Overview

Communities in the western U.S., Australia, and the Republic of Korea are competing against time. Drought-related natural disasters (dust, smoke, wildfire, intense storms, and flash flooding) are widespread and becoming more frequent, forcing rapid change and adaptation. Our activities address pre-disaster mitigation and planning, disaster response, and recovery. In addition, we develop timely, sustainable, and scalable solutions, systems, and use-inspired technologies by applying emergent learning, adaptation, and collaboration strategies that engage under-resourced communities, stakeholders, and public and private institutions.

The International Center for Resilient Infrastructure and Zero Emissions (IRIZE) combines the unique expertise of fire scientists, ecologists, engineers, designers, and sociologists to solve complex and ambitious issues regarding community resiliency to drought and flood-related phenomena. The proposed center partners have over two decades of experience in resiliency modeling and implantation, wildfire prediction and management, stormwater, and flood control, developing blue-green infrastructure technologies, and designing and constructing energy-efficient, resilient building systems. The IRIZE collaboration between research centers and groups in the United States, Australia, and the Republic of Korea creates a unique platform for solving this century's most complex climate-change challenges for affected communities.

Our international partners are the University of Melbourne (Australia), Hanyang University (Republic of Korea), and the Land and Housing Corporation (LH – Korea). IRIZE will consist of these partners and several groups and centers from the University of Utah and the State of Utah (Dept. of Civil and Environmental Engineering, Wilkes Center for Climate Science and Policy, the Center for Medical Innovation, Healthy Aging and Resilient Places Lab, Envision Utah).

Intellectual Merit

We develop timely, sustainable, and scalable solutions by implementing emergent learning, adaptation, and collaboration strategies that engage under-resourced communities, stakeholders, and public and private institutions. We research and implement models and solutions for predicting, managing, and responding to wildfires by advancing our understanding of firebrand, radiant, and convective exposure and their combined impact on dynamic fire behaviors, infrastructure, buildings, air, and water quality. We reduce the potential for urban flooding and air and water contamination by developing and implementing multipurpose decentralized stormwater management systems. We create blue/green resilient technologies that mitigate the impacts of climate-change drought and its effects on air and water quality. We assist communities on the path to resilient, zero-carbon communities by reducing greenhouse gas (GHG) emissions and developing zero-carbon, low-carbon, and carbon-neutral infrastructure and housing technologies.

Broader Impacts

We envision a world where communities are empowered to adapt and thrive in the face of urgent and significant climate change challenges. We will assist these communities on the pathway to improved resiliency and zero carbon emissions by creating systems and technologies that support livable, sustainable, and equitable development. Achieving these outcomes will generate significant economic, environmental, and social benefits. The social and cultural benefits include the protection of lives and homes, preserving heritage buildings, and the safeguarding cultural and social assets in affected communities.

IRIZE Center's Motivations

Communities in the western U.S., Australia, and Korea communities are competing against time. Drought-related natural disasters (dust, smoke, wildfire, intense storms, and flash flooding) are widespread and becoming more frequent, forcing rapid change and adaptation. The consequences of climate change-related natural phenomena are degrading the health and vitality of these communities. For example, drought conditions in Australia and the western U.S. have led to significant reductions in streamflow, created severe water shortages, and spawned widespread wildfires [1]. Changing climate also resulted in the lowest recorded water level of the Great Salt Lake (GSL). Since 2020, the GSL has lost slightly more than one million acre-feet of water per year, significantly more than predicted by current hydrographic models [2,3,4]. If this rate of water loss continues, the GSL will disappear in the next five years [5].

This loss would be an unparalleled catastrophe in the State's history. The Lake provides more than $1 billion in economic impact and is a refuge for millions of birds. Its shores reside in ancestral lands that sustained the Shoshone, Bannock, and Ute Nations and the current home of the Confederate Tribes of the Goshutes Nation. On its eastern side, GSL waters protect 2.5 million inhabitants against exposure to harmful wind-born toxins (natural and human-made) that would become airborne from a dry lake bed. Arsenic, cadmium, mercury, nickel, chromium, lead, copper, selenium, organic contaminants, and cyanotoxins are found in the GSL sediments [6,7,8,9-15]. Frequent wind and thunderstorms can transport these toxins as microdust (i.e., particulate matter with a particle size of less than 10 microns). Ultimately, dust originating from the GSL and other western U.S. dried lakebeds could significantly increase the rates of chronic and acute diseases associated with air pollution, including reproductive dysfunction, developmental defects, cognitive impairment, cardiovascular damage, and cancer [16-19]. Air pollution causes 1-in-5 deaths globally and about 12.1 million premature deaths annually [18,20]. Also, poor PM2.5 air quality in the Salt Lake City area disproportionally affects under-resourced communities[1]. Schools with higher proportions of racial/ethnic minority students were unequally exposed to all PM2.5 pollution. Disproportionate exposure in public schools based on race/ethnicity and socioeconomic status is concerning, given that air pollution negatively impacts children's health and academic performance. These findings suggest that policy changes are needed to protect children in SLC from environmental harm. PM2.5 dust and emissions disproportionally also affect older adults in these under-resourced communities.

Also, Korea is plagued with the increased degradation of air quality due to high levels of PM2.5 resulting from regional PM2.5 (microdust) carried by changing weather patterns, rapid urbanization, and fossil fuel emissions. This crisis has caused the government to take emergency measures to restrict the operations of emitters (e.g., power plants, construction sites, etc.) and the use of private vehicles.

Australia's climate has warmed by more than one degree Celsius over the past century, causing an increase in the frequency and intensity of heat waves and droughts [21] Eight of Australia's ten warmest years on record have occurred since 2005 [22]. A study in 2018 conducted at the University of Melbourne found that the significant droughts of the late 20th century and early 21st century in southern Australia are "likely without precedent over the past 400 years" [23]. Across the country, the average summer temperatures have increased, leading to record-breaking hot weather [24], with the early summer of 2019 being the hottest on record [25]. This year was also Australia's driest year since 1900, with rainfall 40% lower than average [26]. As a result of climate change, Australian wildfires have become more intense, the risks to people and property have increased, and fire seasons have lengthened.

Urban flood also continues to challenge communities. In the U.S., urban flooding is the natural hazard with the most significant economic and social impact. Catastrophic urban flooding from recent hurricanes, including Superstorm Sandy in New York (2012) and Hurricane Harvey in Houston (2017), caused billions of dollars in property damage, adversely affected millions of people, and damaged the economic well-being of major metropolitan areas [27]. Unfortunately, increased urbanization and the use of hardscape (i.e., impervious engineering materials such as concrete and asphalt) have reduced stormwater infiltration in the urban watershed. Additionally, Western states suffer from seasonal flash flooding from summer thunderstorms or excessive runoff from wildfire burn scars and early snow melt. Similarly, the Republic of Korea has been impacted by severe urban flooding caused by increasing recent typhoon events and rainfall in the middle and eastern parts of the country [28]. This flooding has produced significant damage in metropolitan areas.

The pressing concern of climate change has prompted individuals, communities, and governments to reduce their carbon footprint, resulting in a growing interest and emphasis on developing innovative sustainable solutions to mitigate this trend worldwide. The zero-carbon community represents a highly sustainable and self-sufficient community to achieve carbon neutrality by reducing greenhouse gas emissions. The commonly offered solution for improving air quality, reducing greenhouse gas emissions, and the consequences of climate change is a pivot to green and renewable energy sources. While this is a laudable long-term strategy, it may disadvantage under-resourced communities in many ways. For example, the installation and maintenance costs for many residences and schools are high; hence unaffordable. Also, older structures generally have inadequate insulation and substandard heating and air-conditioning systems; therefore, they are not feasible candidates for green energy conversion.

Additionally, energy sources like solar and wind are location-specific, and under-resourced communities may not have capital investment and the necessary infrastructure backbone to harness such sources effectively. These factors could leave older structures in under-resourced communities disadvantaged compared to more affluent areas. Thus, improving community wellness and equity motivate us to find solutions that bridge these gaps and place these communities on the path to disaster-resistant, zero-emission infrastructure while maintaining these communities' unique character and vibrance.

IRIZE Center's Vision

The International Center for Resilient Infrastructure and Zero Emissions (IRIZE) envisions a world where communities are empowered to adapt and thrive in the face of urgent and significant climate change challenges. We are an international interdisciplinary team of innovators, entrepreneurs, scientists, and engineers that seeks to empower communities through compassionate service, research, education, and workforce development. In addition, we develop timely, sustainable, scalable systems, solutions, and new technologies by applying emergent learning, adaptation, and collaboration strategies that engage under-resourced communities, stakeholders, and public and private institutions.

