PennState

PHRC

2024 Residential Building Design & Construction Conference

March 27-28 | The Penn Stater Hotel & Conference Center
State College, Pennsylvania, USA

Welcome

Registration opens at 7:30 am

It is my great pleasure to welcome you to the 7th Residential Building Design and Construction (RBDC) Conference being held March 27-28, 2024, at the Pennsylvania State University in State College, PA. This biennial conference is organized by the Pennsylvania Housing Research Center (PHRC) at Penn State and is being held in conjunction with the 2024 PHRC Housing Conference at The Penn Stater Conference Center & Hotel.

The Annual Housing Conference has been a successful PHRC program for 32 years with emphasis on topics of interest to developers, builders, remodelers, design professionals, planners, regulatory and code officials, modular and HUD code builders, and housing product manufacturers. On the other hand, the biennial RBDC Conference that is being held for the seventh time is a program organized by the PHRC to provide a forum for researchers, design professionals, manufacturers, builders, and code officials to exchange knowledge and understanding on the latest research, development, and advancements and to discuss and share their own findings, innovations, and projects related to residential buildings, covering materials and their manufacture, design, analysis, and construction.

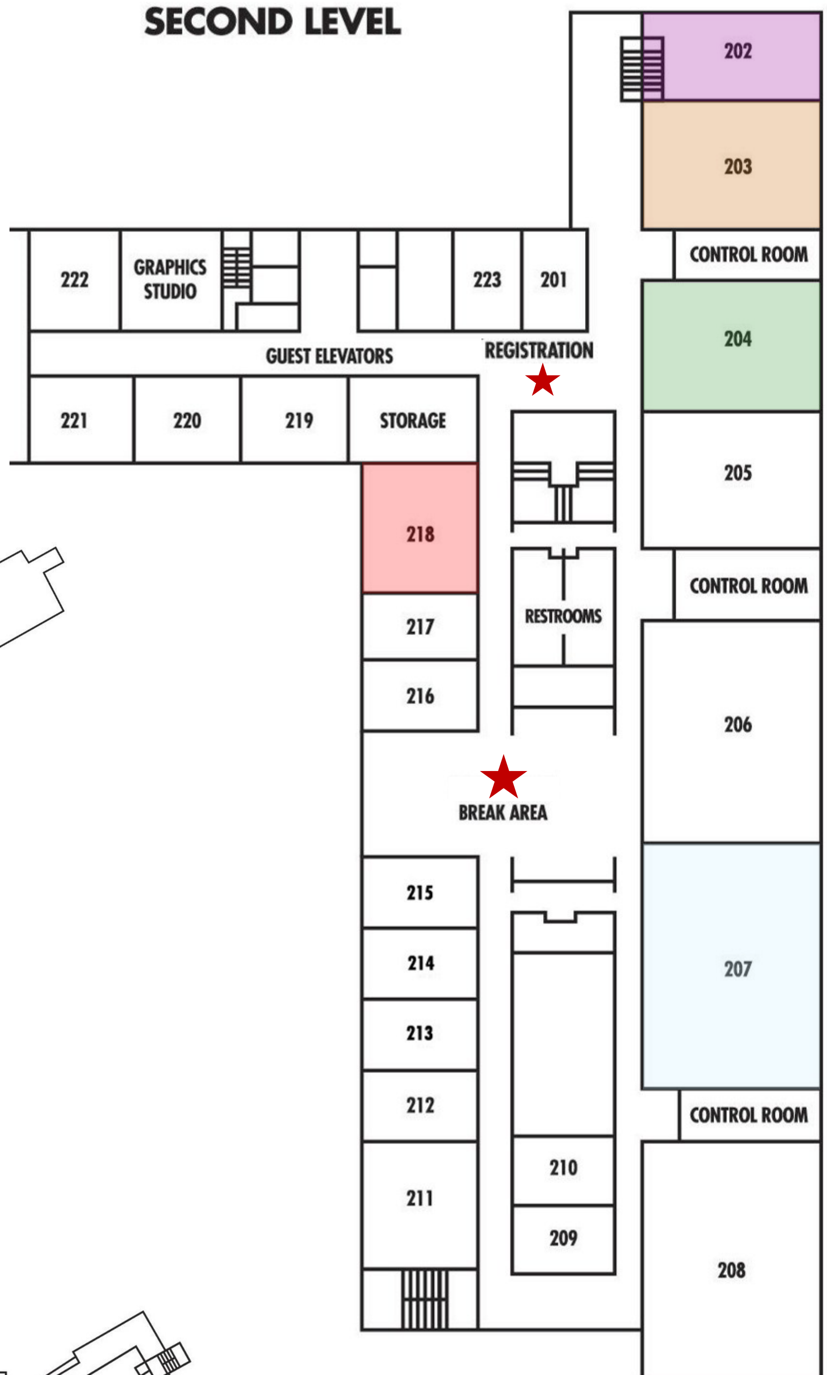
At the 7th RBDC Conference, we are very excited to have two keynote speakers: Professor Vivian Loftness, Paul Mellon Chair in Carnegie Mellon University's School of Architecture, will speak on "Environmental Surfing at Home for a Resilient Future" on Wednesday morning. Then on Thursday morning, Graham Finch, senior building science specialist at RDH Building Science Inc., will present "Lessons in the Development of Innovative Prefabricated Façades for Mass Timber Buildings."

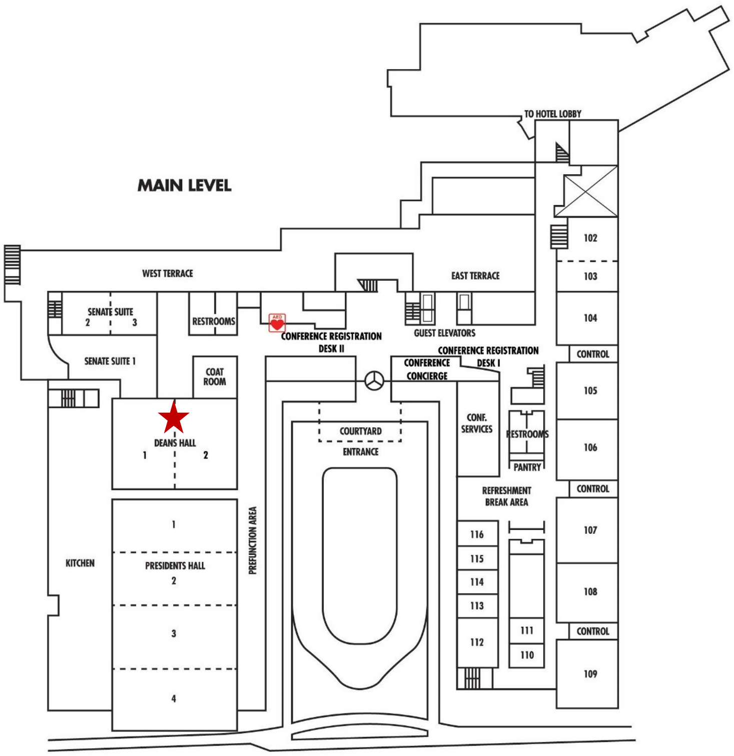
Being more about research and development, advancements in technology, materials, design, construction, and case studies, most of the presentations at the RBDC conference are by university professors, researchers, graduate students, architects, consulting engineers, product manufacturers, and product related associations or councils.

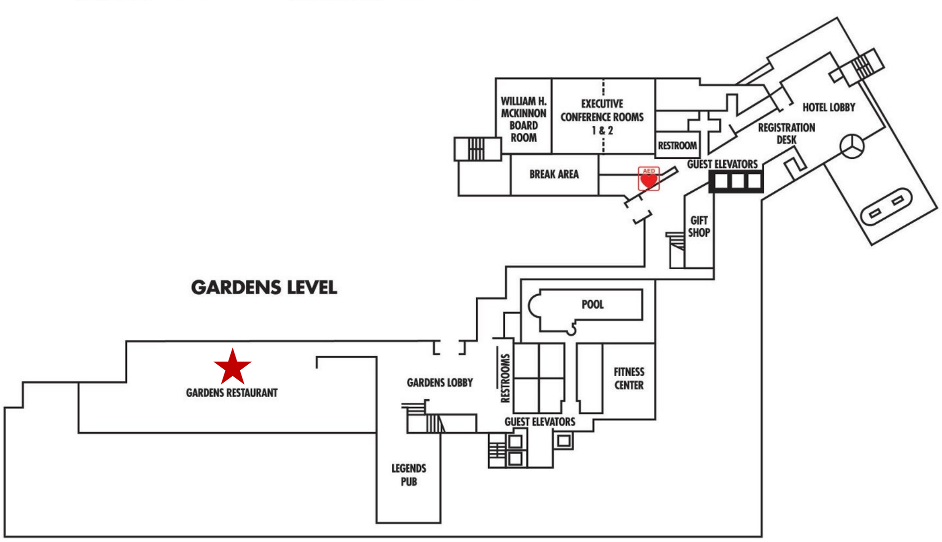
Files for the RBDCC, including the full conference proceedings, will be made available as we receive them at this link, RBDCC, and on the PHRC website after the conference. I hope that you find the technical content of the conference of value to you and your organization. I also encourage you to use the available opportunities at both conferences for
interaction and networking with colleagues.

Ali Memari, Ph.D., P.E., F.ASCE, Professor
2024 RBDC Conference Chair
Bernard and Henrietta Hankin Chair in Residential Building Construction
Director, Pennsylvania Housing Research Center (PHRC)
Department of Architectural Engineering and Department of Civil and Environmental Engineering
The Pennsylvania State University

Facility Maps







Wednesday, March 27 Schedule

8:15 AM Opening Remarks: Dr Ali Memari

8:30 AM Keynote: Vivian Loftness, "Environmental Surfing at Home for a Resilient Future," Room xxx

10:00 AM Break with Exhibitor Plus Sponsors and Snacks, Break Area

10:30 AM

Building Envelope | Building Science
Room 204

Moisture Control with Continuous Insulation
Justin Koscher and Marcin Pazera

Hello Ci, Meet Windows and Siding. Now Get Along!
Jay Crandell

In-Situ Field Study and WUFI Simulation of the Hygrothermal Performance of a Cross-Laminated Timber/Wood Fiber Insulation Building Assembly
Liam O'Brien, Jake Snow, Ling Li and Benjamin Herzog

Aging in Place
Room 203

A Net-Zero Energy Aging-in-Place Solar-Powered House Design
Hessam Taherian, Rahman Azari and Lisa Iulo

How Did the COVID-19 Pandemic Affect the Shared Living Model for Aging in Place: Case Studies in British Cohousing Communities
Jingjing Wang

12:00 PM Lunch, The Gardens

1:00 PM

Building Envelope | Airtightness
Room 204

Study on Airtightness of Partition Walls between Adjacent Residential Units
Michal Bartko, Travis Moore, Heather Knudsen and Iain Macdonald

Commercial Whole Building Airtightness Testing ....Don't Be Scared!
Adam Ugliuzza

Methods for Detection and Quantification of Building Leaks Using Background-Oriented Schlieren Imaging
Gurneesh Jatana, Philip Boudreaux and William Partridge

Healthy Homes
Room 203

Impact of Light Level on Physical Self-Maintenance of Elderly Dementia Patients in Care and Attention Homes
Mei-Yung Leung and Yueran Li

A Review of Relationships Between Residential Environments and Human Health
Tasneem Tariq, Sina Memarian, Lisa Domenica Iulo and Rahman Azari

Understanding How Different Building Designations Impact Conscious and Unconscious Evaluations of Housing Developments
Isabella Douglas and Sarah Billington

2:30 PM Break with Exhibitor Plus Sponsors and Snacks, Break Area

3:00 PM

Building Envelope | Building Science
Room 204

Window/Door Condensation: Practical Insights on In-Service Performance
Hamid Heidarali

Microwave Radar for Non-Destructive Quantitative Moisture Content Measurement of Critical Envelope Materials
Philip Boudreaux, Stephen Killough and Diana Hun

Rapid Decarbonization of Residential Construction by Novel Foundation Methods
Daniel Hindman and Joseph Loferski

Building Design & Climate
Room 203

Building Integrated Photovoltaic and Cool Roof Passive Ventilation Strategy in the Refurbishment of Existing Buildings: a Case Study in Italy
Silvia Brunoro, Giacomo Bizzarri, Laura Ferrari and Enrica Boldrin

Integrated Design for Environmental and Climate Justice Research, House 360
Jessica April Ward

Embodied Carbon Evaluation and Comparison of Prefabricated Façade Panels
Samantha Leonard and Graham Finch

