to as many people as we could reach. Here a few key ways we accomplished our outreach:

- Tours
- Monthly email newsletter
- AIA Continuing Education credits for the Weyerhaeuser Sustainable Building Seminars
- Presentations and Papers especially participation in the:
  - · International Mass Timber Conference
  - · World Council on Timber Engineering
  - Mass Timber+ (IWBC Conference at Greenbuild)
- Softwood Lumber Board sponsored faculty training programs
- Appearances to support agencies and industry in Washington DC

#### Tours

- Nathaniel Hardy, KPFF, Birmingham AL tour (Jan 24)
- Corey Lee & Jim Chamberland, Smallwood Architects (Feb 24)
- SC Society of American Foresters State meeting (June 8)
- Timber Innovations Workshop for Engineering Faculty (June 12-13)
- Talbot Rueppel of the US Army Corps of Engineers (June 28)
- Britt Peters and UGA senior engineering students (Oct 5)
- Forest & Mill tour, Faculty, Staff & Graduate students (Aug 17)
- ARPA E Hestia Program Staff (May 12)
- Tour of new building site at Madren with Ken Scar (April 13)
- SC Forestry Association Board members (Sept 13)
- German Architecture Faculty and Students (Oct 16)
- Will Layden, VP Government Affairs, American Wood Council (Oct 31)

![](_page_18_Picture_24.jpeg)

![](_page_18_Picture_25.jpeg)

Clemson faculty Brandon Ross and Weichiang Pang with students Sovanroth Ou and Amin Nabati.

SC Society of American Foresters meet at the Andy Quattlebaum Outdoor Education Center.

WU+D Institute members hosted a booth at the ARPA-E Summit March 22-24 in National Harbor, MD. The booth included hands-on demonstrations of proto-type connections. The booth also allowed WU+D to engage with a broad cross-section of professionals in the energy sector, an audience that is new to WU+D.

### Mass Timber Structure Training Program

WU+D and the Nieri Family Department of Construction Science and Management (CSM) have developed an active training program for mass timber construction in conjunction with WoodWorks – Wood Products Council (WW). WW has provided the materials needed to construct and deconstruct a mass timber structure at Clemson's Experimental Learning Yard. The structure is being used by CSM

![](_page_19_Picture_2.jpeg)

Students construct the mass timber structure.

students and contractors in the region for training employees and subcontractors on mass timber construction. Trainings in the actual installation process will be paired with tours of existing buildings on campus such as The Andy Quattlebaum Outdoor Education Center and the Samuel J. Cadden Chapel, as well as buildings that may be under construction on campus or in the upstate area to provide an excellent training scenario for contractors and subcontractors at all levels within the construction industry.

#### Timber Design Faculty Development Workshop

Clemson University's Glenn Department of Civil Engineering and WU+D partnered with the Softwood Lumber Board to host a two-and-a-half-day, hands-on workshop for engineering faculty. Held June 12-14, 2023, the workshop included presentations from guest speakers, tours of Clemson's mass timber facilities and active dialogue. Twenty-one faculty members from as many institutions were chosen from a pool of applicants, who together described a range of different and compelling motivations for attending and participating. Some cited their desire to expand the research in concrete and steel buildings at their universities to include mass timber and some feel that timber engineering plays a significant role in progressing towards the goals of mitigating the factors driving climate change. Travel expenses, lodging and meals were funded through a generous grant from the Softwood Lumber Board.

The workshop's focus was to educate attendees about wood engineering and design, and strategies for incorporating this subject matter into their teaching, research and outreach through nine interactive sessions. Presenters include a cross-section of Clemson faculty and invited guests with expertise in building successful timber engineering design programs at their respective universities: Andre Filiatrault,

![](_page_19_Picture_8.jpeg)

Timber Design Faculty Workshop participants.

Emeritus Professor, State University of New York at Buffalo; John Lawson, Professor, Architectural Engineering, Cal Poly, San Luis Obispo; Jeff Vance, Senior Design Engineer, MiTek USA; Jessica Scarlett, Regional Director, WoodWorks; David Impson, Vice President, Britt Peters and Associates; and Weichiang Pang, Michael Stoner, Dustin Albright and Pat Layton, WU+D Director, Clemson University. More information can be found in the LinkedIn story about the event.