We assist communities on the pathway to improved resiliency and zero carbon emissions by creating systems and technologies that support livable, sustainable, and equitable development. We develop timely, sustainable, and scalable solutions and then work to implement them through adaptive practices, emergent learning, and collaboration strategies that engage under-resourced communities, stakeholders, and public and private institutions.

IRIZE Center's Research Goals

(1) **We engage under-resourced communities and research partners to develop use-inspired research and solutions using adaptive models**. A challenge in addressing climate change is convening disparate groups in ways that can capitalize on interdependencies and effectively scale change. Research on complexity leadership theory provides evidence-based findings for how to do this through the adoption of leadership and collaboration practices that enable adaptive space. These practices will be expertly applied to generate adaptive solutions and scale them into formal operating systems in the form of adaptive new order.

(2) We will develop models and solutions for predicting and managing wildfires and protecting infrastructure. The research conducted by the FLARE group at the U. of Melbourne and the U. of Utah

Wilkes Center Climate Science and Policy will advance our understanding of firebrand, radiant, and convective exposure and their combined impact on structures, air quality issues, and dynamic fire behaviors. These models will inform strategies or technologies that protect or adapt infrastructure to wildfire, erosion, flash flooding, debris flow, and smoke hazards. Also, the U of Utah and Melbourne are developing fire-resistant building and system technologies.

(3) We reduce urban flooding and air and water contamination by developing and implementing multi-purpose decentralized stormwater management systems. The U. of Utah, the Land and Housing Corporation of Korea (L.H.), and Hanyang University are developing decentralized stormwater detention systems with additional beneficial water and filtering functions, geothermal heat exchange capabilities, and underground secondary water storage capacity for landscaping, agriculture, and fire suppression, geothermal heat exchange systems with buildings, etc.).

(4) We create blue/green resilient technologies that mitigate the impacts of climate-change drought and its effects on air and water quality. This effort will focus on developing methods, systems, and technologies to treat, remove, or sequester microdust (PM2.5) and other particulates and contaminants originating from dust, smoke, and fossil fuel combustion,

(5) We assist under-resourced communities on the path to resilient, zero-carbon communities by reducing greenhouse gas (GHG) emissions and developing zero-carbon, low-carbon, and carbon-neutral infrastructure and housing technologies. IRIZE seeks to revolutionize the lifecycle development of future zero-carbon communities through the digital twinning of buildings and communities. Additionally, we will develop mass timber structural systems resilient to multi-hazards (wind, seismic, flooding) and rapid construction building techniques to speed community post-disaster recovery. Lastly, we will implement retrofit technologies for substandard houses to reduce energy consumption and improve their Fire/Wind/Flood/Seismic resiliency, placing at-risk communities on the path to zero carbon emissions.

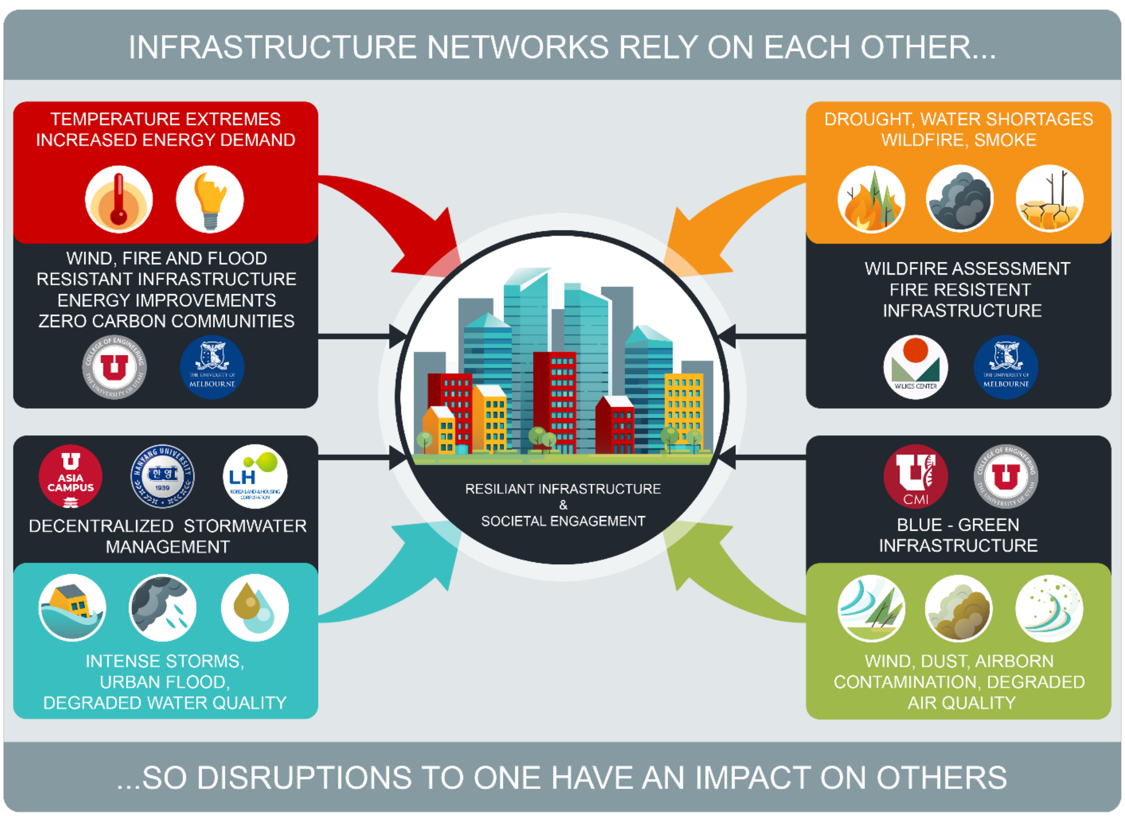


Fig. 1 Partners and Research Area of the IRIZE Center (see PMP for a description of teams).

Adaptive Community Engagement for Use-Inspired Solutions

Climate change is a manifestation of complexity imposed on the physical and social world [29]. Complexity occurs when parts of a system interact with other components and generate phase transitions to a new state [30], such as when drought-related phenomena cause permanent changes in ecosystems, which in turn cause communities to adapt rapidly. Complexity also challenges leadership because it must be responded to differently from traditional management systems. Instead of being able to plan, organize and control, complexity requires heterogeneous groups to partner under emergent conditions of adaptive space to generate new, adaptive order [31].

The process through which this occurs is shown in Fig 2. Complexity, such as climate change, is experienced in a system as adaptive challenges, e.g., increased wildfires, urban flooding, contaminants from dust, smoke, fossil fuel combustion, and greenhouse gases. Each of these challenges requires heterogeneous and potentially conflicting groups to come together and bridge differences to identify adaptive solutions and scale them into formal operational systems to meet the adaptive challenge. For example, the IRIZE center will gather community stakeholders, governmental officials, advocacy groups, scientists, engineers, etc., to address and adapt to climate change problems.