5:00 PM Networking on the Exhibit Floor, Deans Hall

MEP
Room 202

Ductless Heat Pump Energy Monitoring in a Cold Climate
Vanessa Stevens, Rachel Dodd, Andrew Worthman, Tom Marsik and Jessica Biddle

Lessons Learned from Demand Control Ventilation in Commercial Buildings and Their Application to High-performance Residential Buildings
Niloufar Ghazanfari and Georg Reichard

Evaluation of Artificial Neural Network and Multiple Linear Regression Models for Indoor RH Prediction of a Residential Building in a Marine Climate
Yina Shang and Fitsum Tariku

Housing & Society
Room 218

Challenges in Mixed Methods Research: Data Collection and Assessment of IAQ in Low-Income Households
Ramyar Tajik and Simi Hoque

A "Connected Communties" Approach to Delivering Value to Builders, Property Owners, Utilities, and Customers
Ari Rapport

Residential Construction Education
Room 202

Online Programs in Residential Buildings Energy-Efficiency: Curriculum Design, Development, and Delivery
Omar Al-Hassawi

Reimagining How We Live: The HUD Innovation in Affordable Housing Competition
Joe Colistra and Nilou Vakilbahrami

Residential Construction Education
Room 202

Alley House: Educational Highlights from Ball State University's 2023 Solar Decathlon Build Challenge Project
Tom Collins

Globalizing Construction Education: Study Abroad Course on Residential Construction
Atefeh Mohammadpour and Gareth Figgess

Thursday, March 28 Schedule

8:15 AM Opening Remarks: Dr Ali Memari

8:30 AM Keynote: Graham Finch, "Lessons in the Development of Innovative Prefabricated Façades for Mass Timber Buildings," Room xxx

10:00 AM Break with Exhibitor Plus Sponsors and Snacks, Break Area

10:30 AM

Building Envelope & Energy Efficiency
Room 204

A Comparative Analysis of Five Residential Wall Assemblies to Assist in Design of a Zero Energy Home
Jonathan Bluey, Philip Agee and Andrew McCoy

A Comparison of Single Family Home Energy Usage Based on Exterior Wall Assemblies and Insulation
Ben F. Bigelow, Somik Ghosh and Francesco Cianfarani

Guidance for the Evaluation and Early-stage Design of Mass Timber and Hybrid Mass Timber Floor Systems
Samantha Leonard and Ryan Solnosky

Disaster Resiliency
Room 203

State-of-the-Art Review of the Performance of Residential Structures under Tornado Effects
Wei Tong, Ali Memari and Corey Griffin

Assessing the Seismic Performance of Non-Code Compliant Wood Shear Walls
Polly Murray and Scott Hamel

Quantifying the Wind Performance of Manufactured Homes
Elaina Sutley, Afeez Badmus, Arindam Chowdhury, William Collins, Thang Dao, Amal Elawady, James Erwin, Jonathan Hankins, Omar Metwally, Victor Onyia and Ioannis Zisis

12:00 PM Lunch, The Gardens

1:00 PM

3D Printing
Room 204

Interface Behavior between Two 3D-Printed Concrete Layers under Different Loading Conditions
Pedram Ghassemi and Natassia Brenkus

Enabling Formwork-Free 3D Printing of Spanning Roof Structures Using Multi-Directional Slicing to Decrease the Printing Angle
Nusrat Tabassum, Jose Duarte, Shadi Nazarian and Nathan Brown

A Platform to Support the Design of 3DCP Housing Solutions: Development, Validation, and Fabrication of Smart Wall Patterns
Jose Duarte, Gonçalo Duarte, Nate Watson, Sven Bilen and Shadi Nazarian

Disaster Resiliency
Room 203

Sustainability and Resilience Policy Simulation Modeling for Post-Disaster Residential Building Reconstruction
Linda Waters, Allison Reilly and Roshanak Nateghi

Understanding the Complexities of Evacuation Choices for Home Owners in Response to Natural Disasters
Sandeep Langar

Underground Stormwater/Rainwater/Thermal Storage Tanks: Solving Three Problems with One Solution
Edward Louie

2:30 PM Break with Exhibitor Plus Sponsors and Snacks, Break Area

3:00 PM

Building Materials & Hempcrete
Room 204

Incorporating Carbon-Negative Hempcrete in 3D-Printed Eco-Friendly Residential Houses
Eden Binega Yemesegen and Ali M. Memari

Getting Real with Hemp in Residential Construction
Michael Gibson

Assessing the Thermal Performance of Bio-based Building Materials for Sustainable Building Construction
Rui Zhang, Andre Desjarlais and Emishaw Iffa

High-Performance Housing
Room 203

Evaluation of Wind Effects on Ballasted PV Panels
Houssam Al Sayegh, Arindam Chowdhury, Ioannis Zisis and Amal Elawady

Alley House: Using Phius Certification to Leverage Solar Decathlon Performance
Walter Grondzik, Tom Collins and Pam Harwood

Evaluation Approaches for Energy and Carbon Target Achievement in Single-Family Homes
Jie Li, Lisa D. Iulo and Ute Poerschke

5:00 PM Networking on the Exhibit Floor, Deans Hall

Housing & Affordability
Room 202

Designing Affordable Apartments for Changing Demographics in South Africa
Gerald Steyn

A Comparative Analysis of UK Sustainable Housing Standards
Mahmoud Alsaeed, Karim Hadjri and Krzysztof Nawratek

Understanding How Different Building Designations Impact Conscious and Unconscious Evaluations of Housing Developments
Isabella Douglas, Arash Tavakoli, Draper Dayton and Sarah Billington

3D Printing
Room 218

3D Printing of "Clay-Hemp" Sustainable Structures for Residential Construction
Eden Binega Yemesegen and Ali M. Memari

Potential Use of Granulated Cork as Sand Replacement in the Design of Eco-Friendly Lightweight 3D-Printed Concrete
Hanbin Cheng, Aleksandra Radlińska, Ali Memari, Jose P Duarte, Sven Bilén and Shadi Nazarian

Enabling Concurrent Reinforcement During 3D Concrete Printing (3DCP) to Create Spanning Structures Using Tensile Cables
Ali Baghi, Shadi Nazarian and Jose Pinto Duarte

Housing & Affordability
Room 202

Challenges and Opportunities for Basic Efficiency Measures in Low-Income Homes
Vanessa Stevens, Georgina Davis, Rachel Dodd and Robert Tenent

Redlining's Impact: An Exploratory Study on the Long-Term Effects of Historical Housing Policies on Marginalized Communities in Denver
Mitali Vaidyanath, Rodolfo Valdes-Vasquez and Erin Arneson

Balancing Cost and Performance in Affordable Homes: A Case Study in Data-Driven Decision Making
David Hinson, Mackenzie Stagg and Elizabeth Farrell Garcia

Structural Design & Wind Loading
Room 202

Enabling Accessible Design of Complex Concrete Structures Using Real-Time Iterative Design, Visualization, and Analysis
Mohamed Ismail

Study of Wireless Pressure Sensors Casing Effects in Full-size Wind Tunnel Measurements
Jian Zhang and Chelakara Subramanian

Implications of Vertical Interaction of Separated Airflows on Wind Pressures Experienced by Building Structures
Chia Mohammadjani and Ioannis Zisis

Wednesday, March 27 | 8:30 am

Environmental Surfing at Home for a Resilient Future

Vivian Loftness
FAIA, LEED AP, CPHC, Design Futures, NIBS Fellow
University Professor, Paul Mellon Chair
Carnegie Mellon University School of Architecture

Goals for zero carbon, zero energy, and environmental effectiveness do not demand stylistic responses for home designers, beyond a critical commitment to celebrating the materials and climate inherent to place, to sailing over yachting, to wind surfing over jet skiing. Engaging the environment that we live in by "environmental surfing" makes our home a continuous celebration of the seasonal qualities of nature and life itself. Environmental surfing merges the built and natural landscapes uniquely for each climate and culture, creating views, managing sun and shade, regenerating our water resources, and ensuring the diversity of place. Environmental surfing captures both the skill and the excitement of designing and operating our buildings and communities with the full complement of nature's resources—abundant, renewable, and varying over time of day and season.

Thursday, March 28 | 8:30 am

Lessons in the Development of Innovative Prefabricated Façades for Mass Timber Buildings

Graham Finch

Dipl.T, MASc, PEng
Principal, Senior Building Science Specialist
RDH Building Science Inc.

While there is an increasing interest in the use of mass timber for structural systems of buildings, there is relatively much less discussion on the use of such emerging construction material for building envelope systems. In this presentation, Graham will talk through the process of what it actually takes to design, develop and test new façade systems like curtainwall and prefabricated panels to meet the rigorous requirements for high-rise commercial and residential buildings including fire, wind, earthquakes, and moisture durability, but then for carbon and aesthetic reasons, build them out of mass timber.

BUILDING ENVELOPE | BUILDING SCIENCE ROOM 204

Wednesday, March 27 | 10:30 am-12:00 pm

Moisture Control with Continuous Insulation

Justin Koscher and Marcin Pazera, Polyisocyanurate Insulation Manufacturers Association

The problem with bad or inaccurate information is that it is often repeated so many times that users begin to believe it is true. It happens a lot in the construction industry as building practices change and evolve overtime. Unfortunately, CI is often victim to this common problem of misleading information. This presentation will breakdown the myths of using CI in colder climates, demonstrate how CI can be used to effectively manage moisture risk in walls by controlling bulk water as well as water vapor transported by diffusion and air movement, and provide guidance on how to calculate the proper R-value to leave moisture problems in the rearview mirror.

Hello Ci, Meet Windows and Siding. Now Get Along!

Jay Crandell, ABTG / ARES Consulting

Continuous insulation (ci) is often considered the new kid on the block when it comes to insulation methods. But, it has been used effectively for energy code compliance and integrated with windows and siding since the 1970s. Much has progressed since that time with new research and new code provisions and technical resources to effectively integrate siding and window components with continuous insulation on exterior walls. This presentation will provide details, options, and guidance to help ensure code compliance, minimize cost, and maximize installed performance.

In-Situ Field Study and WUFI Simulation of the Hygrothermal Performance of a Cross-Laminated Timber/Wood Fiber Insulation Building Assembly

Liam O'Brien, Jake Snow, Ling Li and Benjamin Herzog, University of Maine

Hygrothermal performance of external wall and roof envelopes greatly impacts the durability, safety, comfort, and energy requirements of a building. In recent years, emphasis on maximizing the thermal efficiency of new buildings has increased significantly, leading to design and construction of larger wall thicknesses. These increases in thermal insulation can lead to a greater risk of interstitial condensation, potentially causing mold, fastener corrosion, condensation, and material degradation. The objective of this study was to evaluate the hygrothermal performance and durability of a building system constructed from cross-laminated timber (CLT) and wood fiber insulation (WFI). In our study, WFI is a type of thermal insulation derived from mechanically fibrillated softwood chips; the first domestic manufacturer of this product has recently begun production in Madison, ME. These hygroscopic materials allow water vapor to flow between indoor and outdoor spaces, resulting in improved moisture tolerances even in climates with strong seasonal variation; thus increasing occupant comfort. A one-story school building, located in Belfast, Maine, was selected for monitoring and instrumented for temperature (°C), relative humidity (RH) (%), and wood moisture content (%) measurement during panel fabrication. Sensor clusters were installed in the north- and south-facing walls (R-40) as well as the roof (R-60). This building was first introduced at the 2022 RBDCC conference. Since that time, data, collected over a one-and-a-half-year period, were used to validate a one-dimensional hygrothermal WUFI model before performing a long-term durability assessment. Results showed that the model sufficiently predicts the temperature and moisture profiles in the wall assemblies and therefore the simulated temperature and RH results can be used to evaluate the mold growth risk for an extended time period (i.e., 5 to 10 years). Understanding the performance of these assemblies will be used to assist in the design of highly thermally efficient wall assemblies using wood fiber insulation.

Wednesday, March 27 | 10:30 am-12:00 pm

A Net-Zero Energy Aging-in-Place Solar-Powered House Design

Hessam Taherian, Penn State Harrisburg; Rahman Azari, Penn State; and Michael Warren, AECOM

The aging population is growing worldwide, and there is a need to address the unique spatial needs of the elderly. In this paper, the authors report on the Penn State University entry for the 2023 Solar Decathlon Build Challenge competition, in which students, faculty, and professionals collaborated in the design and development of a small, modular high-performance housing option for the elderly. The proposal, which was recognized and received a $50k grant from the US Department of Energy, characterizes a high-performance building skin and an energy-efficient mechanical system, yielding an energy use intensity (EUI) of 20.2 kBtu/ft^2, embodied carbon intensity of 571 kg CO_2/m^2, and energy generation of 7,500 kWh annually with a 6-kW PV array at a 23-degree tilt angle.