#### 2023 Forest Products Summer Camp

![](_page_20_Picture_1.jpeg)

WU+D Director Pat Layton and Dr. Brunela Rodrigues led the Clemson University 2023 Forest Products summer camp, which included tours of Baillie Lumber, West Fraser, Canfor, Huber Engineered Woods, Boise Cascade Company, Roseburg Forest Products, Sylvamo, Enviva and AHC Hardwood Group. The camp is part of Clemson's Forest Resource Management curriculum, which is accredited by the Society of American Foresters and provides a strong program in the basic knowledge and skills required of a professional forester.

2023 Forest Products summer camp participants.

#### Senate Working Forest Caucus/American Wood Council Event

![](_page_20_Picture_5.jpeg)

Michael Stoner presents to the Senate Working Forest Caucus and American Wood Council.

The Senate Working Forest Caucus held an event with the American Wood Council on Tuesday, May 16 detailing Department of Defense (DOD) applications for mass timber products. Attendees learned about the past testing involved in ensuring forest products meet DOD standards, how DOD can deploy innovative wood technologies and what kind of cost, schedule and workforce efficiencies mass timber can offer DOD military construction. Michael Stoner presented Clemson's designs for the Tyndall Air Force Base, research on wind resilience and whole building life cycle carbon assessments.

#### Energy Innovation Showcase on the Hill: ARPA-E Technologies

On July 18, Chairman Brandon Williams of the House Science, Space and Technology Committee's Subcommittee on Energy, Bipartisan Policy Center and ClearPath hosted the ARPA-E Energy Innovation Showcase on the Hill in the Rayburn House Office Building. Six ARPA-E project teams displayed their technology for Members of Congress, House and Senate staff, energy innovation leaders, members of the business community, and more. ARPA-E Director Evelyn Wang and Members of Congress addressed the audience and highlighted the importance of energy R&D. Brandon Ross, Dustin Albright and Mik Carbajales-Dale attended and presented a Clemson project. This project, which examines a long-spanning, systems-integrating composite timber floor assembly, is ongoing. Project faculty, students and industry advisors are connected through WU+D.

![](_page_20_Picture_10.jpeg)

Evelyn Wang (ARPA-E Director), Brandon Ross, Dustin Albright, Mik Carbajales-Dale, Marina Sofos (ARPA-E Program Manager) and Clete Boykin (Clemson Government affairs).

### Civil Engineering Education Summit Tour of Quattlebaum Outdoor Education Center

Clemson WU+D hosted a group of attendees at the Civil Engineering Education Summit in April. The discussion and visit to the Andy Quattlebaum Outdoor Education Center focused on how such a building could be utilized as an educational tool for students and faculty. The Quattlebaum building utilizes mass timber construction, an engineered wood product which was recently developed and has been part of the research at Clemson University for the past decade. Many attendees were encouraged by the tour to push for sustainable building development on their campuses with a focus on using such development as a tool for education.

![](_page_21_Picture_2.jpeg)

*Civil Engineering Education Summit attendees tour the Andy Quattlebaum Outdoor Education Center.* 

#### Clemson Timber Strong Design Build Team

![](_page_21_Picture_5.jpeg)

The Clemson University Timber Strong Design Build team competed at the American Society of Civil Engineers Gulf Coast Symposium on March 9th in Mobile, AL. The team constructed a 6' x 6' x 12', 2-story, lightframe timber structure as part of the competition. Because Clemson was invited as a guest to the competition, they were unable to place, but received the highest score of all teams competing. The team learned from the competition this year and is already planning and excited for next year's competition.

Timber Strong Design Build team members in front of their structure.

### Clemson Disaster Resilience Research Workshop

The Disaster Resilience research team organized a one-day research workshop at Clemson University, with guest speakers from the South Carolina Emergency Management Division (SCEMD), including their

Chief of Recovery of Mitigation, Ms. Emily Bentley. This workshop: (i) brought the researchers and practitioners together to ensure the realistic aspect of the research project; (ii) reassured the alignment of the research direction with the interests and priorities of SCEMD's disaster housing planning; (iii) motivated new research topics. After the workshop research ideas were presented to the SC Day of Recovery event organized by the SCEMD, and the Clemson team was able to make additional connections with various stateand local-level government agencies.