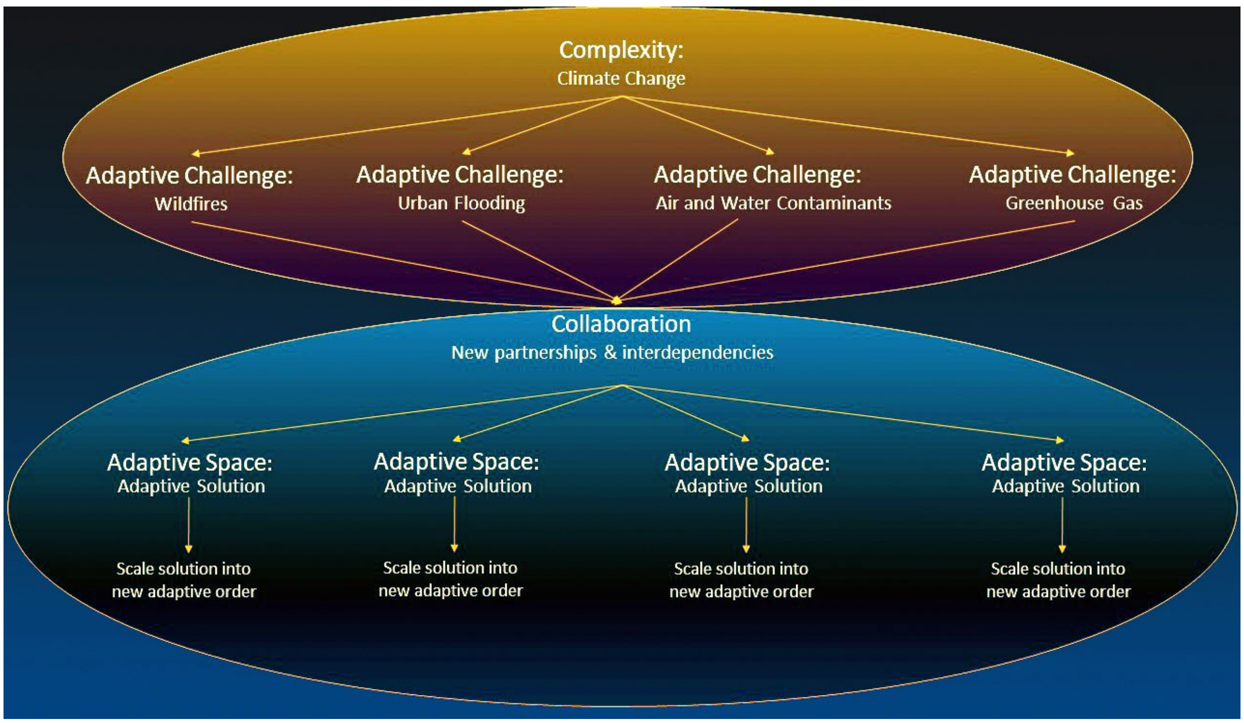


Fig. 2 Adaptive Community Engagement for Use-Inspired Solutions

Unfortunately, many attempts to address adaptive challenges fail because people do not understand the leadership activities associated with creating and enabling adaptive space. Adaptive space happens in two phases: (1) generation of adaptive solution(s) and (2) championing/scaling the adaptive solution(s) into system adaptation [32]. In the first phase, leaders convene adaptive space by identifying and bringing together the appropriate heterogeneous groups and then engaging them in the tension dynamic: a "conflicting-and-connecting" process under conditions of adaptive pressure and psychological safety to ideate and iterate adaptive solutions. In the second phase, leaders enable adaptive outcomes by using the linking-up dynamic to foster generative emergence: a "connecting-and-conflicting" process that fosters recombination and realignment of system components until they stabilize into new processes and formalized procedures [33]. Adaptive space has been shown to be effective in healthcare [34], business [35], and global crises such as COVID-19. Complexity principles have also been discussed relative to climate change and sustainability [36]. They will be applied here to generate Use-Inspired Adaptive Solutions.

Wildfire Prediction, Management, and Resiliency

Over the last 15 years, there has been a significant increase in the number of houses lost worldwide due to wildfires, with the western United States and Australia alone losing over 17,663 and 5,900 structures, respectively, in 2020 [37,38]. Wildfires pose the greatest threat to life and property in the Wildland-Urban Interface (WUI), where structures and human development meet or intermingle with undeveloped wildland or vegetation fuels. The density of people and houses within this zone leads to greater losses. Research has found a correlation between life and house loss [39], highlighting the importance of fire-resistant structures in reducing casualties. The expected expansion of population in the WUI [40] and the likely increase in the occurrence and intensity of wildfires due to climate change wildfires [41] make this issue even more critical.

The ignition of community structures is caused by exposure to heat fluxes from flames or firebrands generated by the wildland fire or adjacent burning houses [42]. Firebrand generation occurs when wildland fuels are heated and broken into smaller burning pieces during combustion. Smoldering and flaming firebrands are produced in large amounts during wildland fires, transported by wind over long distances [43-45], and can ignite structures by depositing on the building surface or finding a way through the structure to reach easy-to-ignite fuel or structural elements within [46]. The main exposure condition from firebrands in the WUI is a firebrand shower, which is an intense exposure to firebrands in the vicinity of a firefront. Most house loss during a wildfire occurs via ignition from firebrands, emphasizing the need for fire-resistant structures [47,48].

Wildfires are not only destructive to the environment but also pose a significant threat to human health through the release of smoke and air pollution. On a global scale, wildfires release an estimated 2.2 billion tons of emissions annually, contributing to air pollution and climate change [49,50]. The emissions have led to an estimated annual mortality rate of 339,000 deaths, with sub-Saharan Africa and Southeast Asia being the most affected areas [51]. As wildfire activity and human population growth continue to increase, population exposure and respiratory health impacts from wildfire smoke are expected to grow [52]. PM2.5 exposures due to wildfire smoke in the western U.S. are projected to be 160% higher by 2046-2051 under moderate climate change. Additionally, projected population and climate change increases are estimated to double the number of premature deaths attributable to wildfire-generated PM2.5 by the late 21st century compared to the early 21st century [53].

The increasing trend of extreme wildfires has enormously impacted environmental and human assets [54-58]. Their occurrence and behavior are driven by complex processes, making them difficult to control and unpredictable, with fire propagation significantly affected by dynamic feedback processes that result in erratic behavior and difficulty to control [54]. These factors make extreme wildfires particularly dangerous and capable of causing loss of human life and large-scale destruction.

Furthermore, runoff and erosion from areas burnt by wildfire can impact downstream water quality, particularly when high-severity wildfires intersect with intense rainfall in steep terrain. Vegetation cover loss and subsequent regeneration can also affect streamflow and water yield, depending on vegetation type and fire severity. Recent studies [59-61] highlighted significant knowledge gaps in our understanding of extreme wildfire propagation, conditions of wildfire transition to WUI, smoke emissions and their impact, wildfire exposure to structures and communities, and fire transition from structure to structure. Without answers to these questions, future improvements of existing models and standards are uncertain.

Wildfire Research Questions

Decision-making tools need to be developed to help land and fire managers predict the wildfire exposure to communities and the subsequent spread of fire within a community under extreme conditions (Fig. 3). Such tools require reliable and accurate models to simulate the wildfire spread rate and its exposure mechanisms, i.e., radiation, convection or flames, firebrands, and smoke. This prediction cannot be made with existing operational models. Current physical or semi-physical models cannot simulate all these mechanisms simultaneously. Moreover, they are not validated to simulate all the processes of spotting, the dynamic fire behaviors, and the effects of fuel distribution, structure, and arrangement due to the lack of laboratory and field experimental data.

Fig. 3 Decision-Making Tools for Wildfire Prevention, Management and Control

Therefore, the following areas need to be investigated: (1) Understanding the combined effects of firebrand, radiant and convective exposure to structures during extreme fire events to develop more effective strategies for designing and building homes and other structures in wildfire-prone areas and protecting existing structures during extreme fire events. (2) Creating a database of natural and WUI fuel emissions for representative species and materials to understand the types and amounts of pollutants released during wildfires and develop more effective strategies for managing air quality during and after wildfire events. (3) Understanding the effect of dynamic fire behaviors (massive spotting, merging fires, pyro-convective events, etc.) on fire spread and exposure in WUI communities to help us better predict and manage the impacts of extreme wildfire events and develop more effective strategies for protecting communities from these events. (4) Developing decision-making tools for land and fire managers to develop more effective strategies for managing wildfires and reduce the risk of uncontrolled fire events that can have devastating impacts on communities and ecosystems.

In addition, the proposed research aligns with the problem of construction in WUI. Advanced manufacturing technologies can be utilized to develop new building materials and construction techniques that can withstand the extreme exposure of wildfires. This development can include the use of fire-resistant and non-combustible materials and the development of new construction methods that can improve the fire resistance of houses. This research can lead to new industries and markets for manufacturing these materials and technologies, providing significant economic benefits for the country and creating new job opportunities. In addition, more resilient houses can also contribute to the protection of the environment, as structural fires are typically fueled by materials such as plastics, insulation, and other synthetic materials, which can produce a range of hazardous chemicals.

Wildfire Research Approach

The IRIZE combines the unique expertise of fire scientists, ecologists, engineers, designers, and sociologists to solve complex and ambitious issues. The Center partners (i.e., FLARE – U of Melbourne and Wilkes Center, U of Utah) have more than two decades of experience in wildland and WUI fires, covering research topics from fire dynamics to wildfire propagation and interaction with the atmosphere. This creates a unique platform for solving the most complex problems of the century. The areas mentioned above will require testing representative species from the northern and southern hemispheres to analyze the effects of fuel structure and arrangement on fire rate and propagation ability. Multi-scale laboratory experiments and simulations should be used to understand the physical processes governing the burning of vegetative fuels and their production of gaseous and particulate effluents. Utilizing both experimental and numerical approaches, simplified models will help to describe emission factors for different fuels that are a function of critical burning conditions identified experimentally, such as fuel composition, fire intensity, wind velocity, and degree of degradation. To better understand short- and long-range spotting during wildland and prescribed fires, innovative medium- and large-scale laboratory experiments are needed to identify the mechanisms of firebrand formation potential as a function of fuel type, weather conditions, and fire intensity to create a simplified model that considers downscaled atmospheric properties (turbulence, wind, heat, moisture, etc.). These experimental results will enable the physics-based model to be calibrated and validated to extrapolate experimental results to extreme wildfire conditions. In addition, it will allow the development of simplified tools that can simulate the full range of wildfire conditions and test communities' resilience to develop the best fire management strategies. These activities will enhance understanding and guidance on selecting appropriate building materials for WUI housing and other infrastructure to improve robustness and redundancy against future wildfire events.