How Did the COVID-19 Pandemic Affect the Shared Living Model for Aging in Place: Case Studies in British Cohousing Communities

Jingjing Wang, The University of Sheffield School of Architecture

In the last three years, the global COVID-19 pandemic has become one of the most frequently searched topics globally. It has had and continues to have a dramatic impact on almost every aspect of people's lives. During the long period of lockdown people –particularly older generations – began to think about the meaning and advantages of a shared/collaborative living model (cohousing) for aging in place, meanwhile, evaluating the most fundamental social needs in our daily life. This study takes three British cohousing communities as case studies: Lancaster cohousing, LILAC (Low Impact Living Affordable Community) and Cambridge K1 cohousing. The research employs qualitative interviews and content analysis as the main research methods. The findings of this research revealed detailed 'COVID- related coping strategies', including both physical and social measures, in cohousing communities in the UK. Meanwhile, this study found the social need is the most crucial factor of attracting older generation to join a cohousing; however, the global pandemic has permanently changed their social pattern in the cohousing communities examined here to some extent; some of the older members are still facing challenges in post-COVID period. Finally, cohousing communities exhibit a strong degree of social and physical resilience due to its unique neighbourhood layout, social structure, and principles during the global pandemic. By analysing the data, this study proposed that a pre-arranged management plan for cohousing communities to deal with possible future crises is essential. How cohousing groups respond to global pandemics can serve as a significant reference for understanding basic needs of older residents. At the same time, the conflicts between social interaction and potential health risks become valuable indicators for producing a more 'balanced' future neighbourhood design and management scheme for cohousing in the UK.

Wednesday, March 27 | 10:30 am-12:00 pm

Ductless Heat Pump Energy Monitoring in a Cold Climate

Vanessa Stevens, Rachel Dodd, Andrew Worthman, Tom Marsik and Jessica Biddle, National Renewable Energy Laboratory

In 2018, the City and Borough of Juneau, Alaska, set the goal of reaching 80% renewable energy for heating and transportation by 2045. An important factor to help reach this goal is energy-efficient home heating technologies such as ductless air-source heat pumps (DHPs), which rely on the local hydropower electric grid to provide space heating for an entire home or a main living area. To help residents reduce energy costs and move toward the community renewable energy goal, a team of local, state, and national partners joined together to run Thermalize Juneau 2021, an energy campaign that provided education, a simplified installation process, and a bulk purchase discount. Overall, the campaign enrolled 165 participants, resulting in 75 DHP installations and over 30 other energy efficiency improvements. To evaluate the reliability and energy use of the DHPs installed during the Thermalize Juneau campaign, researchers installed energy monitors on heat pumps of 14 participants and conducted interviews with homeowners. Data from two heating seasons (2021–2022 and 2022–2023) allowed researchers to examine the accuracy of pre-campaign energy savings predictions, establish energy savings for a small group of households, and provide insights on the energy use and occupant satisfaction of DHPs, which will help inform future heat pump deployment efforts in the area.

Lessons Learned from Demand Control Ventilation in Commercial Buildings and Their Application to High-performance Residential Buildings

Niloufar Ghazanfari and Georg Reichard, Virginia Tech

Historically, in residential buildings in the U.S., designers saw no need for mechanical ventilation, due to relatively high infiltration rates and the option of manual ventilation through operable windows. Building practices today have moved to more stringent performance mandates including greater airtightness as enhanced energy efficiency becomes a priority. High-performance buildings, such as Passive House and Net-zero energy buildings, highly require air-tight building enclosures, where extremely low rates of infiltration can lead to indoor air quality (IAQ) issues and require additional mechanical ventilation to maintain adequate IAQ levels without sacrificing energy efficiency. In any case, uncontrolled incoming air through infiltration may not be adequately tempered and dehumidified, which can lead to additional indoor air quality issues, ranging from condensation to mold and rot. As ventilation needs became a more defining factor in terms of energy efficiency, the focus shifted to advanced ventilation technologies, such as heat recovery or energy recovery systems. Mixed-mode ventilation has also attracted the attention of researchers, as it combines the best features of natural and mechanical ventilation and offers significant benefits for reducing energy consumption, especially in retail buildings. However, the intricacy of the involved systems and the associated air flows, as well as disturbances in the indoor and outdoor environments, make it a difficult endeavor. Demand control ventilation is another measure in this direction and is mostly employed in commercial buildings. The focus of this study is to investigate the most prevalent technologies and approaches used for demand control ventilation and evaluate their application for residential buildings across different climates. This study aims to provide insights into how demand control technologies could help further the energy efficiency of ventilation systems in high-performance residential buildings.

Evaluation of Artificial Neural Network and Multiple Linear Regression Models for Indoor RH Prediction of a Residential Building in a Marine Climate

Yina Shang and Fitsum Tariku, BCIT

Effective indoor RH prediction models are needed to be able to accurately assess the moisture performance of buildings and optimize HVAC controllers for improved building durability, energy efficiency, and occupant comfort. Consequently, the development of prediction models using artificial neural networks (ANNs) has emerged due to their promising forecasting ability. This paper addresses a research gap concerning the application of ANNs for indoor RH predictions in residential buildings. ANN models are trained and tested using over one year of indoor and outdoor climate data collected from an apartment suite located in the marine climate of Vancouver, Canada. Given that in a residential setting, occupancy does not follow a set schedule, and therefore the RH patterns may change throughout the year, the performance of the models is evaluated for each season. The ability to forecast the indoor RH up to six hours into the future was evaluated in comparison with multiple linear regression (MLR) analysis. In general, the ANN models outperformed the MLR models, however, the MLR model performance was comparable when past input conditions were included as input variables, indicating the importance of input selection for MLR models. The performance of both the ANN and MLR models was relatively poor during the winter and improved in the increasing order of spring, fall, and summer likely due to differences in outdoor air exchange rate resulting in varying the influence of outdoor climate and occupant activity. As a result, it appears that forecasting models applied to residential buildings should be evaluated at different times of the year.

Networking on the Exhibit Floor

Wednesday 5:00-7:00 pm in Deans Hall

After educational sessions end for the day, stop by for a networking reception with exhibitors! It will be a fun time to catch up with excellent people, food, and drinks!

Check out:

- Exhibits from your (or soon to be) favorite product manufacturers, suppliers, and professional services
- Networking with attendees from the RBDCC AND the PHRC Housing Conference
- Highlights from student competition teams
- Poster presentations from RBDCC attendees

Pre-registration required. See Alayna at the Registration Desk by 3:00 pm.

Wednesday, March 27 | 10:30 am-12:00 pm

Challenges in Mixed Methods Research: Data Collection and Assessment of IAQ in Low-Income Households

Ramyar Tajik and Simi Hoque, Drexel University

Indoor air pollution is a pressing public health concern, particularly in low-income households where residents are exposed to hazardous compounds and pollutants. However, collecting comprehensive data on indoor air quality (IAQ) in these households poses significant challenges due to limited resources and logistical constraints. This case study investigates the challenges and opportunities encountered in gathering IAQ data from 54 low-income households in Philadelphia, PA, with collaborations involving community and government organizations including an energy authority, a non-profit energy services provider, a neighborhood energy community, household members and academic researchers. Findings reveal key challenges encompassing limited resources, technical limitations, optimal monitor placement, monitoring of specific pollutants, and complexities associated with studying an underserved population. By employing targeted education and community engagement, researchers can overcome these challenges and acquire robust IAQ data. Implications of the study include the development of tailored interventions to enhance IAQ and promote healthier indoor environments in low-income communities. The insights gained contribute to the implementation of specific strategies to mitigate IAQ issues, guiding resource allocation and public health initiatives. This case study highlights the challenges and opportunities in collecting IAQ data from low-income households, emphasizing the importance of addressing these challenges to improve IAQ and well-being in underserved communities.

A “Connected Communities” Approach to Delivering Value to Builders, Property Owners, Utilities, and Customers

Ari Rapport, IBACOS, Inc.

According to the U.S. Department of Energy, a "connected community" is a "group of grid-interactive efficient buildings (GEBs) with diverse, flexible end use equipment and other distributed energy resources (DERs) that collectively work to maximize building, community, and grid efficiency while meeting occupants’ comfort and needs." In 2022, IBACOS and a team of industry leaders including Tierra Resource Consultants, Energy & Environmental Economics (E3), the National Renewable Energy Laboratory, Duke Energy, Meritage Homes, Elevation, and others kicked off a 4-year project to create and evaluate a 1,000-home connected community in North Carolina to define successful business models that will scale winter peak grid services from distributed energy resource (DER) measures situated in homes. Winter peak is a growing issue for utilities that are pursuing clean energy goals, and utility decarbonization plans are driving increased adoption of renewable generation and electrification that will exacerbate winter peak issues. Winter peak will also be driven by climate actions plans adopted by cities and states. Electric utilities have much less experience with winter peak focused demand response (DR) and demand-side management (DSM) programs, and new program designs are needed for new home construction and existing home retrofits to drive winter peak solutions successfully and cost-effectively into the market. The Advanced Clean Communities Collaborative (AC3) project, led by IBACOS, is addressing these needs, and this presentation will provide an overview of the project and updates on project activities and lessons learned to date.

Wednesday, March 27 | 1:00-2:30 pm

Study on Airtightness of Partition Walls between Adjacent Residential Units

Michal Bartko, Travis Moore, Heather Knudsen and Iain Macdonald, National Research Council Canada

In North America partition walls between adjacent residential units in row-house and multi-unit buildings are commonly a double wood stud construction. Existing building codes define several requirements for this construction type, such as fire resistance, acoustical resistance. This study addresses the identified need to define airtightness requirements of partition walls in codes. Adding to its significance, the study also addresses the growing concern of contaminants transfer such as kitchen fumes, tobacco and/or cannabis smoke etc. between adjacent units. An air leakage test facility able to accommodate the specimen size of 2.4 x 2.4 m was used to identify leakage of several partition wall assemblies, consisting of: 1) double stud wall (DSW) with airtight drywall approach air barrier (AB), 2) DSW with one polyethylene sheet AB; 3) DSW with two polyethylene sheets AB; 4) DSW with two spun bonded polyolefin (SBPO) membranes AB. Due to the lack of a test protocol for the laboratory experiments, the ASTM E2357 standard test protocol was used. The results varied from 0.005 to 0.3 L/(s m2) at a pressure difference 75 Pa (0.003 to 0.26 L/(s m2) at a pressure difference 50 Pa), and will serve as an input for a proposal for the future code considerations for the partition wall construction airtightness requirements, including defining appropriate assemblies and their corresponding air leakages.

Commercial Whole Building Airtightness Testing ...Don't Be Scared!

Adam Ugliuzza, Sustainable Building Partners

Building air barriers are now being recognized for more than to simply save energy. Building airtightness is also key to moisture management, proper operation of mechanical equipment, control of exterior air borne contaminates/pollution, indoor air quality, and comfort. Airtightness plays a significant role in reducing greenhouse gas emissions and moving the industry to Net Zero, passive building construction. But how do we measure and verify the airtightness of building? The answer is whole building airtightness testing, commonly known in the residential space as "blower door testing." This presentation will dispel many of the myths around whole building airtightness testing, walk through a typical test and provide guidance on what to do if you do not meet the air leakage rate required. An overview of the current industry standards will be provided, specifically ASTM E3158, Standard Test Method for Measuring the Air Leakage Rate of a Large or Multizone Buildings recently developed by members of the Air Barrier Association of America (ABAA) for larger more complicated commercial building construction. The intent is for ASTM E3158 to supersede current industry standards like ASTM E779, Standard Test Method for Determining Air Leakage Rate by Fan Pressurization. Its purpose, to improve testing accuracy and repeatability. Lastly, the topic of training and certification will be discussed. To universally adopt mandatory whole building airtightness testing in building codes, it is very important that there are enough qualified testing agencies able to service the industry. In 2022, ABAA launched a training and certification program for Blower Door Technicians to help the industry achieve widescale accurate and accessible testing. An overview of the ABAA training and certification program will be presented including information about how this program is set apart from current industry training available.

