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The Network Coordination Office of NHERI (Natural Hazards Engineering Research Infrastructure)

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Since 2015, NHERI, or the Natural Hazards Engineering Research Infrastructure, began research operations supported by the United States National Science Foundation (NSF) as a distributed, multi-user national facility that provides the natural hazards research community with access to a powerful research infrastructure. NHERI is comprised of separate research infrastructure awards for a Network Coordination Office (NCO), Cyberinfrastructure, a Computational Modeling and Simulation Center, eight Experimental Facilities, and CONVERGE (an initiative to advance social sciences and interdisciplinary research). Awards made for NHERI contribute to NSF's role in the National Earthquake Hazards Reduction Program and the National Windstorm Impact Reduction Program of the United States. The mission of NHERI is to provide the earthquake, wind, coastal engineering, and social sciences communities with access to research infrastructure, education, and community outreach activities focused on improving the resilience and sustainability of the civil infrastructure against earthquakes, windstorms, and associated natural events such as tsunami and coastal storm surge. In this paper, the role and key NHERI activities are described for the NCO, which is led by Purdue University, along with partner institutions—the University of Texas at San Antonio, North Carolina State University, Texas Tech University, the U.S. Naval Research Laboratory, and the University of Hawaii at Manoa. The NHERI NCO serves as a focal point and leader of a multi-hazards research community, and maintains a community-based NHERI science plan. It manages scheduling for partner NHERI Experimental Facilities and coordinates all components to ensure effective and fair governance, efficient testing, and user support within a safe environment. Another important role of the NCO is to lead NHERI-wide educational and outreach activities: the network

facilitates educational experiences ranging from summer programs for undergraduates to workshops for post-docs and early-career faculty that also both involve development of K-12 lesson plans. The NCO works to develop strategic national and international partnerships and to coordinate NHERI activities with other awardee components to form a cohesive and fully-integrated global natural hazards engineering research infrastructure that fosters collaboration in new ways.

Keywords: natural hazards, network coordination, NHERI, earthquake, storm surge, tsunami, wind

INTRODUCTION

Around the globe, the vulnerability of civil infrastructure to natural hazards presents one of the greatest risks to life, safety, and property damage. It also impairs the resiliency and sustainability of communities. In the United States, the frequency and scale of disasters has grown in recent decades. The U.S. has experienced 10 or more billion-dollar weather and climate-related disasters in 9 years since 1980; 7 of them occurred in the last decade (National Oceanic Atmospheric Administration, 2020). Recent experiences with multiple hazards, such as Hurricane Katrina, the Tohoku tsunami in Japan, earthquakes in New Zealand, and tornados in Joplin, Missouri, have shown the long timescales associated with recovery from damage to civil infrastructure (Edge et al., 2020). The scientific community has recognized the need for interdisciplinary collaboration in order to reduce the loss of life, economic damage, and community disruption caused by these hazards (National Research Council, 2006).

Established to combat these risks, the Natural Hazards Engineering Research Infrastructure (NHERI) is a shared-use, distributed national facility that provides the natural hazards engineering and social science research community with a network of state-of-the-art laboratories, computational modeling and simulation capabilities, convergence-science and research network support, and cyberinfrastructure. The community of NHERI researchers, educators, and students encompasses a large group of universities, industry partners, and research institutions in the United States and abroad.

NHERI is a multi-hazard expansion of the United States National Science Foundation's (NSF) first-generation natural hazards research network focused on earthquake events, the George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES, 1999–2014). In November 1998, the National Science Board approved NEES for construction with funds totaling $82 million from the NSF Major Research Equipment and Facilities Construction appropriation. Construction occurred during the period 2000–2004. Over a decade of operations, NEES provided a vibrant collaboratory consisting of unique experimental facilities and a collaboration platform that served tens of thousands of users from over 210 nations with more than 400 multi-year, multi-investigator projects. NHERI builds upon that legacy by supporting research on earthquakes, windstorms, tsunami, and storm surge.

The objectives of NHERI are to more effectively generate, collect, and publish data; and to educate the next generation of leaders in the field of natural hazards research, particularly including a multi-hazards focus in efforts to improve the resilience of civil infrastructure. Funded by the United States National Science Foundation (NSF), NHERI's various geographically distributed components (see **Figure 1** and **Table 1**) facilitate physical tests and numerical simulation of groundbreaking concepts to protect people and communities, including their homes, businesses, and civil and lifeline infrastructure. This work enables engineering and scientific innovations to help prevent natural hazards from becoming societal disasters. In its first 4 years (2015–2018), research utilizing NHERI facilities and/or data have produced over 300 research publications, including over 160 peer-reviewed journal articles, as tracked by DesignSafe Cyberinfrastructure (Rathje et al., under review); it has also led to numerous other positive advances in the natural hazards community outlined in this paper.