Reducing Urban Flooding and Multipurpose Decentralized Stormwater Management

The U. of Utah Civil and Environmental Department (CVEEN) and the Korea Land and Housing Corporation (LH) entered an MOU to develop Decentralized Stormwater Management System (DSMS) technology. The Korean model uses sidewalk areas adjacent to roadways and buildings as underground stormwater detention (Fig. 4). The U. of Utah and LH have signed a "Resilient Urban Infrastructure for Sustainable Cities." In 2021, the U of Utah and the US DOT National Center for Transportation Infrastructure Durability and Life-Extension (TriDurLE) entered a 3-year research contract. In the Spring of 2022, researchers from Hanyang University, Korea, joined the collaboration, and the U of U TriDurLE USDOT contract ends in June 2024 and will not be renewed.

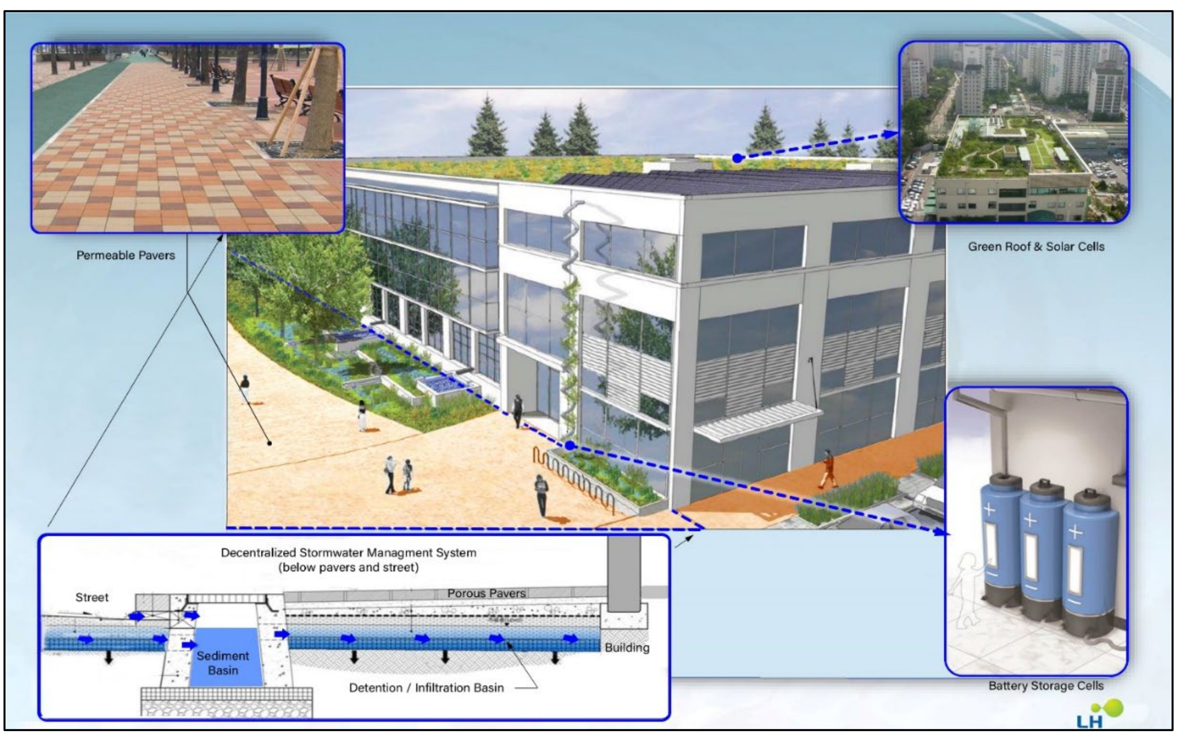


Fig. 4 Conceptual Decentralized Stormwater Management System for Urban Landscape (courtesy of L.H. Korea).

The scope of this work was to explore if the Detention / Infiltration Basin (Fig 4 lower left) could be extended under street or roadway areas, thus significantly increasing the potential volume of stormwater detention. The

The U of Utah research team proposed to replace the crushed bottom ash used in an L.H. Korean demonstration project with permeable lightweight cellular concrete (PLCC) (Fig. 5). We recommended the PLCC replacement of bottom ash introduced the potential for heavy metal contamination of the groundwater (Hg, Pb, Cd, Cr, and Ag). Also, at this time, Dr. Steven Bartlett was part of a technical advisory team advising qualifying the use of PLCC for the Mission Rock Project in the Port of San Francisco (Fig. 6). The design criteria required a lightweight porous material that could increase the elevation of the landscape and streets across the site by about 5 feet (Fig. 6). This project performance requirement needed a highly porous material, such as PLCC, to prevent flooding from future global seawater elevation changes and storm surges, and allow for daily tidal fluctuations in groundwater levels.

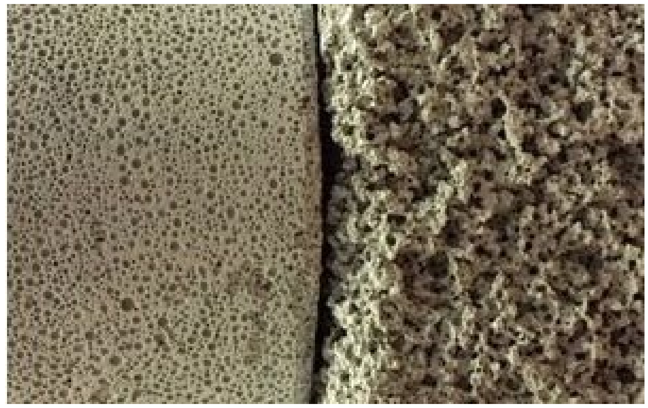


Fig. 5 Comparison of fabric of closed fabric of LCC (left) and porous fabric of PLCC (right)

Fig. 6 Mission Rock Project, Port of San Francisco

Preliminary findings from the U of U - TriDurLE research suggest that PLCC is a preferable replacement for earthen or ash materials in the following regards. (1) Compared with closed-cell lightweight cellular concrete (LCC), PLCC has a very open and connected pore space fabric (Fig. 3). This fabric produces several desirable material properties. (2) With a dry unit weight of about 25 pcf, PLCC is five times lighter than conventional construction or earthen materials. This property allows for new or retrofit installments in urban infrastructure without damaging nearby buildings, buried utilities from the effects of soil pressures, or long-term consolidation settlement. (3) PLCC has water storage capacity three times greater than gravel. For example, 1 m of compacted gravel can store approximately 0.2 m^3 of stormwater, whereas PLCC can hold about 0.6 m^3. (4) It has a hydraulic conductivity equal to coarse gravel to fine sand, allowing a relatively high flow of fluids such as water and air. (5) The cement found in PLCC has a high cation exchange capacity; hence it can effectively sequester certain types of water and airborne contamination Based on unpublished results for the U. of Missouri – Kansas City. (6) PLCC low-strain stiffness (i.e., resilient modulus) is comparable to other types of roadway subbase materials; thus, it can support heavy truck traffic when used with a conventional pavement system. Thu, it appears feasible for use under roadways and parking lots as the detention basis as a component of DSMS. (7) The use of non-woven geotextile fabric in conjunction with PLCC appears to protect sediment plugging of the PLCC from waterborne sediments.

Urban Flooding Research Questions

In Spring 2022 research meetings between LH, the U. of Utah, and Hanyang University (ERICA), the team suggested that the functions of the DSMS could be extended to include (1) filtering or sequestering of airborne or waterborne contaminants, such as PM2.5 (2) reducing the energy consumption of buildings are residences by creating ground heat exchange system(s) within the underground detention basin of the DSMS, and (3) storing or harvesting groundwater within the DSMS for irrigation or fire suppression (Fig. 4). The potential multifunctional use of the DSMS to sequester contaminants, reduce energy consumption and stormwater for multiple uses appears feasible, but remains unexplored from research, system and operational perspectives.