Methods for Detection and Quantification of Building Leaks Using Background-Oriented Schlieren Imaging

Gurneesh Jatana, Philip Boudreaux and William Partridge, Oak Ridge National Laboratory

Air leakage is a significant contributor to the energy inefficiency in buildings. Identifying and repairing leaks through the building envelope can not only improve the energy efficiency and moisture durability of the building stock but also improve occupant comfort through improved air quality. Current 'blower door-based' approaches used to identify air leakage in buildings can be time consuming, are difficult to apply to large buildings, and disruptive to building occupants. This presentation discusses the adaptation of the background oriented schlieren (BOS) imaging technique to detect and quantify air leakage through building envelopes. BOS relies on the changes in refractive index induced by temperature gradients in the air when the air infiltration or exfiltration is at a different temperature than the ambient air. When such refractive index gradients occur between a textured background (e.g. wall) and an observing camera the resultant light refraction induces shifts in the background texture and allows for detection and quantification of the leakage. Oak Ridge National Laboratory has previously shown that visualization of leakage through exterior building claddings with sufficient texture or contrast is possible. Further development in measuring the velocity of air leakage, a critical step in estimating the volumetric flow of leaks, is presented here.

Wednesday, March 27 | 1:00-2:30 pm

Impact of Light Level on Physical Self-Maintenance of Elderly Dementia Patients in Care and Attention Homes

Mei-Yung Leung and Yueran Li, City University of Hong Kong

The physical self-maintenance has performed essential function to ensure individual well-being and self-esteem, especially for elderly dementia patients in care and attention homes. Light level, which supports various daily activities, may contribute to promoting one's capacity of physical self-maintenance. This study aims to explore the influence of light level on different aspects of physical self-maintenance among elderly patients with dementia in care and attention homes. Four types of light level (i.e., natural lighting, daytime artificial lighting, nighttime artificial lighting, and task lighting) and five activities of physical self-maintenance (i.e., toilet use, bathing, dressing, feeding, and moving) were identified. Based on the questionnaire survey with the elderly dementia patients from eight care and attention homes, the relationships between physical self-maintenance and light level in care and attention homes were revealed by correlation analysis: 1) bathing is positively influenced by natural lighting and artificial lighting; 2) nighttime artificial lighting has positive effect on moving; 3) no significant relationships were founded between other physical self-maintenance activities (i.e., toilet use, dressing, feeding) and light level. Practical recommendations were put forward accordingly, including the size and material of windows for introducing natural lighting, suggested illuminance in different areas and periods for fulfilling dynamic needs, types of light sources, etc.

A Review of Relationships between Residential Environments and Human Health

Tasneem Tariq, Sina Memarian, Lisa Domenica Iulo and Rahman Azari, Penn State

Urban health is a field of research and practice in various disciplines that investigates the analogy between the built environment and human health. Relatedly, energy efficiency can have profound implications on human and global environmental health. Several studies have been conducted to analyze the dynamics between these variables. However, not much is known about how much a healthy efficient home can contribute to the mental and physical health of low-income residents. Therefore, a systematic literature review of selected journals has been conducted for this study focusing on energy consumption in residential buildings as well as building and human health in the case of low-income solutions. Studies show that efficient use of energy promotes human health and sustainable economic development. A study by Grey et al shows that cold inefficient homes contribute to poor physical and mental health and that interventions in poor-quality housing may lead to health improvements. In another study, Calthorpe shows that rather than providing a checklist of new energy sources, an integrated approach of home improvements, innovative design strategies, and forward-thinking policies are needed to create a transition to a low-carbon economy and lifestyle benefits. Another investigation of the short-term health and psychosocial impacts of a domestic energy efficiency program reveals that, though the program was not associated with reductions in self-reported respiratory and asthma symptoms in the short term, it was associated with improved subjective well-being and improvements in psychosocial outcomes, including increased thermal satisfaction, reduced reports of putting up with feeling cold to save heating costs and fewer financial difficulties and reduced social isolation in the long run. Another housing insulation and health study with cost-effective interventions to improve the characteristics of ill-fitted older homes reveals that insulating houses have significantly improved the occupants' health and well-being as well as household energy efficiency. As the indoor temperatures increased and levels of NO2 were halved, less poor health in children was reported, including lower levels of asthma symptoms and sleep disturbances from wheezing and dry coughs, as well as fewer missed days from school. This study examines the relationship between energy efficiency investments in homes in low-income areas and the impact on the mental and physical health of residents. This literature review reveals a number of psychosocial outcomes likely to be part of the complex relationship between energy efficiency measures and health outcomes. Interestingly, better living conditions can contribute to improvements in health outcomes in the longer term. In conclusion, healthy and energy-efficient residential environments are linked to a number of psychosocial intermediaries that are conducive to better health. Therefore, improving the energy efficiency of older housing can lead to health improvements and energy efficiency enhancements. Multidisciplinary studies are needed for low-income housing interventions to support policies for sustainable housing developments that will improve human health and well-being in the long term.

Understanding How Different Building Designations Impact Conscious and Unconscious Evaluations of Housing Developments

Eva Bianchi and Sarah Billington, Stanford University

There is an ongoing affordable housing crisis in the United States with every state and major metropolitan area having a sizable deficit of units for extremely low-income households. Any approach to tackling the affordable housing crisis will need to involve new construction developments, which are commonly subject to public comment during the typical entitlement process. Despite majority support of hypothetical increases to the affordable housing stock in those surveyed, local public opposition remains a major obstacle for proposed affordable housing developments in practice. Our study investigates what is contributing to this local opposition with the aim of offering solutions to reducing opposition through various strategies. As many development proposals are communicated to the public visually, we investigate how images impact public opinion and interact with other aspects of a development presented in accompanying written descriptions (i.e., if it is affordable, historic, or designed with a focus on environmental sustainability). We are conducting an online study with a between-subjects design where California residents are shown pairs of promotional and aerial images for a variety of affordable housing developments and asked to evaluate each development on several metrics including aesthetics and acceptance. Additionally, we employ webcam eye tracking to include an unobtrusive, unconscious measure of participants' engagement with the images. The results of this research provide insights into how the public's perceptions of building types, usage, and features that are cued by both images and descriptions impact their evaluation and acceptance of housing projects. A more nuanced understanding around public evaluations and reactions to housing developments can help inform strategies to address public opposition that delays or blocks crucial development proposals.

Wednesday, March 27 | 1:00-2:30 pm

Online Programs in Residential Buildings Energy-Efficiency: Curriculum Design, Development, and Delivery

Omar Al-Hassawi, Washington State University

This paper describes the curriculum design, development, and first year of delivery of new online educational programs in building energy efficiency, with a focus on residential occupancy. A review of existing educational programs across North America, focused on minimizing the built environment's impact on the natural environment, indicated that they are generally a broad survey of a wide range of topics, long-term post-professional degrees, and delivered in person. The proposed programs address these drawbacks and provide an interdisciplinary emphasis on energy-efficient residential buildings, covering all phases of the design process, from conceptualization through construction and post-occupancy evaluation. The curriculum is shaped by a series of learning modules that each focus on a specific topic. The modules are packaged into courses, and the courses are combined into three fully online offerings: an undergraduate certificate, a graduate certificate, and a professionally oriented master's degree. The certificates address four areas of knowledge (environmental control systems, building enclosure and structural systems, simulated performance data, and performance benchmarks), whereas the master's degree addresses three additional areas of knowledge (measured performance data, smart building systems, and comprehensive design). Seven courses have been delivered thus far, with positive initial feedback from the students. The first cohort of students completing the certificate are projected to graduate in the Spring semester of 2024.

Reimagining How We Live: The HUD Innovation in Affordable Housing Competition

Joe Colistra and Nilou Vakilbahrami, University of Kansas

The University of Kansas (KU) has participated in the US Department of Housing and Urban Development (HUD) Innovation in Affordable Housing Student Design and Planning Competition every year since 2015. HUD invites multidisciplinary teams of graduate students to explore social, economic, and environmental issues in responding to a specific housing problem developed by an actual public housing agency (PHA) (HUD, 2023). During this time, KU's School of Architecture & Planning have fielded over 40 teams of more than 200 students. KU teams have been named finalists or semifinalists in 2015, 2016, 2017, 2019, 2022, and 2023. The exercise offers three components rare to typical design competitions. First, a financial pro forma is required to be submitted to ensure a comprehensive building cost analysis has been conducted and understood. Competition deliverables include a design solution, financial pro forma, and written narrative. Second, a real client is involved. The sponsoring PHA hosts students from the finalist teams to visit the site, meet with PHA staff, and engage with residents currently housed in an affordable housing project. Third, finalist teams travel to Washington, DC to present their schemes to a panel of jury members at HUD headquarters. Winners are announced at the conclusion of the event. KU has offered this competition experience as part of a final-year design studio in conjunction with the NSPJ Endowed Housing Studio, the Social Entrepreneurship program, and the Downtown Lawrence Design Center. This paper will describe the structure of the HUD competition, the studio methodology, and the successes and challenges posed by the competition.

Window/Door Condensation: Practical Insights on In-Service Performance

Hamid Heidarali, Hamid Design Build

Condensation and frost on windows and doors are a nuisance for the occupants, especially in locations that experience cold winters. The industry practice of determining the condensation resistance of windows/doors is focused on the glazing assembly's thermal performance (frame, perimeter of the IGU, and the central part of the IGU), indoor relative humidity levels, and the temperature difference between inside and outside of a building. While this approach can provide a reasonable indication of the performance comparison of various windows and doors, it falls short in providing the complete picture of the influencing factors, and how they can impact the in-service moisture management of a given window or door as far as the control of condensation and frost is concerned. Based on a recently completed (February 2022), three-story building in Kamloops, Canada, this paper demonstrates how the combination of air leakage and interior blinds have led to sliding doors exhibiting condensation performance far from what was originally anticipated, and how these factors greatly compromised the thermal performance of otherwise highly thermally efficient sliding doors. More importantly, intuitive and insightful experiments show how the condensation and frost on the sliding doors was manifested differently in each level of the building. This paper underlines the importance of taking a holistic approach towards assessing the in-service condensation resistance of windows and doors, in particular the operable ones, and presents practical steps to greatly reduce the likelihood of similar occurrences. Furthermore, it necessitates the re-evaluation of the current methods of determining the window and door air leakage rates under the North American Fenestration Standard (NAFS). The findings and analysis of this paper are supported by physics, whole-house air tightness tests, smoke pencil tests, and infrared thermal imaging.

Microwave Radar for Non-Destructive Quantitative Moisture Content Measurement of Critical Envelope Materials

Philip Boudreaux, Stephen Killough and Diana Hun, ORNL

Measuring the moisture content of existing building envelopes, whether due to suspected water intrusion or to prepare for a retrofit, is critical in ensuring long-lasting durable buildings and enabling energy and emissions-saving retrofits. Current quantitative measurement techniques are destructive to the envelope because they require contact with the material. If wall sheathing is being measured a hole needs to be cut in the wall to gain access to the wood. Microwaves offer a unique solution because electromagnetic waves can pass through some materials and interact with moisture at specific frequencies. We will describe the development and testing of a microwave radar system that can "see" into the envelope to measure the moisture content of the wood sheathing. Data will be presented for oriented strand board sheathing, which is one of the most common wall sheathing materials.

Rapid Decarbonization of Residential Construction by Novel Foundation Methods

Daniel Hindman and Joseph Loferski, Virginia Tech

In order to fulfill many climate change goals, there is a need for rapid decarbonization strategies for buildings during the construction process. While green building strategies have placed a high emphasis upon energy efficiency goals, these efforts have been largely successful and will only continue to yield mild decreases in the remaining building carbon stock. A new emphasis needs to be placed on the embodied carbon present in the building materials themselves. The use of reinforced concrete in green buildings is a material which often goes unchallenged, since the role of concrete as an anchor and moisture protector is rarely questioned. However, the disproportionate carbon required to produce reinforced concrete must be interrogated if significant changes in buildings are to be made. The purpose of this paper is to explore foundation solutions which minimize or eliminate the use of reinforced concrete while still accomplishing the basic functions of anchorage and ground moisture protection. Both conventional and non-conventional solutions are explored, with a novel proposal for the use of mass timber elements for foundation solutions.

Building Design & Climate

Wednesday, March 27 | 3:00-4:30 pm

Building Integrated Photovoltaic and Cool Roof Passive Ventilation Strategy in the Refurbishment of Existing Buildings: a Case Study in Italy

Silvia Brunoro, Giacomo Bizzarri, Laura Ferrari and Enrica Boldrin, University of Ferrara Department of Architecture

The paper reports about an experimental case study in Italy: the energy retrofit of a complex of 10 rural buildings in the Province of Reggio Emilia. The environmental technical solutions have been studied "ad hoc" to improve energy efficiency of buildings, making them suitable for hydroponic and aquaponic greenhouses cultivation. The intervention has involved the removal of the asbestos layer and the installation of a new and more thermal performing roof with integrated photovoltaic modules, for a total Peak Power of 785.4 kWp (744,4 Btu/s). In particular, a new false ceiling has been studied to act as a thermal buffer, aiming at protecting the indoor volumes from external thermal fluctuations and radiation loads, reducing thermal losses in winter nights and mitigating heat gains in summer. The air gap will be used in summer and winter to regulate the internal temperature, ensuring in all seasons indoor optimal climatic conditions. The solution has been found very efficient and cost effective, with the addition of the environmental benefits given by the considerable electricity production allowed thanks to the PV plant.