![](_page_21_Picture_11.jpeg)

Disaster Resilience Research team.

#### Weyerhaeuser Sustainable Building Seminars

Made possible by a generous gift from the Weyerhaeuser Foundation, WU+D, along with the Glenn Department of Civil Engineering and the School of Architecture, are offering a series of seminars during the fall semester. Topics include designing for sustainability and landscape sustainability practices. A full list of the seminars can be found on the WU+D website, and videos of presentations have been uploaded to the <u>WU+D YouTube channel</u>.

The Weyerhaeuser Carbon Story: Vaughan Andrews & Sarah Fulcher, Weyerhaeuser

Life Cycle Analysis/Embodied Carbon: Indroneil Ganguly, University of Washington

Ethical Considerations for Sustainable Buildings: Bill McCoy, Clemson University

Weyerhaeuser Forest Operations: Katie Jordan & Kelly Dougherty, Weyerhaeuser

Timber to the Extreme – The Intersection of Resiliency and Sustainability in the Performance of Timber Structures under Extreme Hazards: David Roueche, Auburn University

MEP Insights to the IECC and Title 24 Energy Codes – What the Future Holds: Justin Judy, Engineering System Solutions

Design for Reuse with Mass Timber: Tom Frantzen, Lemniskade projects and FRANTZEN et al.

Sustainable Building – A Policy Perspective: Will Layden, American Wood Council

Modern Mass Timber in the Market: Dean Lewis, Skanska USA

Designing for Sustainability and Climate Action with AIA Resources: Betsy del Monte, Cameron MacAllister

Seedlings to Solutions – 619 Ponce: Georgia's First Locally Grown Mass Timber Building, Troy Harris, Jamestown, L.P.

Landscape Sustainability Practices: Darren Meyer, MKSK

How Mass Timber Works for Building Owner/Occupants: Robert Taylor, Clemson University & Peter Brewitt, Wofford College

![](_page_22_Picture_15.jpeg)

### Grants & Contracts

#### New for 2023

"Building Partnerships for Climate Smart Commodities in SC," USDA, WU+D portion: \$100,000 (2022-2024).

### **Ongoing or Completed**

"An Entirely Wood Floor System Designed for Biogenic Carbon Storage, Adaptability, and End of Life De/ Re/Construction," U.S. Department of Energy, \$1,042,934, (2022-2025).

"Timber Design Faculty Development Workshop," Softwood Lumber Board, \$50,000, (2022-2023).

"The Clemson Mass Timber Structure Training Program," USDA Forest Service, \$128,093, (2022-2025).

"Mass Timber Reconstruction of a High-Profile Academic Building at Clemson University: Lehotsky Hall, " USDA Forest Service, \$250,000, (2022-2025).

"An Integrated Housing Design and Logistics Operations Modeling and Analysis Framework for Hurricane Relief," National Science Froundation, \$399,999, (2021-2023).

"Enable the Use of Mass Timber Products for Non-Residential Buildings in High Velocity Hurricane Zone," United States Department of Agriculture, Forest Service (FS), \$249,999, (2019-2022).

"Development and Promotion of Mass Timber Noise Barriers for Highways," United States Department of Agriculture, Forest Service (FS), \$248,809, (2019-2022).

"Integrated Housing Design and Logistics for Disaster Relief," USDA, Forest Products Laboratory, \$50,000, (2019-2021).

"Full-scale testing of cross-laminated timber diaphragm in-plane shear and development of a design guide for practitioners," United States Endowment for Forestry and Communities, \$305,000, (2017-2022).

"Utilization of Cross Laminated Timber (CLT) in Low and Mid-rise Buildings for Enhanced Wind Performance," United States Department of Agriculture, Forest Service (FS), \$244,956, (2016-2021).

### **Publications & Presentations**

Ravindran, P., Owens, F. C., Costa, A., Rodrigues, B. P., Chavesta, M., Montenegro, R., Shmulsky, R., and Wiedenhoeft, A. C., "Evaluation of test specimen surface preparation on macroscopic computer vision wood identification." Wood and Fiber Science, (2023).