Urban Flooding Research Approach

Regarding (1), the DSMS detention basis could also capture and sequester air and water contaminants, thus cleansing the air and water. Regarding (2), underground stormwater detention basins could function as ground heat exchange systems to create a precooling/preheating of intake air to HVAC systems and air filtering as the intake air contacts and interacts with the very porous and partially saturated porous medium in the basin. Regarding (3), stormwater harvesting and storage can improve or maintain watershed hydrology, reduce pollutant loading to receiving waters, increase water conservation, reduce stress on existing infrastructure, and reduce energy consumption. Potential outdoor uses include irrigation, fire suppression, landscaping, sanitary sewer flushing, street cleaning/dust control, and wetland recharge. In addition, PLCC can be incorporated into urban green spaces for biofiltration and as a substrate for growing plants in biofiltration systems. The porous and interconnected nature of the PLCC allows for air and water, providing a suitable environment for plant growth and allowing the plants to filter pollutants from the air and water. PLCC has the potential to be used to create rain gardens in urban green spaces.

We will explore the range of potential materials used in the DSMS, focusing on characterizing and defining the following physical properties: hydraulic conductivity, rates of infiltration and desaturation, buoyancy, porosity, water and air storage capacity, strength, stiffness, and durability. We will also explore methods/systems to prevent future plugging of the system from water and airborne particles. We will also investigate the chemical, filtering, and sequestering properties of the DSMS materials for their suitability for treating effluent water and air. We will develop or test potential additives or filters that might be used in conjunction with the porous medium of the DSMS to remove water and airborne contaminants. Depending on the type of pollutant removal desired, these additives could include the following: compost, sesquioxide-based clays, biochar, activated carbon, woodchips, oyster shells, fly ash, water treatment residuals, metal ions (e.g., calcium, magnesium, iron, or aluminum), and their co-products (e.g., iron aggregate, alum, zeolites), and hardness/pH modifiers (e.g., sulfur, dolomite, gypsum, and lime). We will use the above activities to inform the design and construction of a field demonstration project(s) of potential systems. Monitoring devices (flow meters, soil moisture sensors, settlement monitors, weather stations, etc.) were installed to obtain performance data for the prototype detention/infiltration gallery. In addition, potential effluent air and water quality improvements will be evaluated by comparison sampling. Finally, we will use the results and experiences of these demonstration projects to recommend design criteria, construction methods, and specifications for future implementation and commercialization.

Creating Blue-Green Technologies for Dust Control and Air and Water Purification

All collaborating countries in the IRIZE Center have compelling reasons to reduce the harmful effects of windborne PM2.5 and PM10 from dust, smoke, and the combustion of fossil fuels. In addition to new and innovative Decentralized Stormwater Management Systems applied with Blue-Green Technologies have the potential to improve water quality by removing dust and other contaminants from stormwater runoff, thus creating a livable, attractive, and sustainable urban environment. These benefits will also produce urban biodiversity and reduce the damage from urban flooding.

Air and Water Purification Research Approaches

Mitigating the harmful effects of drying lake beds in drought-stricken areas, like the Great Salt Lake, will require a combination of measures and technologies to reduce the dust generated and stabilize the lakebed. These may include the following techniques and technologies.

Decentralized Stormwater Management Systems with Biofiltration

A multi-use decentralized urban stormwater system (see Reducing Flooding Section) that includes green roofs, permeable pavements, rain gardens, vegetated swales, bioretention basins, and rainwater harvesting systems can be developed to manage, collect, and purify water. The biofiltration process at the system's core uses plants, soil, and organisms to filter and purify water. Other benefits include reducing the urban heat island effect, improved biodiversity, and more attractive and sustainable urban environments for healthier and more livable cities.

Water Purification via Sustainable Urban Drainage Systems

Sustainable urban drainage systems (SUDS) (e.g., green roofs, permeable pavements, and rain gardens) are drainage and water management techniques designed to mimic natural processes and manage urban runoff more sustainably. Sustainable urban drainage systems (SUDS) can help capture and treat stormwater, reducing the risk of flash floods and improving water quality.

Biofiltration Systems and Bioswales

Biofiltration systems with green roofs, green walls, and urban green spaces incorporating PLCC can be a practical approach for mitigating air and water pollution in urban environments and a valuable tool for adapting to extreme weather events and the GSL dust crisis. These systems can be integrated into the urban environment and require low maintenance. Biofiltration systems that use plants and soil to filter air can be incorporated into green roofs, green walls, and other urban green spaces. These systems provide additional benefits (e.g., reducing the urban heat island effect and improving the overall air quality). Bioswales are effective and practical options for treating stormwater runoff in urban environments. In addition, they can be integrated into the landscape design of parks, greenways, and other public spaces and used to complement the aesthetics of the surrounding area.

Multiple Barriers Techniques

We plan to deploy technologies and systems that use the Multiple Barriers Technique to combat potential air and water quality issues. These include barriers at the lake perimeter that controls dust near the source, green fences, green roofs, and green walls outside the homes, business and residential complexes, and vegetation that sequesters urban dust particles and stormwater before dust and contaminants enter homes and buildings and surface and subsurface water storage systems.

Advancing Resilient Zero-Carbon Communities by Retrofitting Substandard Homes

Researchers at the U of Utah CVEEN Department have considerable experience in retrofitting infrastructure. This experience and our research laboratories will be used to improve energy efficiency and the multi-hazard resiliency of substandard homes.

Currently, renewable energy accounts for approximately 30% of global electricity generation and is increasing rapidly due to climate change concerns, technological advancements, and falling costs [62]. According to data from the International Energy Agency [63], [64], the solar and wind sectors have experienced annual growth rates of 10% to 20% globally in recent years, making them the fastest-growing energy supply sectors to meet the increasing energy demands. This trend is projected to continue in the coming decades. Decarbonizing the grid with renewable energy is essential for reaching carbon neutrality and introducing benefits such as reducing air pollution [65], [66]. However, the intermittent nature of power generation with renewable energy presents new challenges in power system operation, such as supply and demand balancing and voltage regulation [67], [68], [69]. Therefore, optimized design and smart operation of buildings are essential to realizing a zero-carbon community with stable grid operation at both individual building and urban scales.

In addition, there are numerous unreinforced masonry homes and buildings worldwide (i.e., older buildings with a brick structural support system) worldwide (Fig. 7). To attain carbon neutrality in the built environment, it is imperative to incorporate renewable energy and optimize building/community design and smart operation for sustainability and retrofit existing buildings to enhance energy efficiency and decrease energy demands on power grids. The existing building stock, primarily comprised of aged constructions, poses a significant challenge in achieving carbon neutrality. Specifically in the United States, extensive building surveys conducted by the Census Bureau and the Energy Information Administration [18], [19] revealed that the median age of residential and commercial buildings is greater than 40 years. These antiquated structures, constructed before the 1980s, were built sub-standard and lacked sufficient thermal performance due to obsolete techniques and a lack of building codes to standardize practices.

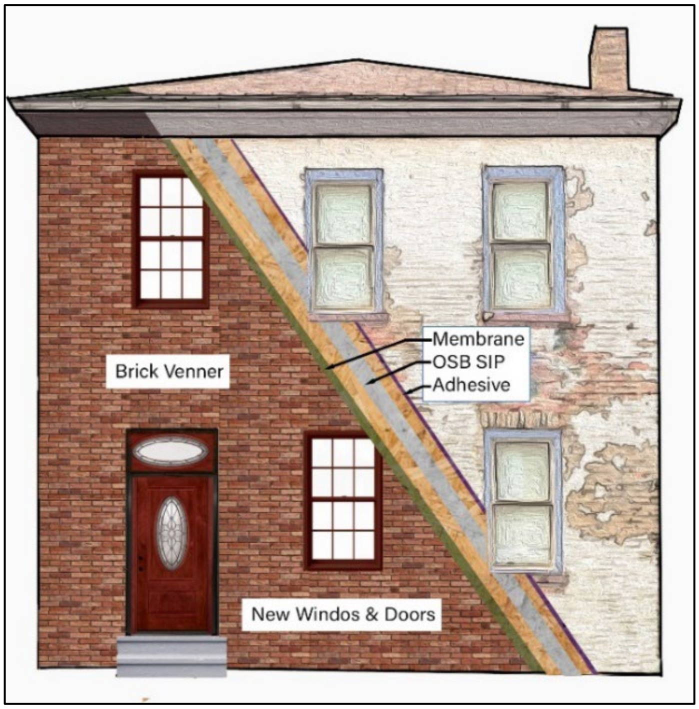


Fig. 7 Unreinforced Masonry retrofit using a High-Performance Pane and door and window upgrades.