Integrated Design for Environmental and Climate Justice Research, House 360

Jessica April Ward, Prairie View A&M University

The Prairie View A&M University (HBCU), School of Architecture, Integrated Design for Environmental and Climate Justice Research (IDEA-CJR) design studio strengthens resilience in previously segregated and historically significant communities in the Gulf Coast Region and the City of Houston most impacted by the compounded effects of environmental injustice over time. This regional disaster resilience research-based design studio in the Gulf Coast identifies and addresses stakeholder needs through an integrated architectural design course each year. Resident homes in the Gulf Coast are disproportionately negatively impacted during extreme weather events. Fourth-year architecture students in the IDEA-CJR studio conduct qualitative and quantitative stakeholder need assessments during pre-design meetings with seniors aging in place during and after extreme weather events associated with hurricanes, power grid failure, poor indoor air quality and flooding. Student designs of pocket communities with smart homes emerge from community-driven feedback, meetings with industry professionals and municipal leaders in Houston. The architecture students conducted applied research in energy efficient building envelope design with the goal of providing useful and sustainable benefits to those in the local and regional community. Students designed a climate responsive, hurricane-resistant, micro-housing prototype with renewable solar energy and also addressed climate justice issues in the Gulf Coast Region. IDEA-CJR is designed to serve the needs of a growing global environment awareness and meet the demands of energy efficient sustainable building design and built environment while mitigating climate change and environmental impacts in our society through service-learning curriculum.In 2018 the IDEA-CJR students were honored at the City of Houston Council with a *"Special Distinction for Building Community through Architecture"* award. One demonstration prototype home was built on campus through a three-year Department of Education, Title III grant and another iteration was built through partnership with Houston Habitat for Humanity. The 1 bedroom, 1-bathroom prototype was published in the 2021 *"City of Houston Planning & Development Department, Accessory Dwelling Unit Design Guide"* and received an award for best student design.

Embodied Carbon Evaluation and Comparison of Prefabricated Façade Panels

Samantha Leonard, Penn State; and Graham Finch, RDH Building Science

Innovative prefabricated façade panels are an ideal choice for mass timber buildings for several reasons. One reason is that prefabricated façades can contribute to lower embodied carbon (EC) by minimizing waste and improving design efficiency over more traditional site-built façades. However, there is limited guidance on evaluating and comparing façade panels for EC. This paper discusses strategies to evaluate panels for EC. The discussed methods are used to compare several case study panel designs for their mass and EC by using Environmental Product Declaration (EPD) data. The example panels cover a range of backup structure options, including those with varying mass timber panels, cold-formed steel framing, aluminum curtain wall framing, and precast concrete sandwich panels. Panels include equivalent options for windows, insulation, air and water control layers, and panel anchorage. The EC analysis compares panels to each other, as well as the share of panel components to overall EC, so that efforts to improve EC can be better targeted. This study found significant EC variation between façade panels. The mass timber and steel stud-framed panels offered the lowest-EC options. The concrete panel performed relatively well and has potential for improvement with more efficient designs. The aluminum system had the highest EC because of aluminum's high material EC despite its low weight. Finally, strategies to reduce panel EC are proposed.

Wednesday, March 27 | 3:00-4:30 pm

Alley House: Educational Highlights from Ball State University's 2023 Solar Decathlon Build Challenge Project

Tom Collins, Ball State University

In Fall 2021, Ball State University's College of Architecture and Planning entered the 2023 Solar Decathlon Build Challenge student design competition. The Alley House, a net-positive energy, affordable, duplex home, was designed and constructed during a 2-year process that engaged 105 students across 4 disciplines and involved community and industry partnerships. One of 11 competing projects at the Solar Decathlon Build event, the Alley House won the 1st place Overall prize. This paper presents educational highlights from the project. A core faculty advising team was involved throughout the process and met weekly to review progress and plan next steps. CAP ran the Solar Decathlon Build Challenge competition primarily through preexisting courses including undergraduate and graduate upper-level design studios. These courses were adjusted to accommodate a multi-semester design/build project. Also, community and industry partners were involved in working with the team on the technical design. The Alley House was almost exclusively funded by external sources, and the paper addresses how faculty and students worked with partners to secure grants, affordable housing financing, and material donations/discounts. Student team hand-offs between semesters were a particular challenge. Hiring student assistants allowed the team to maintain some continuity. CAP students worked with a general contractor on the the construction of the home, and lessons learned from the construction are shared. Finally, in addition to meeting the stringent and rigorous Solar Decathlon requirements/standards, Alley House also sought a PHIUS Core Prescriptive pathway certification, which exposed the team to the certification documentation and submission process.

Globalizing Construction Education: Study Abroad Course on Residential Construction

Atefeh Mohammadpour and Gareth Figgess, California State University Sacramento

To introduce residential construction concepts into an existing curriculum that is traditionally focused on commercial construction, the authors are developing a 6-week experiential learning opportunity for students to explore residential construction estimating, planning, and construction techniques. The course will include a 10-day study abroad experience in which students travel to a developing country to build a single-family home. For undergraduate students, studying abroad can be a transformative and life-changing experience, providing them with skills and experiences that will serve them both professionally and personally. Students will experience different cultures and construction practices while developing important skills such as teamwork, communication, and problem-solving. As a result of studying overseas, students gain a more comprehensive understanding of global issues and appreciate diversity and cross-cultural communication. This project is a work in progress and the course will be offered in Summer, 2024. Discussion will include the rationale for developing the course, challenges faced, and principles and methodologies employed for curriculum development. In addition, it will include building relationships with local building associations and foreign partners to facilitate the hands-on component of the course.

Thursday, March 28 | 10:30 am-12:00 pm

A Comparative Analysis of Five Residential Wall Assemblies to Assist in Design of a Zero Energy Home

Jonathan Bluey, Philip Agee and Georg Reichard, Virginia Tech

This research summarizes a student experiential learning project. The student project team, consisting of undergraduate and graduate architecture, engineering, and construction management students designed a single-family detached affordable home. During the iterative design process, simulations and physical prototypes were developed to inform system optimization decisions and support student critical thinking development. The goal of the project was to create a prototype net-zero house that combined modular construction in an industrial factory setting for mass production. This required the team to balance multiple criteria of wall performance, including thermal performance, cost affordability, and industrial and commercial design-build methods for construction. Five wall assembly designs were evaluated using multiple simulation and empirical methods. Evaluation methods included, techno-economic analysis, heat transfer modeling, whole house energy modeling, and steady state thermal lab testing. The data collected from this research assisted in the design selection criteria for the prototype house.

A Comparison of Single Family Home Energy Usage Based on Exterior Wall Assemblies and Insulation

Ben Bigelow, Somik Ghosh and Francesco Cianfarani, University of Oklahoma

Managing energy consumption in homes has been of increasing importance in the residential construction industry over the years. Various techniques, technologies, and construction methods have affected the energy consumption in homes over time. This study investigated an alternative building material for exterior wall framing, namely Insulated Concrete Form (ICF), in comparison to the most widely used option, wood framing. The initial comparison was carried out using eQUEST, a simulation software. Those results were then compared to actual energy usage data collected from a sample of occupided homes to validate or refute the results. Data were collected from five single-family homes for the comparison. In the model, the energy consumption for the ICF homes was 6% to 14% less than wood-framed homes. The results of the simulation were compared with actual electric consumption data collected from the homes after they were sold and occupied. The actual consumption was 30%-40% less in the ICF homes when compared to the wood-framed homes. The consistency of results when comparing simulated to actual consumption suggests that the energy model is conservative in its simulation, and perhaps that ICF walls are not adequately considered in energy modeling.

U.S. Design Guidance for CLT Floor Systems with Residential Occupancy Loads

Samantha Leonard and Ryan Solnosky, Penn State

There has been a recent market share expansion of mass timber structural usage for multi-family and mid- to high-rise apartment buildings over that of light framed construction due to mass timber's prefabrication capabilities, low embodied carbon (EC), aesthetics, ability to go taller, and for the potential to reduce construction schedules. Because modern mass timber structures are relatively new, practitioners are still learning how to properly select systems, navigate mass timber design provisions, and understand how design decisions affect the final design performance. While numerous design guides and tools are available for mass timber, few offer guidance at the early design stage when many key decisions are made. Further, none of the available tools link early-stage design guidance with decision effects on various design goals, such as reducing EC, limiting structural depth, and more. Based on parametrical modeling of mass timber floors, this paper includes design guidance for early decision making to inform goals of EC, fire design, structural depth, and mass.

Thursday, March 28 | 10:30 am-12:00 pm

State-of-the-Art Review of the Performance of Residential Structures under Tornado Effects

Wei Tong, Ali Memari and Corey Griffin, Penn State

There are approximately 1,200 tornado events that take place in the United States each year according to statistics from the National Oceanic and Atmospheric Administration (NOAA). Lack of proper resistance and poor performance of residential buildings under tornado effects can directly affect the safety of people due to potential damage to their homes. Based on the reports of tornado events in the US, there is an average annual loss of $982 million according to the insurance catastrophe data from 1949-2006. Furthermore, there is also a considerable risk of casualties due to accidents associated with tornadoes. Most of the residential buildings in regions known to be susceptible to tornadoes are not designed for tornado loading, which results in a high-risk level of casualties and property damage. The high cost of rebuilding is also a crushing task in the region after disaster recovery. To minimize such damage, it is necessary to develop an understanding of the common failure modes of residential structures under tornado loads. Accordingly, both after-disaster analysis and laboratory testing and performance simulation are needed to develop a more comprehensive understanding of the causes of failures to give suggestions for proper design, construction, and retrofit in high tornado-risk regions. From the comparison of different structural materials, roof systems, and construction details, more effective tornado-resistant structure characteristics can be formulated. Specifically, suggestions on material selection, geometric design, and construction details are made based on the overall analysis from previous data collections. The paper presents a review of different residential structure performances and available research related to the resistance of buildings under tornado effects.

Assessing the Seismic Performance of Non-Code Compliant Wood Shear Walls

Polly Murray and Scott Hamel, University of Alaska Anchorage

The seismic performance of wood stud-wall building components in low-rise residential construction have been widely tested and modeled, and design limits are established and codified in the various building codes. However, what about the performance of substandard or deficient construction? How will structures perform if not properly designed or constructed? This study conducted both laboratory testing of code-compliant and non-compliant wall components and assessed seismic risk using computational models and nonlinear dynamic analysis. The study was motivated by the wide variation of building code enforcement within the Municipality of Anchorage, Alaska coupled with the corresponding variation of damage that occurred in the 2018, a Mw 7.1 earthquake. This paper presents the procedures and results of the laboratory testing portion of this study. Anchorage contains a subset geographic area in which building codes have been actively enforced since the early 1990s, but many existing structures were built prior to building code enforcement, and a large portion of new construction occurs outside the bounds of the enforcement area. Outside of enforcement area, and prior to the onset of residential building code enforcement, evidence suggests that houses were and are sometimes built with framing and walls systems that lack all the necessary components or detailing to adequately resist the seismic forces imparted by design-level or larger earthquakes. These deficient systems may be due to either design or construction errors or omissions, or both. The extent to which these structural deficiencies affect the building's seismic resistance is unknown, and is the focus of this work. Laboratory testing includes cyclic loading of deficient walls to determine the nonlinear hysteretic responses of components.

Quantifying the Wind Performance of Manufactured Homes

Elaina Sutley, University of Kansas; Afeez Badmus, University of Kansas; Arindam Chowdhury, Florida International University; William Collins, University of Kansas; Thang Dao, University of Alabama; Amal Elawady, Florida International University; James Erwin, Florida International University; Jonathan Hankins, University of Kansas; Omar Metwally, Florida International University; Victor Onyia, Florida International University; and Ioannis Zisis, Florida International University

Manufactured homes have poor performance during major wind events and cause significant fatality counts. Manufactured homes are governed by a different code system than site-built housing. The design and construction processes are not well documented in the public domain and are nearly non-existent in the research literature. This presentation shares findings from a project funded by the Florida Division of Emergency Management aimed at developing a quantitative understanding of hurricane effects on manufactured housing. Moreover, the findings identify ways to make improvements in terms of both new design recommendations and retrofit strategies for existing structures. Common structural details for manufactured homes in wind speed Zones II and III were obtained from a major U.S. manufactured home producer with feedback from the U.S. Department of Housing and Urban Development. This presentation will share the most recent findings from integrated numerical and experimental research, including (1) aerodynamic wind load data (collected at the NSF NHERI Wall of Wind Experimental Facility (WOW EF) at Florida International University (FIU)) on small scale manufactured housing units in different mobile home park arrangements and in isolation, (2) monotonic and cyclic testing on variations of full-scale roof sheathing-to-rafter connections, roof-to-wall connections, and wall-to-floor system connections performed at the University of Kansas, both of which feed into (3) a finite element model of a manufactured housing unit exposed to dynamic wind loading capable of capturing nonlinear behavior, developed at the University of Alabama, that is validated with (4) large-scale experimental testing performed at the NHERI WOW EF. Findings quantify structural capacity and performance of manufactured homes, providing insight and offering recommendations towards remedial measures.