The leadership of NHERI is its Network Coordination Office (NCO), whose mission is (i) to serve as a focal point and leader of a multi-hazards research community focused on mitigating the impact of future earthquakes and windstorms, including the natural hazards caused by these events such as tsunamis and storm surge, respectively; and (ii) to support the NHERI governance and coordinate NHERI laboratory scheduling, education and community outreach activities with the other awardee components to form a cohesive and fully-integrated global natural hazards engineering research infrastructure that results in a collaborative effort greater than the sum of its individual components.

In its fourth year of activities as of early 2020, this complex organization is a collaborative effort for multi-hazards research. The process of awarding the various components started in July 2015 with the establishment of the cyberinfrastructure at the University of Texas at Austin. The various experimental facilities, with the exception of the RAPID facility, were awarded throughout the period from September 2015 to January 2016. The Network Coordination Office was awarded to Purdue University in July 2016, followed by the Computational Modeling and Simulation Facility at the University of California-Berkeley and the RAPID facility to the University of Washington. As of October 2016, NHERI—supported by NSF as a distributed, multi-user national facility that provides the natural hazards research community with access to research infrastructure—was fully in place. CONVERGE, an initiative to advance social sciences and interdisciplinary research, was later awarded to University of Colorado-Boulder in September 2018 under

TABLE 1 | List of NHERI components.

Institution	Component	Location	Principal investigator	NSF award number
Florida International University	Wall of Wind International Hurricane Research Center	Miami, FL	Arindam Chowdhury	1520853
Lehigh University	Large-Scale Multi-Directional Hybrid Simulation Testing	Bethlehem, PA	Jim Ricles	1520765
Purdue University	Network Coordination Office	West Lafayette, IN	Julio Ramirez	1612144
Oregon State University	O.H. Hinsdale Wave Research Laboratory	Corvallis, OR	Dan Cox	1519679
University of California at Berkeley	SimCenter	Berkeley, CA	Sanjay Govindjee	1612843
University of California at Davis	Centrifuge Facility	Davis, CA	Ross Boulanger	1520581
University of California at San Diego	Large High-Performance Outdoor Shake Table	La Jolla, CA	Joel Conte	1520904
University of Colorado-Boulder	CONVERGE	Boulder, CO	Lori Peek	1841338
University of Florida	Wind Experimental Facility	Gainesville, FL	Forrest Masters	1520843
University of Texas at Austin	DesignSafe Cyberinfrastructure	Austin, TX	Ellen Rathje	1520817
University of Texas at Austin	Large Mobile Shakers	Austin, TX	Kenneth Stokoe	1520808
University of Washington	RAPID Natural Hazards Reconnaissance	Seattle, WA	Joseph Wartman	1611820

the NHERI umbrella. CONVERGE also coordinates several networks for sub-communities, such as the Social Science Extreme Events Research (SSEER), Interdisciplinary Science and Engineering Extreme Events Research (ISEER), and Structural Extreme Events Reconnaissance (StEER) networks, which complement a long-established research network Geotechnical Extreme Events Reconnaissance (GEER) (Peek et al., 2020). More information about each of the NHERI components is provided in **Table 1**, and the other papers comprising this special issue provide detailed descriptions of other facilities' and components' activities.

Information about the unique capabilities of each NHERI component can be found at the NHERI website[1], and more information about the 5-year award is provided on NSF's website[2]. Awards made for NHERI contribute to NSF's role in the National Earthquake Hazards Reduction Program and the National Windstorm Impact Reduction Program.

This paper describes the governance structure of the NHERI NCO and the many functions and activities it provides to support the community of NHERI stakeholders. These include the creation, maintenance, and promotion of a 5-year Science Plan; education and outreach through various intensive programs and regular communications; centralized scheduling of NHERI's facility resources; strategic promotion of technology transfer; and collaboration with likeminded natural hazards engineering facilities outside of the United States.

GOVERNANCE

The governance of NHERI consists of the Council of Principal Investigators (PIs), the User Forum, and the Network Independent Advisory Committee. These three components of the governance work together to ensure that the users of NHERI have clear and transparent access to all NHERI resources.

The Council is composed of the PIs of each NHERI Awardee or a designated substitute member, as chosen by any PI not present at the monthly Council meetings. The role of the Council is to provide collective and coordinated leadership for NHERI through the development of network-wide policies and annual work plans.