However, replacing these structures is neither sustainable due to the waste produced during demolition nor cost-effective or even feasible given the vast amount of existing building stock. An exemplar case is an unreinforced masonry (URM) building, representing one of the most prevalent yet antiquated construction types worldwide [81]. In the Wasatch Front region of Utah, which accommodates over three million individuals, URM structures comprise more than 20% of the entire building stock, accounting for more than 150,000 structures in northern Utah [82]. Due to the age of the structures (approximately 1910 to 1950), these homes are commonly located in older, under-resourced neighborhoods. The building envelope of URM is typically constructed of only one layer of brick, hollow clay tile, stone, or concrete block and consequently suffers from severely degraded thermal performance caused by the high conductivity of masonry materials. In addition, due to their age and construction, many URMs will have unacceptable seismic performance (i.e., the potential for collapse due to the inhomogeneous, anisotropic, and inelastic nature of masonry materials [83], [84], [85].

Research Questions

The research questions to be answered include (1) how to enhance building and community intelligence to achieve a net-zero built environment with optimized design and smart operation and (2) whether nested building techniques can effectively retrofit existing substandard buildings to improve energy efficiency, reduce carbon emissions, and improve wind, fire, and earthquake resiliency, (3) can high-performance panels be directly attachable to the exterior of buildings with minimal interference or disruption to occupants, (4) is the technology easily deployable and scalable, (5) what is the nature of the workforce training required to commercialize the developed technologies, (6) what strategies or resources can be used to foster deployment in under-resourced communities?

Research Approach

To address these issues, this U of U CVEEN Department proposes to revolutionize the lifecycle development of future zero-carbon communities through the digital twinning of buildings and communities. This approach will empower the future built environment with intelligent design, construction, and operation to achieve energy efficiency and improved building-renewable energy integration. A digital twin is a comprehensive representation of a built system that utilizes physical models and sensor updates to enable the flow of information between physical and virtual systems, allowing for the twinning or mirroring of real space conditions and optimizing service or production [70]. Digital twinning can use physics-based and data-driven computing to support community planning, design, and operational decision-making. Although physics-based digital twinning is the most classic approach, its effectiveness and accuracy are often compromised due to simplifications, incomplete physics rules, and reliance on assumptions (such as heat transfer phenomena and building system logic) during analysis. Therefore, in actual applications, significant discrepancies may exist between physics-based analysis and actual observations [71], [72]. On the other hand, the rapid advancements in computing power, Internet of Things (IoT) and sensing infrastructure, and cutting-edge Artificial Intelligence (A.I.) algorithms have unlocked a plethora of opportunities to enhance the planning and intelligent operation of buildings and communities through the integration of big data and computational intelligence. The use of data-driven approaches holds immense potential in reconciling the modeling discrepancies between physics-based models and actual measurements, as well as among different fidelities of physics-based models by comprehensively addressing the simplification and incompleteness of physics rules in the analysis [73], [74], [75], [76]. Despite the vast potential of big data from diverse sources such as household metering, indoor environment measurements, and occupants, these resources and cutting-edge data-driven techniques remain significantly under-utilized. A paradigm shift is urgently needed to reconsider the collection, processing, integration, and exploitation of big data, in conjunction with well-established physics-based approaches, to enable advanced performance analysis, comprehensive planning, and intelligent decision-making for future smart built environments. Drawing from the principles of graph theory [77], we can leverage the underlying physics knowledge to construct graph-based models as digital replicas of buildings and communities [78]. The nodes in this model represent individual buildings, characterized by their unique features. At the same time, the edges describe the direct and indirect interactions between different urban elements, such as radiative heat transfer between neighboring buildings, convection, heat rejection from buildings, and human movements across the urban landscape. This bottom-up approach facilitates holistic planning and design of both individual buildings and communities, accounting for the complex interactions between urban elements, leading to enhanced energy efficiency and decarbonization at an urban scale. Continuous streaming of data from community operations ensures the digital replica remains up to date, facilitating the smart operation of buildings and communities, and improved building-renewable energy integration for efficient demand response. The graph-based models, once created, can be effortlessly adapted to different communities, enabling the transfer of knowledge for sustainable planning and smart operation of zero-carbon communities in various climatic zones. In this age of data explosion, this approach allows for the full utilization of big data integrated with physics-based analysis to create digital twins and revolutionize the lifecycle development of zero-carbon communities.

Wind and Seismic Resiliency and Sustainability Using Mass Timber Buildings

Research Questions

Advancements in timber technology are opening new avenues for sustainable mass timber to commercial markets where steel and concrete systems dominate the landscape. However, in high wind, flooding, or seismic regions, mass timber buildings lack code-defined lateral force resisting systems (LFRS). This deficiency limits the usage of mass timber as a construction material at a large scale. This research proposes to overcome this deficiency. This will position mass timber buildings with an LRFS to withstand wind, water, and earthquake loads via braced frames, moment frames, and shear walls.) Our research on the development and testing of an 18-story high MTB with timber buckling restrained braced (TBRB) frame system will enable the future construction of tall, high-wind resistant MTBs. We noted that in most cases, the seismic loading controls the building and LRFS designs (i.e., the earthquake loading combination is the most critical); hence by meeting seismic design requirements, buildings with LRFS also meet design wind loads.

The use of buckling-restrained braces (BRBs) as LFRS for buildings has been codified in the 2005 AISC Seismic Provisions (AISC 2005). This technology has expanded since then to become the primary braced frame system used in many seismic regions. Recently component tests on six timber buckling restrained braces (TBRB) have been completed [86]; the restraining element is two blocks of mass ply panel (MPP) sandwiched on either side of the steel core and bolted together. The TBRBs tested by Murphy et al. [86] were 12 ft long and were designed to have a 60-kip yield capacity.

However, the length of TBRBs needs to be extended before their implementation in multi-story buildings. TBRBs with a 19 ft, or longer, must be tested. In addition, other TBRB configurations with higher tensile capacity (e.g., 40 to 80 kips) should be developed. These braces must be tested as "Elements" and "Sub-assemblages"according to AISC341-16 Seismic Provisions (AISC 2016b) criteria for qualification before they can be used in multi-story construction as the LFRS.

The experimental goals for the TBRB braces in this research are: (1) Qualify the braces per AISC requirements and industry standards; (2) Test each brace to failure, followed by continued testing if other failure modes are possible. Both Element and Subassemblage tests will be carried out for two levels of TBRB tensile strength, i.e., 40 kip and 80 kips. The test matrix includes 10 TBRBs within three categories: (Type 1) four tests with bolted mass ply panel (MPP) casing using cyclic AISC qualification tests; (Type 2) four tests with screwed MPP casing using cyclic AISC qualification tests; and (Type 3) four earthquake simulation tests. The best TBRB candidates will be subjected to cyclic loading simulation tests. Through item 2 above, validate the brace design analytical approach related to restrainer design for local stiffness and stability response, global stiffness and stability response, local and global strength, hinge response, and comparison of analytical values of the strain hardening adjustment factor and the compression strength adjustment factor. To accomplish our research goals, full-scale element and subassemblage tests will be conducted at the University of Utah. The testing will be performed to evaluate the performance of the restrained buckling braces against the criteria outlined in the AISC Seismic Provisions, AISC 341-16. The protocol and instrumentation will also include additional criteria based on available literature. The acceptance criteria will be based on AISC 341 (AISC 2016b).

The numerical evaluation goals for TBRB frames for this research are: (1) Numerical models for the TBRB and beam-column connections will be developed and validated by experimental results from the present and previous research. These component models will be combined into a single-story frame model and validated by the TBRB single-story braced frame experimental results from an earlier Wood Innovations project; (2) Numerical models from the single-story TBRB frame model will be extrapolated into an 18-story mass timber frame to study the seismic performance of TBRB frames.