Thursday, March 28 | 10:30 am-12:00 pm

Designing Affordable Apartments for Changing Demographics in South Africa

Gerald Steyn, TUT

This article focuses on an emerging demographic phenomenon that is transforming the urban housing market in South Africa: the circular migration of members of middle to high income households, who regard their ancestral villages as their real homes, and who want cheap, centrally located accommodation. The purpose of this study is to examine the requirements of these households and translate them into tentative normative design principles. This study relies primarily on observation and interviews for information. A review of the demographic dynamics under study is followed by a discussion of density and urban issues, spatial typologies, and floor area norms.

A Comparative Analysis of UK Sustainable Housing Standards

Mahmoud Alsaeed, Karim Hadjri and Krzysztof Nawratek, University of Sheffield School of Architecture

Over the last few decades, the UK government has developed several sustainability policies, namely the National Planning Policy Framework, the Building Regulations Part-L, the Environmental Impact Assessment and others form the basis for sustainable housing provision in the UK. However, studies by the UK Green Building Council have shown that developers are not familiar with or do not adopt all parts of these regulations and standards, citing complexity and rising costs as barriers. We suggest that the complexity, fragmentation, and misunderstanding of sustainability regulations and standards must be overcome in order to effectively design sustainable housing. This study argues that a mapping of existing sustainability standards and their use would help in this endeavour. This will be done, firstly, to identify sustainable housing standards and discuss their structure and challenges, and, secondly, to examine their effectiveness in delivering sustainable housing by conducting a comparative analysis that identifies similarities, differences and relationships between regulations and standards. A literature review was used to identify relevant UK sustainability regulations. This served as the basis for a comparative analysis examining the scope, applicability, areas of intervention and methods of sustainability regulations and standards. In addition, a desktop analysis was conducted on three case studies of sustainable housing in England to identify the building standards applied and assess their effectiveness in terms of the project's environmental impacts and sustainability outcomes. The result of this study contributes to the theoretical discourse on sustainability regulations and standards. It presents a comprehensive mapping of the existing regulatory structure of sustainability in housing with its challenges to help developers navigate the complexities.

Understanding How Different Building Designations Impact Conscious and Unconscious Evaluations of Housing Developments

Isabella Douglas, Arash Tavakoli, Draper Dayton and Sarah Billington, Stanford University

There is an ongoing affordable housing crisis in the United States with every state and major metropolitan area having a sizable deficit of units for extremely low-income households. Any approach to tackling the affordable housing crisis will need to involve new construction developments, which are commonly subject to public comment during the typical entitlement process. Despite majority support of hypothetical increases to the affordable housing stock in those surveyed, local public opposition remains a major obstacle for proposed affordable housing developments in practice. Our study investigates what is contributing to this local opposition with the aim of offering solutions to reducing opposition through various strategies. As many development proposals are communicated to the public visually, we investigate how images impact public opinion and interact with other aspects of a development presented in accompanying written descriptions (i.e., if it is affordable, historic, or designed with a focus on environmental sustainability). We are conducting an online study with a between-subjects design where California residents are shown pairs of promotional and aerial images for a variety of affordable housing developments and asked to evaluate each development on several metrics including aesthetics and acceptance. Additionally, we employ webcam eye tracking to include an unobtrusive, unconscious measure of participants' engagement with the images. The results of this research provide insights into how the public's perceptions of building types, usage, and features that are cued by both images and descriptions impact their evaluation and acceptance of housing projects. A more nuanced understanding around public evaluations and reactions to housing developments can help inform strategies to address public opposition that delays or blocks crucial development proposals.

INTERNATIONAL SCIENTIFIC COMMITTEE

Clinton Aigbavboa
University of Johannesburg, South Africa

Somayeh Asadi
Penn State University, USA

Naomi Beal
passivhausMAINE, USA

Ben Bigelow
Texas A&M, USA

Melissa Bilec
University of Pittsburgh, USA

Ryan Bradley
University of the Witwatersrand, South Africa

Silvia Brunoro
University of Ferrara, Italy

Carlo Carbone
Université du Québec à Montréal, Canada

Kristen Cetin
Michigan State University, USA

Andre Desjarlais
Oak Ridge National Laboratory, USA

José Pinto Duarte
Penn State University, USA

Jim Freihaut
Penn State University, USA

Alessandro Gaiani
University of Ferrara, Italy

Antonio García-Martínez
University of Seville, Spain

Corey Griffin
Penn State University, USA

Walter Grondzik
Ball State University, USA

Karim Hadjri
University of Sheffield, UK

Dan Hindman
Virginia Tech, USA

Eric Holt
University of Denver, USA

Patrick Huelman
University of Minnesota, USA

Lisa Iulo
Penn State University, USA

Bohumil Kasal
Fraunhofer Wilhelm-Klauditz-Institute WKI, Germany

Mei Yung Leung
City University of Hong Kong, Hong Kong, China

Carlos Martín
Urban Institute, USA

Andrew McCoy
Virginia Tech, USA

Tim McDonald
Onion Flats, USA

Mahua Mukherjee
IIT Roorkee, India

Isabelina Nahmens
Louisiana State University, USA

Esther Obonyo
Penn State University, USA

Cilísia Duarte Ornelas
University of Porto, Portugal

Freddy Paige
Virginia Tech, USA

Shiling Pei
Colorado School of Mines, USA

David O. Prevatt
University of Florida, USA

Georg Reichard
Virginia Tech, USA

Awni Shaaban
Sultan Qaboos University, Oman

Matt Syal
Michigan State University, USA

Fitsum Tariku
British Columbia Institute of Technology, Canada

Sam Taylor
Joint Committee on Building Science Education, USA

Ioannis Zisis
Florida International University, USA

3D Printing of “Clay-Hemp” Sustainable Structures for Residential Construction

Eden Binega Yemesegen and Ali M. Memari, Penn State

Humanity’s quest for sustainable and eco-friendly construction methods has led to a resurgence of interest in ancient earth-based building materials, such as cob, adobe, and hempcrete. This paper explores the historical significance and contemporary applications of these materials, highlighting their eco-efficient, sustainable, and renewable properties. With the aim of reducing the carbon footprint in construction, researchers have turned to earth-based materials, which offer carbon-neutral or even carbon-negative status. The traditional construction methods of earthen-based houses, including cob and adobe, are examined, emphasizing their affordability, sustainability, and cultural significance. These materials, abundant in local environments, provide excellent thermal insulation properties and contribute to improved indoor air quality and thermal comfort. Additionally, the integration of bamboo and wood enhances the structural strength of earthen buildings, ensuring their longevity and resilience. In parallel, advancements in 3D printing technology offer a promising avenue for sustainable construction practices. By combining earth-based materials with 3D printing, researchers aim to create affordable and eco-friendly housing solutions. The paper outlines the methodology for 3D printing earthen-based houses, including the composition of clay-hemp mixtures and experimental set-up parameters. Notably, the honeycomb pattern is identified as an optimal design for 3D printed walls, offering structural stability, material efficiency, and enhanced acoustic performance. Furthermore, the geometric considerations for 3D printable earthen houses are explored, focusing on circular architectural designs. Circular structures exhibit enhanced resilience to environmental forces, efficient material usage, and reduced energy consumption. By modernizing and adapting ancient architectural designs for 3D printing construction, researchers envision sustainable housing solutions that prioritize durability, strength, and environmental sustainability.

Potential Use of Granulated Cork as Sand Replacement in the Design of Eco-Friendly Lightweight 3D-Printed Concrete

Hanbin Cheng, Aleksandra Radlińska, Ali Memari, Jose P Duarte, Sven Bilén and Shadi Nazarian, Penn State

This work examines the potential of advancement of 3D-printed eco-friendly lightweight concrete by utilizing granulated cork as fine aggregate. Reference material with natural river sand as fine aggregate was used as the control and granulated cork of similar grading was used to replace the natural river sand at 25, 50,75, and 100% by volume. Considering the large water adsorption capacity of cork, it was fully saturated before incorporating into the concrete mixture. Concrete with cork as aggregate was assessed in terms of fresh density, rheology, flowability, porosity, water permeability, mechanical properties, and thermal conductivity. The experimental work indicates that the increasing volume fraction of cork aggregates can produce lightweight concrete and remarkably reduce rheological properties. A linear relationship between the equivalent relative density of aggregates and rheological properties was identified. The flowability of the mixture was enhanced due to the incorporation of granulated cork. Additionally, depending on the cork content, the concrete porosity increased by 5.5 to 15.2 times, compared to ordinary concrete. Increasing porosity and cork incorporation enhanced the water adsorption of concrete and contributed to lower compressive strength, flexural strength, and interlayer bonding strength. In terms of thermal insulation capacity, the use of cork leads to an efficient enhancement of the thermal resistance of 3D-printed concrete.

Enabling Concurrent Reinforcement During 3D Concrete Printing (3DCP) to Create Spanning Structures Using Tensile Cables

Ali Baghi, Shadi Nazarian and Jose Pinto Duarte, Penn State

The shift from standardization to customization in the construction process has leveraged additive manufacturing techniques, generally referred to as 3D printing, with promising results in reducing the ecological footprint of conventional construction techniques. In Architectural Engineering and Construction (AEC) industry, additive manufacturing with concrete has facilitated the construction process of a wide spectrum of customized components; however, an automated printing system dedicated to constructing spanning structures, such as flat roofs, is still lacking. Although using formwork and diagonal printing (corbelling) are the most common solution for 3D printing enclosed structures, they pose some challenges in terms of design flexibility and waste material. The ongoing research addresses this critical shortcoming by developing a custom tool to enable 3D Concrete Printing (3DCP) of spanning structures by embedding tensioned cables as the reinforcing and supporting agent into the concrete filament. The hypothesis was that by winding and tensioning cables (e.g., continuous basalt or carbon fibers) around two parallel rows of preplaced pins and simultaneously depositing concrete over and around them, it is possible to print concrete roof structures without formwork. This approach resulted in a fully automated printing/reinforcing smart nozzle compatible with conventional 3DCP hardware. This study proposes a fully automated method for concurrent reinforcement in 3DCP that is consistent with the autonomous nature of additive manufacturing. Compared to other enclosed space printing techniques, such as diagonal printing (corbeling) or using formwork, the current technique requires less concrete than corbeled structures and eliminates the need for formwork and its inherent waste material. As a result, this project will decrease the ecological footprint of 3DCP and provide architects and engineers with a more sustainable construction technique aligned with the design flexibility of 3DCP.

Thursday, March 28 | 1:00-2:30 pm

Interface Behavior between Two 3D-Printed Concrete Layers under Different Loading Conditions

Pedram Ghassemi and Natassia Brenkus, Ohio State University

Additive manufacturing (AM) has presented great potential in many fields, such as aerospace, mechanical engineering, and medical practice. Using this technology has made automation in civil engineering possible. Printing of 3D concrete structures, or 3D concrete printing (3DCP), is one effort targeted at introducing AM technology in the residential construction industry and has the potential to create resilient, sustainable, and equitable housing access. Due to the novelty of this topic, many knowledge gaps need to be addressed. Although recent studies have developed appropriate printable materials, limitations still exist to employing 3DCP in the construction industry. One of the main crucial and significant issues in designing and constructing a 3D printed structure is the interface behavior between concrete filaments. No comprehensive constitutive model exists for the interfacial behavior of the two 3D-printed concrete filaments, nor are there 3DCP systematic computational modeling approaches. This study aims to evaluate and compare two existing FE modeling approaches based on conventional concrete materials to model the interface between two concrete filaments. The results illustrate considerable differences between the two mentioned interfacial FE modeling approaches. Establishing a bond-slip relationship governing the interfacial behavior is a necessity not only for the computational modeling of the interface but also for creating the design codes and standards.