The User Forum (UF) is a NHERI-wide committee elected by the user community. The focus of the UF is to provide the NHERI NCO and Council with specific input on community user satisfaction as well as priorities and needs relating to the use and capabilities of NHERI components. The UF was established in February 2017 after a call for nominations for UF members and subsequent vote from the user community. Currently, the UF is composed of 9 members who represent the broad scientific and engineering communities served by NHERI, including representatives with expertise in coastal, earthquake, wind, and geotechnical engineering; lifeline infrastructure;

[1]https://www.designsafe-ci.org/facilities/experimental
[2]https://www.nsf.gov/news/news_summ.jsp?cntn_id=189975

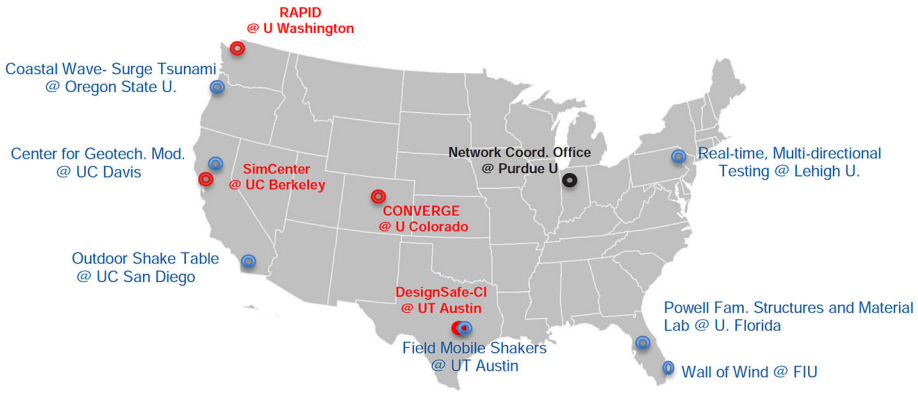

FIGURE 1 | Components of the Natural Hazards Engineering Research Infrastructure, a geographically distributed resource (experimental facilities in blue, NCO in black, and other components in red).

social sciences, and policy. Appointment for the committee members is for 2 years, which can be extended. Two *ex officio* members from the NHERI NCO are appointed to the committee to keep the NCO leadership apprised of committee progress and to coordinate any needs of the committee with the rest of the natural hazards community. There are three officers: chair, vice-chair, and secretary, all of whom are elected by the UF and serve 2-year, renewable terms.

The UF holds monthly meetings, conducted remotely, and a face-to-face meeting once a year during the Summer Institute, which is organized and hosted by the NCO. The UF oversees the annual community user satisfaction surveys for NHERI. Members of the committee also serve as representatives to the NCO, as well as to the Education and Community Outreach, Facility Scheduling Protocol, and Technology Transfer committees.

The Network Independent Advisory Committee is composed of representatives from the broader scientific and engineering communities served by NHERI. Its primary roles are to provide independent guidance and advice to the NHERI Council and to keep the community informed of NHERI activities via the publication of an annual report. To keep the community informed on NHERI activities, the committee produces an annual report which is published and publicly available on the DesignSafe-CI website hosted by the NHERI Cyberinfrastructure, NHERI's online presence.

The committee provides independent guidance and advice to the NCO on (i) progress, plans, and performance of the NHERI Awardees and annual Council work plan; (ii) an assessment of the level of community engagement and user satisfaction across NHERI, with input from the User Forum survey results; (iii) an assessment of NHERI's continuing value added and impact on research and educational advancements; and (iv) an assessment of the transparency and efficiency of the NCO's Facility Scheduling Protocol.

NHERI SCIENCE PLAN

The NHERI NCO is charged with leading the nation's multi-hazards community in the development of a 5-year research agenda that will elucidate grand challenges, key questions, and research objectives for the engineering and social science communities that study earthquake, wind, and coastal hazards. That research agenda is the basic roadmap used to develop the NHERI Five-Year Science Plan. It provides the earthquake, tsunami, wind, and coastal hazards research community, including NSF and other funding agencies, a path to high-impact, high-reward, hazards engineering and interdisciplinary research using NHERI's various facilities and components. The research results are intended to prevent loss of life, mitigate damage, and reduce the social vulnerability of populations to natural hazards.

The Science Plan is grounded on three Grand Challenges with five Key Research Questions to guide NHERI research. The research will deliver technical breakthroughs to fundamentally transform the resilience and sustainability of existing and future civil infrastructure, also known as the built environment. High-priority research subject areas are provided for each of the key research questions to assist future researchers in responding to the Grand Challenges. The Science Plan illustrates how powerful new technologies can empower researchers to accelerate the pace of innovation to achieve NHERI's goals.

Development of the Science Plan

The Science Plan Task Group was assembled to guide the development of the first Five-Year NHERI Science Plan, which was released in July 2017 (Smith et al., 2017). The plan was generated with review and input from the NHERI facility leadership, the NCO, and broad community-based participation of earthquake, wind, tsunami, and coastal engineering professionals, social scientists, and engineering education experts. Stakeholders and leaders in various fields of natural hazards research reviewed the Science Plan before it was published via DesignSafe and widely distributed through

email and newsletter campaigns. It was also highlighted as a resource for the broader natural hazards research community during several professional science and engineering meetings.