Oliveira, J.T.S., Arantes, M.D.C., Moulin, J.C., and Rodrigues, B.P. "Carbon in wood as an important driver of a green economy. In: FIEDLER, N.C., LOUSADA, J.L.P., & CARMO, F.C.A. (Eds.), Gas emissions, and carbon sequestration in forest ecosystems, pp. 210-243. Vitória-ES: EDUFES - E-Livros, v.2, p. 210-243. http://repositorio.ufes.br/handle/10/12161(E-Book Chapter)

Rodrigues, B. P.; Longue Junior, D.; Libarino, C. S., Guimarães, P. P., Nogueira E, N. W., & Botrel, R. T. (2023). Eucalypt essential oil. In: Guimarães, P.P., Nogueira E, N. W., & Botrel, R. T. (Eds.), Non timber products technology. Mossoró: EDUFERSA, v. 1, p. 233-250. (Book Chapter)

DeSantis, Aaron, "Experimental Investigation of the Long-Term Bending Deflection and Creep Performance of Cross-Laminated Timber (CLT)", M.S. Thesis, Clemson University (Aug 2023)

Bhardwaj, B., Pang, W., Stoner, M., Rammer, D., and Pryor, S. (2023) "Experimental Characterization of Cantilever Cross-Laminated Timber Diaphragms under In-plane Shear Load," ASCE Journal of Structural Engineering, 150(2).

Albright, D., Hall, E., Song, Y., Pang, W., and Stoner, W., "Direct Housing for Post-Disaster Recovery: Design and Logistics for Alternative Solutions," Proceedings of the 2023 Building Technology Educators' Society (BTES) Conference, (2023)

Chen, S., Song, Y., Albright, D., and Pang, W., "Logistics Planning for Disaster Housing Assistance under Demand Uncertainty," Proceedings of IISE Annual Conference and Expo, New Orleans, Louisiana (2023) \* Logistics and Supply Chain Best Track Paper Award

Layton, P. 2023. Mass Timber Update. 2023. Invited Presentation to the Appalachian Society of American Foresters, Columbia, SC, January 26, 2023.

Pang, W. 2023. "Performance Assessment of Residential Structures Built using Cross-laminated Timber and Light-frame Wood in High Wind Hazard Regions", 68th Annual Structural Engineering Conference, The University of Kansas, Lawrence, KS, March-02, 2023.

Sheng-Yin Chen, Yongjia Song, Dustin Albright, and Weichiang Pang, "Logistics Planning for Disaster Housing Assistance under Demand Uncertainty", IISE Annual Conference and Expo 2023, May 2023.

Dustin Albright, Elly Hall, Yongjia Song, Weichiang Pang, and Michael Stoner "Direct Housing for Post-Disaster Recovery: Design and Logistics for Alternative Solutions", BTES Biennial Conference 2023, June 2023.

Rodrigues, B.P. 2023. Anatomy, Density, and Chemical Properties of Eucalypt Wood Affected by Abiotic Stress. Presented to SWST 66th International Convention, Crowne Plaza Resort Asheville, Asheville, NC. June 2023.

Rodrigues, B.P. 2023. Eucalyptus Physiological Disorder: wood production, wood quality, challenges, and perspectives. 76th FPS International Conference. 2023.

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*Clemson Student Sovanroth Ou presents at the World Conference on Timber Engineering (WCTE).* 

DeSantis, A., Pang, W., and Stoner, M. "Investigation of Cross-laminated Timber Long-term Performance (Creep)," World Conference on Timber Engineering (WCTE), Oslo, Norway, Jun 19-22, (2023)

Bhardwaj, B., Pang, W., Stoner, W., Rammer, D., and Pryor, S. "Deflection of Cantilever Cross-laminated Timber Diaphragms under In-plane Load," World Conference on Timber Engineering (WCTE), Oslo, Norway, Jun 19-22, (2023)

Pang, W., Stoner, M., Bothra, H., Redmond, L., and Layton, P., "Exploring the Structural Design, Cost and Durability of Mass Timber Noise Barrier for Highway Applications," World Conference on Timber Engineering (WCTE), Oslo, Norway, Jun 19-22, (2023)

Leonard, J., Pang, W., Stoner, M., and Albright, D., "Deployable Wood Structures for Disaster Relief and Military Use," World Conference on Timber Engineering (WCTE), Oslo, Norway, Jun 19-22, (2023)

