Design of a National Full-Scale Testing Infrastructure for Community Hardening in Extreme Wind, Surge, and Wave Events (NICHE)

Arindam Chowdhury [1], Amal Elawady[2], Hermann Fritz[3], Catherine Gorle[4], Tracy Kijweski-Correa[5], Kurtis Gurley[6], Frank Lombardo[7], Pedro Lomonaco[8], Forrest Masters[9], Kristin Taylor[10], John van de Lindt[11], Paul Vasilescu[12], Ioannis Zisis[13]

[1]Florida International University, Miami, FL, US, chowdhur@fiu.edu
[2]Florida International University, Miami, FL, US, aelawady@fiu.edu
[3]Georgia Institute of Technology, Atlanta, GA, US, fritz@gatech.edu
[4]Stanford University, Palo Alto, CA, US, gorle@stanford.edu
[5]University of Notre Dame, South Bend, IN, US, tkijewsk@nd.edu
[6]University of Florida, Gainesville, FL, US, kgurl@ce.fl.edu
[7]University of Illinois Urbana-Champaign, Urbana, IL, US, lombaf@illinois.edu
[8]Oregon State University, Corvallis, OR, US, Pedro.Lomonaco@oregonstate.edu
[9]University of Florida, Gainesville, FL, US, masters@eng.fl.edu
[10]Wayne State University, Detroit, MI, US, kristin.taylor@wayne.edu
[11]Colorado State University, Fort Collins, CO, US, jwv@colostate.edu
[12]Aerolab, MD, US, paul@aerolab.com
[13]Florida International University, Miami, FL, US, izisis@fiu.edu

SUMMARY: (10 pt)
A major interdisciplinary effort to design a new multi-university facility was recently funded through the National Science Foundation's Mid-Scale Research Infrastructure (MsRI) program. The program is led by a consortium of nine universities and a wind tunnel design consultancy firm. The project will leverage field observations, computational modeling, and physical experimentation to design a National Full-Scale Testing Infrastructure for Community Hardening in Extreme Wind, Surge, and Wave Events (NICHE).

The centerpiece of the project is an integrated design testbed (IDT) that couples computational fluid dynamics (CFD) modeling with experiments conducted in a physical design testbed (PDT) that leverages capabilities distributed across multiple experimental facilities to answer specific research questions and prototype various capabilities and components. The PDT experimental data will then be leveraged by the IDT for the design of the full-scale NICHE by [a] addressing fundamental questions on similitude requirements, [b] innovating new experimental capabilities, and [c] minimizing experimental uncertainties.

Keywords: NICHE, wind, water

1. INTRODUCTION

Extreme windstorm events (e.g., hurricanes, downbursts, tornadoes, derechos) occur annually causing damage to civil infrastructure, resulting in population dislocation, economic losses, and community disruption (National Academies of Sciences, Engineering, and Medicine, (2019)).

Increasing hazard exposure and sea level rise due to anthropogenic warming are escalating the risk to society and its assets, especially civil infrastructure, e.g., homes, buildings, bridges, and lifelines and critical utility systems. To help protect the United States against losses from extreme windstorm events, a multi-disciplinary team with demonstrated excellence in their respective disciplines and methodologies, as well as at the interfaces between them, will design a National Full-Scale Testing Infrastructure for Community Hardening in Extreme Wind, Surge, and Wave Events (NICHE). NICHE responds to this pressing national imperative to promote more resilient and sustainable communities by reducing losses, population displacement, and outmigration due to climate-driven hazards.

NICHE will provide a unique, national, multi-user facility to experimentally test and evaluate the impact of extreme winds combined with storm surge and wave actions on different types of civil infrastructure, including full-scale low-rise structures, large-scale infrastructure systems, and communities as scaled models. The design of the NICHE was recently funded through the National Science Foundation's (NSF's) Mid-Scale Research Infrastructure (MsRI) program. The NICHE design process will be led by a team drawn from nine universities and one industry partner. This project will be a component of the NSF-supported Natural Hazards Engineering Research Infrastructure (NHERI) program and will deepen NSF's contributions to the National Windstorm Impact Reduction Program (NWIRP). This presentation will deliver a comprehensive overview of NICHE, the historical context and emerging needs, and the progress to date.

2. SCIENTIFIC OBJECTIVES AND METHODOLOGY

Currently, there is no experimental facility in the world with full-scale (or near full-scale) combined wind and wave simulation capabilities to support novel investigations of the impact of climate driven hazards on our society. Moreover, (i) most existing facilities are able to simulate only one of the aforementioned natural hazards independently, and (ii) in those facilities where these hazards can be simulated simultaneously, the facility dimensions and, therefore, the scale, are significantly reduced and simplified. Hence, the design of NICHE requires a unique combination of state-of-the-art techniques to ensure its functionality and develop the ability to answer the fundamental and applied scientific questions regarding multi-hazard events.