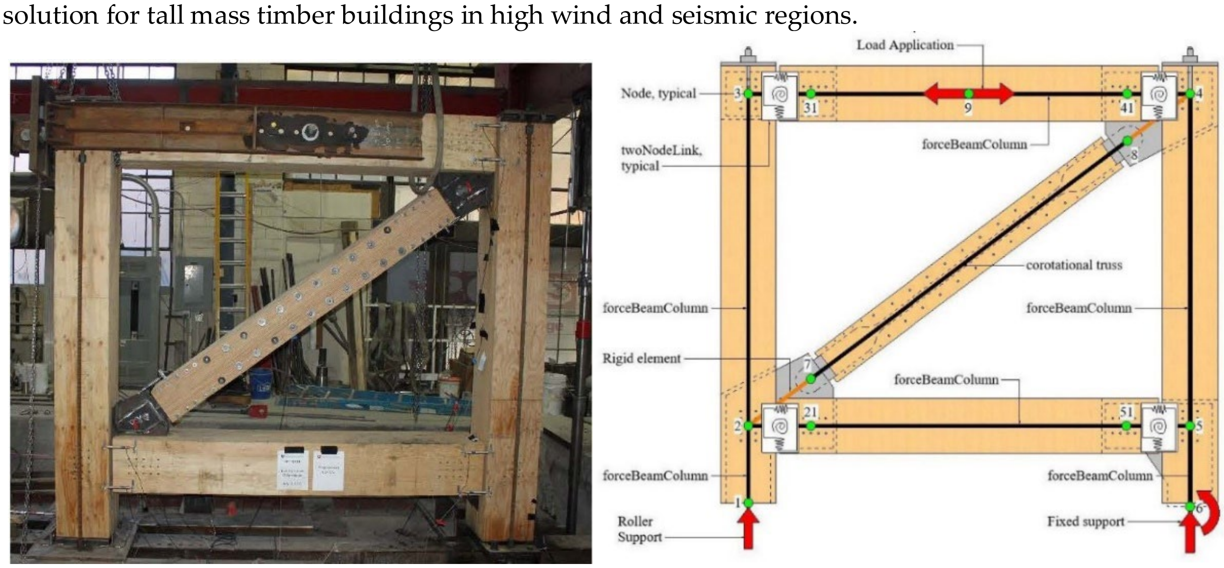
Research Approach

The team proposes to complete the engineering design and experimental verification of a mass timber-based LFRS using a mass timber brace previously developed [86]. The Timber Buckling-Restrained Brace specimens will consist of a steel core supported by a mass timber restraining system. The casing precludes buckling of the core element at the design loads by providing the strength and stiffness required to stabilize the core locally and globally. Steel core areas were selected to satisfy extrapolation limits required by AISC 341-10 (AISC 2010) Section K3. The TBRB will represent real-life dimensions. The overall length is 19 ft; the width of the core is 2 in. for 40-kip TBRB and 4 in. for 80-kip TBRB; the thickness of the core is 0.5 in., and the width and depth of the MPP timber casing vary depending on TBRB tensile strength. Braces will be connected to the gusset plate using pinned connections through standard holes (AISC 2016a). Connections of the brace to the gusset plate replicate those intended for practice per AISC341 Section K3.3f (AISC 2016b). The steel core plates in all specimens will be manufactured from steel plates. Although steel core elements are all certified as ASTM A36, the cores for all specimens will include other grades of steel, including higher strength. The selection of higher-strength steels than typically used in practice produces a suite of testing with predicted lower ductility than one would expect for production braces. However, this selection also gives higher qualified yield strength material options for braces qualified per Section F3.3e of AISC 341 (AISC 2016b).

The brace will be erected nearly vertically at the University of Utah Department of Civil and Environmental Engineering Structures Laboratory Tall Load Frame. The Tall Load Frame contains a single degree of freedom load actuator at the upper end of the frame. Brace erection involves two configurations: (a) Element test and (b) Sub-assemblage test. The following steps are taken to assemble the Element test: (1) the top fixture and gusset plate are first attached to the actuator, and subsequently, the lower fixture and gusset plate are placed and aligned; (2) the TBRB brace is erected into the fixture with the top and bottom pins. The sub-assemblage Timber Buckling Restrained Brace (TBRB) testing will be performed per the requirements of AISC 341 (AISC 2016b). In addition to steps (1) and (2) as outlined above, the following steps are taken: (3) the TBRB brace is rotated 0.02 radians to achieve subassemblage rotation, and (4) the base fixture is rotated to flat to impose rotation at the lower end of the TBRB brace and fixed into place.

The AISC341-16 Seismic Provisions (AISC 2016b) require that buckling-restrained brace design be based upon results from qualifying cyclic tests. The procedures and acceptance criteria for these tests are stipulated in Section K3. A loading protocol with a Northridge Earthquake simulated time history will be used. The protocol will be constructed similarly to seismic risk assessment protocols previously considered for buckling-restrained braces (Vidmar, Uang, and Haselton 2019). The protocol does not include low-cycle fatigue cycles to amplify the Cumulative Inelastic Deformations (CID). The area enclosed by the hysteresis graph represents the hysteretic energy dissipated by the brace. This report will calculate cumulative inelastic deformation (CID)y the method presented in the Commentary on Section K3 and Table C-K3.1 of the AISC Seismic Provisions (AISC 2016b). The Seismic Provisions require a minimum CID value of 200. Based on the results obtained from the tests, conclusions will be made regarding qualification per AISC 341, Section K3.8 (AISC 2016b). The TBRB braces will be tested and checked through a number (one or more) Time History cycles of the Northridge Earthquake. The examination will examine whether local, global, or gusset instability is observed during these cycles. The tests will be terminated once the steel core fractures.

Research by Murphy et al. [86] will be used to calibrate the numerical model for the timber BRB itself using OpenSees). Recent research carried out by at the University of Utah has established numerical models in OpenSees for the beam-column connections. In addition, a single-story TBRB frame was tested successfully under cyclic loads, as shown in Fig. 8(a). A numerical model of the single-story single-bay TBRB frame will be developed using OpenSees. The numerical model will combine elements of the models for the TBRB and beam-column connections. Force-Beam-Column elements will represent the beams and columns of the frame, similar to the beam-column connection model. Zero-length twoNodeLinks will be used to represent the horizontal, vertical, and rotational components of the connection response, and an adapted model of the TBRB will be used to model the 40-kip TBRB used in the recent tests. The gusset plates will be assumed rigid for simplicity. The entire connection behavior will be modeled with twoNodeLinks. The axial load used in the test, applied to the columns, will be included in the model using the force in the prestressed rods. Fig. 8(b) shows a schematic of the possible layout for the model; the elements for the external axial load rods are not shown for clarity. The model will be validated with the experimental results from recent research. Once the single-story frame model of Fig. 8 is validated, the numerical OpenSees model will be extrapolated to model an 18-story TBRB frame with TBRBs. Static pushover, quasi-static cyclic analysis, and dynamic analysis will be completed to compare the seismic demand on the frame to the cyclic capacity and to show the feasibility of using TBRB frames as an LFRS solution for tall mass timber buildings in high wind and seismic regions.



(a) (b)

Fig. 8 Single-story TBRB frame: (a) picture of an as-tested specimen; (b) OpenSees model.

DEIA

The IRIZE Center, through its community engagement and use-inspired research, seeks to leverage partnerships with organizations that share a commitment to advancing diversity, equity, and inclusion. In this proposal, we have championed research focus areas and topics that assist under-resourced communities in meeting climate change challenges regarding improving air and water quality, creating energy efficiency and hazard resiliency for substandard housing, and rapid housing construction technologies for displaced communities.

As we continue to plan and organize the Center, we believe the model adopted by the American Society of Civil Engineers (ASCE) Members of Society Advancing and Inclusive Culture (MOSIAC) provides a model we can emulate https://www.asce.org/-/media/asce-images-and-files/diversity-equity-and-inclusion/documents/dei-front-matter-best-practices-resource-guide.pdf. The role of ASCE MOSAIC is to promote and foster a culture within ASCE that will result in a civil engineering profession that is equitable and inclusive for all. Thought Leaders, DEI Champions, and Strategic Partners create this culture. Thought Leaders serve as representatives responsible for informed decision-making that advances DEI principles in the community. DEI Champions monitor the development and coordination of products and resources that IRIZE will produce to advance DEI. Strategic partners are organizations and community groups that will help IRIZE in research prioritization, selection, and implementation processes.

Broader Impacts

STEM Education

The IRIZE Center recognizes the importance of high school Science, Technology, Engineering, and Mathematics (STEM) education. As part of the kick-off activities of the Center, we will finalize activities that support the following goals (1) Increasing student interest and engagement in STEM subjects, (2) Improving the quality of STEM education in high schools, (3) Increasing the number of students who pursue STEM careers. To address items (1) and (2), the IRIZE team members would like to plan the creation and deployment of a "mobile" laboratory to be taken on-site to various high schools in northern Utah by U of Utah faculty, staff, or graduate students. In addition, the mobile lab would be housed in an enclosed trailer equipped with instructional benchtop experiments using ideas created by our experimental research team. In addition to the laboratory, we plan to develop companion web-based curricula to supplement our benchtop experiments and foster learning. In addition, instruction materials about our visits and other topics would be designed to assist high school instructors. (Our faculty previously developed a similar "earthquake" mobile laboratory and corresponding website. We found this an effective way to engage high school students.) We believe this approach will be an excellent way to extend STEM education to underrepresented and minority students in our communities.