Enabling Formwork-Free 3D Printing of Spanning Roof Structures Using Multi-Directional Slicing to Decrease the Printing Angle

Nusrat Tabassum, Jose Duarte, Shadi Nazarian and Nathan Brown, Penn State

3D concrete printing (3DCP) technology is expected to provide solutions to the construction industry's lack of efficiency, skilled labor, and safety while addressing the shortage of affordable housing resulting from the increasing world population. Current applications in academia and industry have mainly focused on fabricating wall elements, which do not fulfill the potential of this technology to fully automate the construction process, including enclosures. Formwork is an essential part of concrete construction that fundamentally influences labor needs, quality, timeline, and complete expense. Different AM techniques used for 3DCP have already been used to successfully print various building components such as walls, beams, columns, and prefabricated blocks without formwork. However, spanning structures remain an exception because of the restrictions of the current printing angle in 3DCP, which is 60 degrees using a corbelling slicing technique. In most state-of-the-art studies in 3DCP, the focus has always been on developing different strategies to fabricate the formwork rather than developing or improving the existing AM techniques for printing them without formwork.

This research intends to take inspiration from the historical structures and combine corbelling, inclined, and radial slicing techniques for toolpath design and print them using a multi-directional strategy. As the print proceeds, the nozzle will rotate at a different angle as per the slicing types so that the overhang angle starts decreasing. This research will include a series of experiments aimed at decreasing the printing angle and modeling the structural behavior of a barrel vault structure using multi-directional printing strategies for toolpath design. Future work will expand this research by including other types of vaults, such as domes, cross vaults, rib vaults, and other non-corbelling strategies. Developing these multi-directional printing strategies for 3DCP will provide new design freedoms to create optimized geometry and reduce material cost through waste elimination. This research will benefit the Architecture, Engineering, and Construction (AEC) field while contributing to the UN Sustainable Development Goal (SDG).

A Platform to Support the Design of 3DCP Housing Solutions: Development, Validation, and Fabrication of Smart Wall Patterns

Jose Duarte, Penn State; Gonçalo Duarte, Penn State; Nate Watson, X-Hab3D; Sven Bilen, Penn State; and Shadi Nazarian, Penn State

This paper presents a computer platform developed to support the design for 3D concrete printing (3DCP) housing solutions. The platform comprises generation, slicing, simulation, optimization, and construction simulation modules, and is defined as a package developed for Rhino and Grasshopper. The generation module is based on the concept of design patterns. A pattern is a recurrent design element that is encoded by an algorithm that permits to instantiate the pattern. One can design by combining and instantiating patterns according to the current design context. Higher-level patterns (e.g., house types) are defined by combining lower-level patterns (e.g., building elements). The platform is open-ended as patterns can be defined incrementally over time, providing a re-usable library of instantiable design concepts. The slicer encodes shape decomposition rules, following three levels: overall shape–building parts (foundation, walls, roof, and beyond); from building parts to layers (with different slicing strategies); and from layers to filaments (with different infill patterns and linking strategies). The evaluation module links the platform to external simulation and analysis software to verify the performance of the design during and after printing, while performing construction simulation (travel moves, collision detection, etc.). The optimization module supports multi-criteria and multi-fidelity optimization for the overall shape and toolpath, to obtain the design with the best performance during printing (i.e., maximize shape accuracy, structural stability and minimize printing time) and after printing (i.e., structural and environmental performance). This paper also validates the generator, respective design patterns, and the slicer by designing 3DCP smart walls, that are crucial building elements in 3DCP housing construction.

Sustainability and Resilience Policy Simulation Modeling for Post-Disaster Residential Building Reconstruction

Linda Waters, University of Maryland; Allison Reilly, University of Maryland; and Roshanak Nateghi, Purdue University

Every year, tens of thousands of homes in the United States are rebuilt due to disaster damage. This rebuilding process presents an interesting and unexplored opportunity to transition homes to be more sustainable through energy-efficiency modifications. Simultaneously, it is an opportunity to make homes more resilient to an array of hazards, such as by making them more storm and extreme-temperature resistant. However, no systems-level analysis has been performed to quantify the potential energy savings and carbon abatement that could stem from green and resilient rebuilding following disaster damage. In this work, we estimate the energy and environmental effects over time (namely projected residential energy demand and carbon abatement) from implementing energy efficiency and disaster resilience requirements during residential building reconstruction after disasters. The approach builds a simulation modeling platform that includes all homes in the study area and their risk of damage. We focus on the risk from flooding. We then model how residential energy demands and carbon emissions change over time under various reconstruction policy scenarios, such as requiring the implementation of heat pumps or wet flood-proofing. Embedded within the simulation is a household energy consumption model, 'BEopt,' developed by the US DOE and NREL, that reports energy use and carbon emissions of a home given its climatic exposure and structural characteristics. We focus on Harris County, Texas, a region prone to intense flooding and high temperatures that are expected to worsen with climate change. Our findings help to inform and guide future disaster recovery policy, particularly those pertaining to potential energy efficiency and disaster resilience requirements imposed on homes rebuilt after floods, in order to improve the country's long-term adaptation to climate change.

Understanding the Complexities of Evacuation Choices for Home Owners in Response to Natural Disasters

Sandeep Langar, University of Texas San Antonio

Natural disasters are occurring with increased frequency and intensity, posing significant risks to vulnerable communities. Federal, state, and local agencies can issue evacuation orders to encourage residents to seek safety elsewhere to mitigate the dangers associated with these events. However, numerous individuals choose to stay behind for various reasons. In addition, evacuation orders are generally issued within 30-72 hours before the onset of the event, leaving residents with little time to make critical decisions regarding when, where, and how to evacuate. Literature indicates numerous reasons influencing people's decision to evacuate, and some of them are household income, household ownership, social capital, gender, age, race, and others. Given the background, the research identifies the social, behavioral, and evacuation choices made by households in southern Texas in response to impending natural disasters, such as hurricanes and floods. The research used an online survey method to determine the perceptions and choices of the population. Households in Texas were purposefully selected as the research population, as the state has suffered impacts from USD $73 billion-dollar weather and climate disasters in the last two decades, making it the state with the highest disaster incident rate in the nation. Approximately 324 households responded to the online survey. Respondents provide insight into their experiences with natural disasters, their preparedness levels for such events, and their choices when faced with evacuation orders. The results of this study can prove instrumental in improving our understanding of the complexities surrounding evacuation decisions during natural disasters. By examining the various factors that influence these choices, policymakers and emergency management personnel can devise more effective strategies to ensure that at-risk populations make informed decisions when faced with the threat of a natural disaster.

Underground Stormwater/Rainwater/Thermal Storage Tanks: Solving Three Problems with One Solution

Edward Louie, Pacific Northwest National Laboratory

Society's reliance on fossil fuels (coal, natural gas) for electricity and space heating has allowed their use for energy whenever the need arises. This reliance on fossil fuels has resulted in large quantities of carbon dioxide (CO_2) being emitted into the atmosphere, which has contributed to climate change. One result is the increased frequency of extreme weather events, including extreme heat, extreme cold, extreme precipitation events, and extreme droughts. While renewable energy sources (solar photovoltaics and wind) offer the potential to significantly reduce our reliance on fossil fuels, more energy storage options are needed if we are to see non-dispatchable renewable resources meet energy demand at the massive scale desired to impact global CO_2 levels. This paper explores the use of rainwater as a thermal energy storage material and discusses how this solution can simultaneously help (1) heat pumps to improve their efficiency during extreme heat and cold periods, (2) to store water from extreme precipitation events in order to reduce flash flooding and, (3) to increase resiliency to extreme droughts and wildfires.

Challenges and Opportunities for Basic Efficiency Measures in Low-Income Homes: A Southeast Alaska Case Study

Vanessa Stevens, Georgina Davis, Rachel Dodd and Robert Tenent, National Renewable Energy Laboratory

Juneau, Alaska, is the state's capital city and aims to reach 80% renewable energy for the space heating and transportation sectors by 2045. This goal highlights a need to electrify both sectors to take advantage of the inexpensive hydropower available from the local electric utility, Alaska Electric Light & Power. To that end, researchers examined the feasibility of deploying storm windows via a case study of installing storm windows in two local low-income homes. Newer models of storm windows provide an extra layer of insulation over existing windows while preserving operability and views. They can also improve comfort and reduce noise. In addition to conducting pre- and post-installation air leakage tests, energy monitoring, and occupant interviews, researchers worked with the regional housing authority and a local builder to install the storm windows and replace inoperable windows in the two houses in 2021. The team encountered several challenges, including a lack of egress windows, energy data from a wide variety of heating systems, extremely leaky homes, and installation issues, such as windows that were not square. These results point to several barriers to the widespread deployment of window upgrades in the area and open the door to opportunities to design deployment programs that improve safety and efficiency.

Redlining's Impact: An Exploratory Study on the Long-Term Effects of Historical Housing Policies on Marginalized Communities in Denver and Key Successes of Remediation Policies Implemented

Mitali Vaidyanath, Rodolfo Valdes-Vasquez and Erin Arneson, Colorado State University

Redlining policies have had a long-lasting and far-reaching impact on US communities despite being outlawed in 1968. This study explores the impact of historical redlining policies on the development of neighborhoods in Denver. Specifically, the research focuses on how building construction, zoning, and funding of public projects are handled in the Denver Metro Area, based on public records of City of Denver planning and development meetings. The study also focuses on implementing and succeeding programs such as the Denver Social Impact Bond Initiative (Denver SIB) in these neighborhoods. By highlighting the continued effects of these policies on communities, this study emphasizes the need for systemic change and informs interventions to address the challenges faced by marginalized communities.

Balancing Cost and Performance in Affordable Homes: A Case Study in Data-Driven Decision Making

David Hinson, Mackenzie Stagg and Elizabeth Farrell Garcia, Auburn University

Identifying key areas for initial investment relative to improved building envelope and systems performance is critical for housing providers focused on housing affordability. Sustainable building certification programs and sophisticated design tools for modeling assemblies, energy consumption, and embodied carbon have vastly advanced the design and construction of high-performance housing. However, in the market sector of affordable, single-family housing, the value of implementing high-performance measures can be more difficult to assess. When cost-benefit analysis is critical to project feasibility, design teams need tools to identify which measures generate the most benefit for minimal added investment. Implementation requires responsible translation of modeled performance data into realistic expectations for actual operating cost. Common sustainability "best practices" must be reconsidered and recalibrated to variations in building scale and site context. Utilizing a comparative analysis between two built high-performance homes and one simulated comparison home, this research study seeks to find the balancing point between the front-end construction costs of improved performance and back-end performance consequences. In partnership with a local Habitat for Humanity affiliate, the research team analyzed the affiliate's standard practices for building homes in the mixed-humid climate of Alabama and proposed alternative methods that shifted operational expenses into investments in the asset of the home. Initial cost of construction associated with achieving performance outcomes is weighed against the estimated and actual energy use in each home. Through this study, the authors seek to illustrate methods for improving energy performance while minimizing initial costs in small, detached, single-family homes in the southeast United States.

Thursday, March 28 | 3:00-4:30 pm

Incorporating Carbon-Negative Hempcrete in 3D-Printed Eco-Friendly Residential Houses

Eden Binega Yemesegen and Ali M. Memari, Penn State

The construction industry's heavy reliance on concrete, masonry, and steel has had a detrimental impact on the environment, prompting the development of new materials with reduced environmental footprints. Traditional concrete and steel structures are unsustainable and emit high levels of carbon dioxide. For example, the production of one ton of Portland cement generates about 900 kg of carbon dioxide, which accounts for 88% of the average concrete mix's emissions. To address these sustainability challenges, incorporating hempcrete into 3D printing technology for small-scale buildings and houses is one possible solution. Hempcrete is a construction material made by blending woody hemp shiv or hurd with lime, sand, and water. It can be used to construct walls, floors, and roofs, providing excellent thermal resistance and regulating internal humidity. Hempcrete is a carbon-neutral material that can even store, over a century, around 35 kg of CO2 per square meter of wall built with a 25 cm thickness, making it a carbon-negative option for the environment. Earthen materials are highly compatible with 3D printing technology, as they require no formwork or mold and minimize material waste. This paper presents the methodology, experimental investigations, and advantages of using carbon-negative hempcrete as a filler in 3D printed home construction. Hempcrete is casted as a filler in the cells of a 3D printed wall made of "cobcrete." Furthermore, this study contributes to achieving the United Nations' Sustainable Development Goals through the use of hemp-based materials.