The convergent process to design NICHE will be led by a team of multidisciplinary experts. The team will demonstrate proof-of-concept using an integrated design testbed (IDT). The IDT will enable a combined cyber-physical design process, essential to minimize the risk in NICHE's future implementation, providing a critical proving ground to (1) validate the computational modeling of the interacting hazards that can then be scaled up with confidence to inform the design of the full-scale NICHE, (2) reconcile several scientific and practical challenges associated with achieving similitude for simultaneous application of wind and water hazards in a single research infrastructure, and (3) explore design trade-offs to provide the greatest scientific return on a given investment. The proposed approach includes the use of a physical design testbed (PDT) that enables experimental simulation of single-phase and multi-phase combinations of wind and waves. The design approach also includes a complex computational fluid dynamics (CFD) component. Some of the fundamental closure and/or empirical models within the CFD component, particularly those related to the wind-wave interactions, have not been calibrated and fully validated under the conditions required at full-scale NICHE. Therefore, the design supported by CFD requires validation of some of those closure models. The PDT will take advantage of experiments at multiple existing facilities to be operated to produce experimental data needed to validate the CFD models, addressing the lack of experience and of previous validation for this type of complex coupled simulation. The validated CFD models will be upscaled to create a design for a full-scale national NICHE.

The IDT will also aid the design of the non-physical aspects of NICHE: the infrastructure enabling convergence research, workforce development and stakeholder engagement. This will result in a multi-faceted design process with the following scientific objectives:

Objective 1: Integrative Design and Assessment: use the integrated design testbed (IDT) to create a Project Execution Plan (PEP) and implementation-ready design for a full-scale NICHE facility with sufficient scope and capacity to simulate the effects of interacting coastal and wind hazards (for either synoptic or non-synoptic wind hazards) and demonstrate the facility's operational feasibility and technical readiness for future implementation.

Objective 2: Research Capacity Development: develop a convergent research capacity framework and demonstrate example testbed communities to showcase how the full-scale NICHE can integrate physical testing, computational simulation, and field observations to foster breakthroughs in climate-adaptive design and mitigation to inform policy.

Objective 3: Workforce Development: create training modules for students, post-doctoral researchers, facility operators, project managers, and faculty, and pilot test these training modules to facilitate the development of a next-generation workforce trained in a convergent approach to address societal challenges associated with climate-driven hazards.

Objective 4: Stakeholder Engagement: use policy learning tool kit and engagement protocols to develop a stakeholder engagement plan that integrates institutional and community stakeholders to create a mechanism of translating future mainstream research discoveries into policy and practice.

These objectives will be accomplished by operationalizing multiple dimensions of strategic integration depicted in Figure 1:

● *Disciplinary Convergence*: understanding that seminal discovery operates at the intersection of engineering, behavioral, social, and economic sciences

● *Methodological Convergence*: optimally leveraging the strengths of computational simulations, physical testing, and field observations

● *Institutional Convergence*: contextualizing research within disaster-affected communities to accelerate impacts on policy and practice

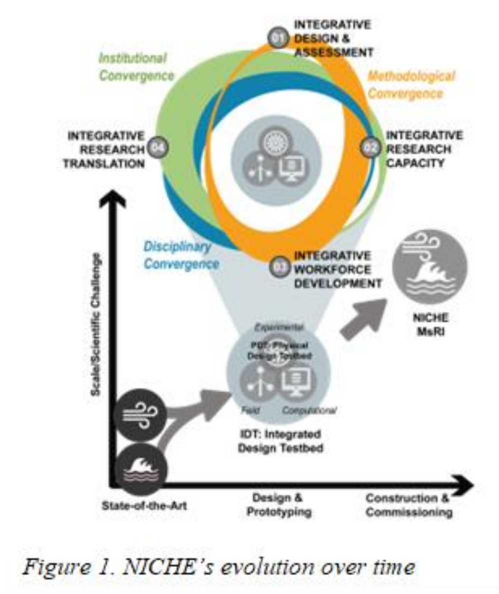

Figure 1. NICHE's evolution over time

3. ONGOING WORK

The current MsRI-1 project will develop and test prototype NICHE functionality by experimenting at (and, if needed, upgrading) four existing facilities (at UF, OSU, UM, and UCSD) and a new wind-only facility (to be built at FIU). The PDT experiments will be conducted by personnel associated with the tasks related to such experiments. The purpose of this distributed Physical Design Testbed (PDT) is to serve as a prototyping testbed to inform the design of the full-scale NICHE. The PDT will answer outstanding scientific and technical requirements associated with the formulation of requirements of the full-scale facility. The PDT will also serve as a physical prototype for certain novel components at full scale which will be included in the full-scale NICHE facility. These novel components include the fans and flow control devices to be used for simulation of non-synoptic wind conditions.

The NICHE project also is striving for a significant number of scientific and broader impacts. Direct losses demonstrate that the current methods for developing the built environment near the coast are not sustainable. To date, the research community has been unable to answer a number of high-priority scientific questions arising from the need to respond to this threat. The failure to resolve these questions stems from: (1) the inability to physically simulate coupled climate-driven hazards at the scales required to faithfully reproduce vulnerabilities in our built environment; and (2) the sole use of such experiments without engaging computational simulations or field observations required to overcome their limitations.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the NSF Mid-Scale Research Infrastructure Program (NSF Award Number: 2131961) for supporting this work. The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the position of NSF or their respective institutions.

REFERENCES

National Academies of Sciences, Engineering, and Medicine (2019). Building and Measuring Community Resilience: Actions for Communities and the Gulf Research Program. Washington, DC: The National Academies Press. https:doi.org/10.17226/25383