Undergraduate Students

To address (3), we believe the best practice is to foster student enrollment and engagement with STEM programs at our University. The U. of Utah has "optional practical training" STEM OPT. This program is designed to provide students with an opportunity to gain a temporary employment experience in a STEM program to complement their academic work. We can also increase access to STEM education for underrepresented groups, such as women and minorities, through outreach programs, scholarships, and other initiatives to increase diversity in STEM fields. These possibilities will be further developed under this planning grant. Lastly, we believe developing and delivering a University General Education Course focusing on climate change resiliency would be a natural outcome of our collective efforts. This course would encourage undergraduate interest and inform students about our research efforts.

Graduate Students

The IRIZE Center will offer the unique opportunity to perform collaborative research in Korea and Australia. For example, the University of Utah Asia Campus (UAC) in Songdo, Incheon, Republic of Korea https://asiacampus.utah.edu/ will provide low-cost student and faculty housing and research space for collaboration projects with LH Korea and Hanyang University. The UAC also offers Urban Ecology and Engineering courses, which can augment students' academic training. The UAC is also the home of the Center for Medical Innovation (Korea). It has collaborating Universities present on the shared global campus (State University of New York (SUNY), George Mason, and Ghent (Belgium). In addition, the University of Melbourne is committed to participating in joint seminar series, exchanging students and faculty, providing access to their facilities, and exploring ways to align their research initiatives with the IRIZE Center.

Community Resiliency for Senior Citizens

Collaboration of the U of Utah Healthy Aging and Resilient Places (HARP) Lab and the proposed IRIZE Center will support the develop use-inspired research and technology by creating a "Living Laboratory" that enables co-creation and experimentation with community partners. Some partner organizations that HARP closely works with are Utah Aging and Adult Services, Utah Commission on Aging, Utah Department of Transportation, and Wasatch Front Regional Council. These organizations provide essential services and support for vulnerable user groups, such as older adults and individuals with disabilities. HARP will liaise between the IRIZE Center and our community partners to support and enable use-inspired research by developing Living Labs. Potential sites for establishing such Living Labs could be senior centers or public spaces where rapid prototyping and testing are feasible and practical. The potential benefits of moving from prototypes to infrastructure design and construction could be maximized.

Improving the Health, Economy, and Resiliency of Ecosystems

We have identified that air and waterborne contaminants pose a serious threat to communities of the tri-country partnership of IRIZE vial increased respiratory problems and other health issues for residents (see IRIZE Center's Motivations). Reducing PM 2.5 contamination is particularly urgent because it disproportionally affects Senior Citizens and School Age children in under-resourced areas [5]. The proposed stormwater management and blue-green technologies we develop will improve these communities' health, economy, and built and natural environment. We improve health by reducing the dust that reaches these communities and providing infrastructure countermeasures to capture and sequester contaminants once they are air or waterborne. Also, the Great Salt Lake is an economic resource for the region, with many industrial, commercial, and recreational uses. Furthermore, the Lake is an important ecosystem, providing habitat for millions of migratory birds and other wildlife.

Wildfire Prediction, Management, and Resiliency

The IRIZE center can help build more resilient communities and promote sustainable land use in areas prone to wildfires. Our research's social, economic, and commercial benefits include reduced property damage, lower insurance claims, and increased confidence for investors and insurers in Wildland Urban Interface (WUI) areas. These outcomes can potentially generate significant economic, environmental, and social benefits. The social and cultural benefits include the protection of lives and homes, preserving heritage buildings, and the safeguarding cultural and social assets in affected communities.

Our efforts will contribute to fundamental research by advancing our understanding of firebrand, radiant, and convective exposure and their combined impact on structures, air quality issues, and dynamic fire behaviors. This new knowledge will significantly influence the development of the physical and mathematical theory of fire safety and enable better protection of communities. In addition, we can address a broader range of fire behavior and risk management issues by addressing existing gaps in our understanding of house loss, allowing for more efficient hardening measures and prevention actions. In addition, improved accuracy and precision in predicting the impact of wildfires due to environmental changes caused by climate and local factors will allow identifying locations where damage to property and loss of life is more likely and therefore allow more efficient management and prevention actions. Improved predictions will enhance fire managers' knowledge base and ability to make informed decisions during extreme fires and better estimate community impact. These outcomes will include improving the efficiency and safety of fire suppression activities, better targeting public information and warnings, and improving an understanding of the potential effectiveness of strategies for managing fire risk in the WUI.

Operational implementation of this research within fire agencies will lead to improved fire management and risk prediction through a better appreciation of the full potential of fire behavior and an enhanced ability to anticipate dangerous escalations in wildfire development and its impact on communities. This new paradigm in wildfire and fire safety science will underpin the provision of more timely and targeted public warnings about the threat of wildfire and significant improvements in firefighter safety and understanding of the operational limitations associated with managing large conflagrations and WUI fires.

Creating Low-Carbon Communities and Multi-Hazard Resiliency

Achieving zero-carbon goals for under-resourced communities necessitates developing and adopting construction practices that rehabilitate the existing building stock and significantly improve energy efficiency. We believe nested buildings with high-performing panels will make these buildings renewable energy-ready, with lower peak loads and significantly reduced energy use overall. Because buildings nested with high-performance insulated panels are also structural panels, resilience to multi-hazard is possible (wind, tornado, hurricane, wildfire, and earthquakes). In addition, by adding 100 years of the additional lifecycle to such structures, the vibrancy and character of these underserved communities will be preserved in the U.S. and worldwide.

Rapid and Affordable Replacement Housing for Flood and Wildfire Devastated Areas

Despite our best efforts to foster pre-disaster mitigation, we believe rapid housing replacement will be required in some areas devasted by flood or wildfire events. IRIZE is currently developing a strategic partnership with CLC Global (CLCG) of Denver, Colorado. CLCG has a strategic, resilient building system and construction methods using lightweight cellar concrete, which is optimal for mid-rise residential and incremental construction. Their developing business model is low capital expenditure, scalable, and relatively low risk.

In addition, CLCG is involved in the "Climate Smart Cities Challenge (CSCC) as the Green Community Cities (GCC) Team, designed by and partnering extensively with UN-Habitat, in a demonstration project for both Affordable Housing and Climate Smart Low-Carbon Development, utilizing planning, innovative construction technologies, waste management, and integrated systems. The CSCC effort includes collaborative stakeholder engagement, staging an enabling environment, creating scalable business models, jobs, and SMEs, and generating carbon credits as revenue. In addition to affordable housing, other benefits include well-paying inclusive jobs, enhanced incomes, and lower living costs. The GCC Team has several partnerships in Kenya, especially in the Kisumu and western regions. In addition, GCC has conceived the idea of a "Kampala to Kisumu Corridor Project" (KKC) project featuring affordable housing and potentially developing multiple non-construction systems, technologies, and business models. This effort aims to create affordable, scalable, profitable housing and accompanying business models across a continuum of densities - from dense urban to rural and a range of demographics-especially women and youth.

Decarbonizing Concrete Building Materials

Recent work performed cooperatively by NREL and Lori Tunstall (Colorado School of Mines) [87] shows that the fast pyrolysis of wood sources used in biochar production yields a superior physical milled product when compared with other pyrolysis and milling methods. One of the intended uses of biochar is partially replacing Portland Concrete Cement in building systems as an additive to sequester carbon and strengthen concrete. The single superior physical milled product increases the surface area, producing more water adsorption capacity and physical sites for molecular nucleation of calcium silicate hydrate during curing. A life cycle analysis for 15% biochar binder replacement shows a 44.5% net CO_2 emissions reduction compared to 100% Portland Cement binder. This finding is important for rapidly constructing affordable, low-carbon housing (previous section) and using biochar as a potential filter and partial cement replacement material for PLCC underground storage reservoirs (see Reducing Urban Flooding and Multipurpose Decentralized Stormwater Management).

Sustainable Construction Using Mass Timber Building

The inherent sustainable nature of wood combined with the advances made using engineered wood products is attractive from the point of view of minimizing the carbon footprint of buildings.

Advancements in timber technology are creating opportunities for sustainable mass timber buildings (MTB) where otherwise steel and reinforced buildings are dominant. In high wind regions, MTBs currently lack code-defined lateral force-resisting systems; as a result, mass timber buildings are presently built with either a steel or reinforced concrete lateral force-resisting system. Our research, development, and testing of an 18-story high MTB with timber buckling restrained braced (TBRB) frame system will enable the future construction of tall, high-wind, and seismic-resistant infrastructure.

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