Getting Real with Hemp in Residential Construction

Michael Gibson, Kansas State University

With the 2018 legalization of hemp in the United States, interest in hemp as an environmentally-friendly material is ever increasing; likewise the acreage of planted industrial hemp is exploding with the CBD industry and the availability of new commercial varieties developed for use as animal and human food. While Europe established the contemporary use of hemp in construction decades ago, in the U.S. this material is still somewhat exotic today, as its opportunities and constraints as a building material are still being learned–despite widespread assertions in the do-it-yourself community that the materials and methods of hemp are "easy." Specifically exploring the use of hemp fiber and hempcrete (i.e. hemp-lime) as a substitute for conventional insulation materials in residential construction, this paper addresses a direct pathway for deploying hemp and hempcrete in large-scale, code-compliant residential construction. Supported by research from graduate seminars at Kansas State University, the research uses thermal analysis and observations from a robust full-scale construction mockup to present a method for implementing hemp fiber and hempcrete that is more compatible with typical U.S. residential building methods, in comparison to methods that typify hemp's use in Europe. The paper also discusses existing literature on the physical properties of hemp and hempcrete, while exploring and challenging the use of specialized proprietary binders in hempcrete construction. Lastly, the paper presents a detailed comparison of annual energy used in a hypothetical home with conventional, baseline insulation methods versus hemp and hempcrete, in the U.S. climate 4A climate zone. Overall, the research argues that hemp can be used in construction now, in concert with established wood construction techniques, for building higher performance, lower cost buildings.

Assessing the Thermal Performance of Bio-based Building Materials for Sustainable Building Construction

Rui Zhang, Andre Desjarlais and Emishaw Iffa, Oak Ridge National Laboratory

Nearly 40% of all CO_2 emissions come from buildings, and embodied carbon is responsible for 25% of these emissions. By 2050, embodied carbon is predicted to account for half of the building sector's CO_2 emissions. To overcome this obstacle and establish a carbon-free building industry, new building materials with less embodied carbon are needed. This study aims to investigate the thermal performance of 7 new bio-based/biodegradable building materials under various thermal conditions in order to address the challenge of climate change and reduce greenhouse gas emissions associated with building construction processes. Using a heat flow meter apparatus, the thermal performance of these materials was assessed at different temperatures (10°C, 24°C, and 38°C) and relative humidity levels (0%, 50%, and 80% at 24°C) or moisture contents (0 g/kg, 9.3 g/kg, and 15 g/kg). The results indicate that there is a linear relationship between thermal conductivity and temperature, but not between thermal conductivity and relative humidity. Recycled blue jeans and low-density hemp were insensitive to changes in relative humidity. The rate of change in thermal conductivity varied from -4% to 17% when the temperature increased from 10°C to 38°C, and from -44% to 19% when the relative humidity increased from 0% to 80% (moisture content increased from 0 g/kg to 15 g/kg). These findings show that bio-based construction materials have the potential to be practical substitutes for traditional methods of lowering greenhouse gas emissions. Additionally, it offers insightful information to legislators, engineers, and architects looking to design the built environment in a sustainable manner.

Evaluation of Wind Effects on Ballasted PV Panels

Houssam Al Sayegh, Florida International University; Arindam Chowdhury, Florida International University; Ioannis Zisis, Florida International University; Amal Elawady, Florida International University; Johnny Estephan, Bliss and Nyitray; and Ameyu Tolera, Verisk Analytics

Ballasted PV panel systems are experiencing a boost in popularity on commercial flat roofs, due to their ease of installation and the benefits they provide by avoiding the need for roof penetration. However, the absence of a mechanical connection to the roof imposes a design challenge for these systems. The challenge lies in accurately estimating the uplift aerodynamic forces and their effects on system responses (e.g., displacements), which could be further amplified by wind induced vibrations. ASCE 7-22 does not include dynamic effects in the design of roof mounted PV systems, thus the design coefficients in the code may be unconservative. Moreover, the existing literature is largely based on roof anchored PV systems, while little research has been carried out regarding ballasted systems, which have distinct behavior and dynamic properties. The current study aims for better evaluation of the behavior of ballasted PV systems during wind events and the mitigation efficiency of wind deflectors. To achieve this, a 2 x 2 full-scale ballasted PV array model, located at the corner of a flat roof, was tested at the Wall of Wind Experimental Facility. The experimental campaign consisted of aerodynamic and dynamic (flexible model) tests, as well as high-speed failure assessment (for wet and dry conditions) tests, to visualize the failure of these systems under simulated wind and rain events. The study showed that wind deflectors help in the reduction of uplift forces on PV systems and are most efficient for cornering winds. The findings of this study provide a tool for incorporating wind induced dynamic effects in the design process, optimizing the design of wind deflectors, and enhancing the ballast design efficiency.

Alley House: Using Phius Certification to Leverage Solar Decathlon Performance

Walter Grondzik, freelance consultant; Tom Collins, Ball State University; and Pam Harwood, Ball State University

Ball State University entered the Alley House project in the 2023 Solar Decathlon Build Challenge competition. The Alley House is a duplex residence located in downtown Indianapolis, Indiana. Design and construction were completed in April, 2023, and occupancy commenced soon thereafter. The Alley House was awarded first place in the 2023 Solar Decathlon Build competition. The focus of this paper is a desire and process to achieve Phius certification for this project. Phius is a non-profit entity that develops ultra-high-performance building design and construction guidelines, certifies projects that meet those guidelines, and trains designers and builders in the nuances of the guidelines and their implementation. Certification through Phius historically involved computer simulation of a proposed design to ensure compliance through a performance pathway. Recently, an alternative prescriptive pathway was made available to smaller-scale residential projects. The Alley House typology fit the bill for the prescriptive path, and Phius certification (passive building certification) was a logical means of enhancing project performance and the odds of success in the Solar Decathlon. This paper broadly describes the Phius prescriptive certification pathway and highlights key design targets that were thus established for the Alley House. Synergies between fundamental passive building precepts and several Solar Decathlon contest evaluation criteria are presented.

Evaluation Approaches for Energy and Carbon Target Achievement in Single-Family Homes

Jie Li, Lisa D. Iulo and Ute Poerschke, Penn State

Residential buildings are a primary U.S. energy consumption sector [1]. It has become a scientific consensus that pursuing energy efficiency in residential buildings is crucial to achieving zero emissions, efficiency, and resiliency, thus mitigating and adapting to the impacts of climate change. A number of widely recognized energy standards and labels have been adopted in the industry, such as the RESNET HERS® index, EPA/DOE ENERGY STAR®, and the U.S. Department of Energy Zero Energy Ready Home program and Architecture 2030 Zero Code, which great guide and promote the development and application of energy efficiency in residential buildings. A prescriptive path, where construction specifications are prescribed and used as program requirements, is adopted to rate and label buildings in these standards and programs. The prescribed construction specifications provide definite guidance for designing and selecting building components and system equipment that meet the performance requirements during the design phase. However, the prescribed construction specifications cannot be directly compared with actual energy use obtained from utility bills. It is not applicable to evaluating the performance target achievement of actual energy use for in-use single-family houses. There remains a lack of establishing comparable performance baselines and targets that can be used to assess the extent of savings and achievements in the actual energy use of single-family homes. This study compares the energy and carbon targets for different single-family residential buildings and suggests an evaluation approach to understand the target achievement of actual energy use and carbon emissions for single-family homes. The goal is to make it more straightforward to reveal and compare the level of energy and carbon targets achieved for the actual energy use of single-family buildings. Applicable energy and carbon targets, benchmarking metrics, and target achievement calculation methods are recommended as an outcome of this project.

Enabling Accessible Design of Complex Concrete Structures Using Real-Time Iterative Design, Visualization, and Analysis

Mohamed Ismail, University of Virginia

Unlike the first generation of computational design and performance analysis tools that widened the gap between disciplines, new design technologies allow us to merge geometric design and structural analysis, bridging between disciplines for a technologically advanced practice of holistic structural design (Barbosa et al. 2017). These tools have renewed interest in expressive structures that both demonstrate and celebrate material efficiency (Block and Paulson 2019) and present a valid pathway towards low-carbon building design. Unfortunately, early-stage structural design is still a disjointed exercise in design and analysis that excludes the untrained stakeholder, builder, or future occupant. By combining machine learning (ML) methods with virtual and augmented reality (VR/AR) environments, new computational structural design tools may unlock workflows that enable construction stakeholders to understand both the performance and spatial implications of early-stage design decisions regardless of their expertise. This paper demonstrates one such workflow that enables thoughtful structural design by visualizing the predicted performance of shape optimized structures through real-time predictive modelling. This research results in a structural design tool that enables users to visualize the vast design space of shaped concrete structures in real time along with an understanding of the predicted environmental and economic impacts of early-stage design decisions such as structural bay lengths and maximum floor depths. This paper provides a high-level overview of the workflow constructed using novel shape optimization and ML modelling methods and presents some cursory designs accessed through an accessible VR environment.

Study of Wireless Pressure Sensors Casing Effects in Full-size Wind Tunnel Measurements

Jian Zhang, Chelakara Subramanian, and Diego Robles Cortes, Florida Institute of Technology

This paper studies the significance of flow acceleration effects on pressure measurements via a wireless sensors network system (WSNS). WSNS is designed by the Florida Institute Technology team for high-resolution absolute pressure, wind speed, and direction measurements in the hurricane-level wind and rainy conditions. The aerodynamic designs of WSNS casings may cause local accelerations above the sensors when the flow is laminar. Therefore, the WSNS sensors with casing may record more negative static pressure values than the sensors without casing. The paper compared the pressure measurements from WSNS pressure transducers covered by hard-surface aerodynamic casings and the pressure measurement from Pressure Taps connected to the Scanivalve pressure scanners, through deployment on a full-scale model house in Florida International University's Wall-of-Wind (WoW) facility. The WSNS sensor(s) were mounted symmetrically to the surface pressure taps (connected to Scanivalve Pressure Transducers) on both vertical and inclined surfaces of a single-story residential building model. The tests assessed the pressure coefficient on different surfaces with WSNS pressure transducers with the casing, Scanivalve pressure taps without casing, and Computational Fluid Dynamic (CFD) values. The CFD analysis replicates the test chamber size and boundary flow conditions using the cobra probe measurements from the wind tunnel test. Both the wind tunnel and simulation results indicate that the casings of wireless pressure transducers do not have a significant impact on the pressure measurements while the surface of deployment is in stagnation or laminar flow regions. And the casing effects may result in lower pressure measurements compared to pressure tap and CFD results, for corners with vortex flows. With proper selection of the deployment locations, WSNS is proved to be as reliable as the SCV system.

Implications of Vertical Interaction of Separated Airflows on Wind Pressures Experienced by Building Structures

Chia Mohammadjani and Ioannis Zisis, Florida International University

This study focuses on the complex phenomenon of turbulent flow around structures with intricate geometries. Extensive previous investigations have explored the vortex patterns that arise from the separation of flow on sharp-edged bluff bodies. These vortices are responsible for the high wind pressures experienced on civil engineering structures. However, there is a knowledge gap concerning the interaction of vortices generated by flow separation on interconnected or adjacent structures with varying heights. Civil engineering structures, such as buildings with diverse roof heights, structures with extensions at lower levels, and high-rise buildings with multiple setbacks, often exhibit such complex integrated volumes. In this study, a series of wind tunnel tests were conducted at the Atmospheric Boundary Layer Wind Tunnel (ABLWT) in the Laboratory for Wind Engineering Research (LWER) at Florida International University (FIU). Preliminary findings have revealed differences in the locations of peak negative and positive pressure coefficients compared to the wind loading zones specified by the ASCE 7-22 standard. The combined flows at perpendicular surfaces have an influence on the peak suction zones, leading to dissimilar wind load zones from those outlined in the ASCE 7-22 standard. Mean and peak pressure coefficients will be presented, and the codification procedure will be providing enveloped area-averaged coefficients versus effective area curves. The study aims to provide modifications in wind loading standards to account for the wind pressures on building structures with an emphasis on the true locations of peak pressures.

The Pennsylvania Housing Research Center (PHRC) collaboratively engages with the residential construction industry to catalyze advancements in homebuilding through education, training, innovation, research, and dissemination. Administered within the Department of Civil & Environmental Engineering at Penn State, the PHRC envisions a residential construction industry equipped with the knowledge, skills, and technology to build better homes. You can learn more at *phrc.psu.edu*.

Director	**Ali Memari**
Associate Director	**Brian Wolfgang**
Residential Design & Construction Specialist	**Chris Hine**
Housing Affordability Specialist	**Rachel Fawcett**
High-Performance Housing Specialist	**Darrin Wright**
Meeting & Events Coordinator	**Alayna Kilic**
Financial & Communications Coordinator	**Mindy Boffemmyer**

206B Sackett Building
The Pennsylvania State University
University Park, PA 16802

814-865-2341

phrc@psu.edu

PHRC.psu.edu

@PHRCPenn State

#PHRChousing2024

PennState College of Engineering | PENNSYLVANIA HOUSING RESEARCH CENTER