Ou, S., Stoner, M., and Pang, W., "Enable the use of Mass Timber Products for Non-residential Buildings in High Velocity Hurricane Zones," World Conference on Timber Engineering (WCTE), Oslo, Norway, Jun 19-22, (2023)

Layton, P. 2023. NASF Forest Management/Forest Markets. 2023. Invited presentation to NASF Joint Committees. Fargo, ND. June 29, 2023

Bhardwaj, B., Pang, W., and Stoner, M., "Design of Bamboo Reinforced Concrete Beams Considering Variability in Tensile Strength of Bamboo," 14th International Conference on Applications of Statistics and Probability (ICASP) in Civil Engineering, Dublin, Ireland, Jul 9-13, (2023)

Bhowmik, S., Pang, W., and Stoner, M., "Probabilistic Modeling of North Atlantic Ocean Hurricane Spawn Considering Climate Change," 14th International Conference on Applications of Statistics and Probability (ICASP) in Civil Engineering, Dublin, Ireland, Jul 9-13, (2023)

Yongjia Song, Dustin Albright, and Weichiang Pang, "An Integrated Housing Design and Logistics Operations Modeling and Analysis Framework for Hurricane Relief", South Carolina Day of Recovery 2023, Aug. 2023. Yongjia Song, Dustin Albright, and Weichiang Pang, "An Integrated Housing Design and Logistics Operations Modeling and Analysis Framework for Hurricane Relief", 2023 Disaster Resilience Symposium (Virtual), Aug. 2023.

Layton, P. 2023. Mass Timber and other new product innovations. 2023. Presentation to the Forest Recovery Task Force. Columbia, SC. August 16, 2023.

Shakya, A. D., Pang, W., Stoner, M., Song, Y., Albright, D., Bhowmik, S., Chen, S.Y., and Hall, E., "Housing Damage, Loss and Shelter Need Estimations using an Ensemble of Return Period Consistent Tropical Storms," 16th International Conference on Wind Engineering, Florence, Italy, Aug 27-31 (2023)

Layton, P. 2023. Mass Timber Overbuilds: A Case Study on 80 M Street 2023. International Wood Building Conference. Panel Moderator, Washington, DC. September 27, 2023.

Layton, P. 2023. Mass Timber: Will There Be Enough Wood to Meet Future Demand? 2023. International Wood Building Conference. Panel Moderator, Washington, DC. September 28, 2023.

Sheng-Yin Chen and Yongjia Song, "A Two-Stage Chance-Constrained Stochastic Program for Disaster Housing Assistance Logistics Planning", INFORMS Annual Meeting 2023, Oct. 202

Layton, P. 2023. Clemson's Wood Utilization + Design Institute. 2023. Invited presentation to the SC Forestry Association Annual Meeting, Isle of Palms, SC. November 9, 2023.

Layton, P. 2023. Innovations in Mass Timber Construction. 2023. Invited Presentation to the Higher Education Facilities Conference, Austin, TX. November 13, 2023.

Pang, W. 2023. "Building a Sustainable and Resilient Future: Harnessing the Power of the Sun to Grow our Cities," 2023 HKUST Civil and Environmental Engineering Distinguished Workshop - Climate Change and Zero Carbon Future: Challenges and Opportunities for the Next Generation of Timber and Hybrid Building Construction, The Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, December 7-8, 2023.

## Media

### National Industry Publications

"<u>How Clemson University researchers are finding eco-friendly solutions</u>," WSPA 7News, October 16, 2023

"Advanced Wood Construction Technologies," National Woodlands, Volume 46, Number 3

"Colleges Showcase Mass Timber, in Research and on Display," New York Times, March 2023

"<u>Faculty Workshops Help to Expand Mass Timber Education Across the Country</u>," Softwood Lumber Board Newsletter, August 2023

### **Clemson University**

"Keeping it green: Broad University collaboration cares for Clemson's urban forest," Clemson News, July 2023

"Samuel J. Cadden Chapel earns international religious architecture award," Clemson News, March 2023

### Honors & Awards

Samuel J. Cadden Chapel earns international religious architecture award

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## WU+D Members

Partners

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**Corporate Partners** 

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