The Science Plan Task Group, along with the Network Independent Advisory Committee and User Forum, sought additional input from the professional and research communities to advance the original Science Plan through an NSF-sponsored international workshop held in March 2019. Participants gathered in interdisciplinary teams, discussed disruptive technologies, and developed research campaigns to advance the NHERI Five-Year Science Plan. The presentations and findings of the workshop are summarized in a report available on DesignSafe-CI (Natural Hazards Engineering Research Infrastructure, 2019), and they ultimately led to a new version of the NHERI Science Plan, published in January 2020 (Edge et al., 2020), also available on DesignSafe-CI.

The inclusion of the CONVERGE initiative as an integral part of NHERI seamlessly advances disciplinary and interdisciplinary hazards and disaster research (Peek et al., 2020). With CONVERGE, NHERI's mission has been expanded to identify and coordinate social science, engineering and interdisciplinary research teams before, during and after disasters. The latest version of the Science Plan reflects this broader mission.

Three Grand Challenges

The Five-Year Science Plan focuses on the process and scope of conducting multi-hazard research for more resilient and sustainable civil infrastructure and stable communities. The three grand challenges identified by the plan are as follows:

1. Identify and quantify the characteristics of earthquake, windstorm, and associated hazards—including tsunamis, storm surge, and waves—that are damaging to civil infrastructure and disruptive to communities.
2. Assess the physical vulnerability of civil infrastructure and the social vulnerability of populations in communities exposed to earthquakes, windstorms, and associated hazards.
3. Create the technologies and engineering tools to design, construct, retrofit, and operate a multi-hazard resilient and sustainable infrastructure for the nation.

As noted above, these three grand challenges are further developed into five key research questions paired with high-priority research subject areas.

Key Research Questions

The five key NHERI research questions for earthquake, wind, and coastal hazards engineering that the community believes will lead to transformative discoveries are listed below:

1. How do researchers characterize the transient and variable nature of the loading actions imposed on the nation's civil infrastructure from earthquakes, windstorms, and associated hazards?
2. How can the scientific community enable robust simulation of the behavior of civil infrastructure to loading from earthquakes, windstorms, tsunamis, and associated coastal hazards, while also considering the effects of these hazards on individuals, households, and communities?
3. What are the key physical responses, vulnerabilities, and factors influencing post-event recovery of civil infrastructure and communities?
4. What are effective and potentially transformative mitigation actions to achieve community resilience, especially when considering different hazards, shifting vulnerabilities, emerging technologies, and sustainability goals?
5. How can the scientific community more effectively collect and share data and information to enable and foster ethical, collaborative, and transformative research and outcomes?

Example of Specific Research for Key Research Question #3

Determining the key physical factors influencing the post-event recovery of civil infrastructure is crucial to reestablishing the physical and social fabric of impacted communities. Characterizing the response and performance of buildings and other structures using "vulnerability" enables the identification of threats to resilience and prioritization of research. **Figure 2** shows a large-scale earthquake simulation on a large, multistory structure which is used to identify better designs for improved building performance. Below are examples of similar research thrusts necessary to answer this question:

- Identify vulnerability indicators and metrics to be employed in resiliency analyses. Vulnerability is used here in both the physical sense of the built environment, as well as in the social sense of the well-being of community inhabitants.
- Systematically investigate interrelationships between components in systems to identify key vulnerabilities affecting resilience at all levels.
- Systematically investigate civil infrastructure and community interrelationships to identify the most efficient balance between improved mitigation and improved response and recovery.
- Enhance performance-based design procedures for tsunamis, storm surge and waves, and wind effects parallel to those available for earthquakes, particularly considering debris impact and performance of the building envelope. These procedures should enable economical designs for improved performance and life-cycle analysis with defined uncertainty. Eventually, these procedures should be integrated to produce consistent multi-hazard analysis.
- Improve system and component fragilities for use in performance-based design and loss estimation.

Specific research for other Key Research Questions can be found in the 2020 NHERI Science Plan on DesignSafe-CI (Edge et al., 2020). The 2020 NHERI Science Plan also identifies research needs that can be conducted and supported by the NHERI components. These research needs are not intended to be exhaustive but rather to encourage use of the unique NHERI research infrastructure in traditional and innovative ways.

FIGURE 2 | Large-scale hybrid simulation of a self-centering steel moment-resisting frame building under simulated earthquake loading. (Photo: Jim Ricles).

The NHERI Science Plan as a Living Document

The Five-Year NHERI Science Plan is intended to provide information for constituents, including practitioners, as well as guidance for members of the broad research community. The Science Plan will continue to be updated as feedback is received from NHERI researchers, practitioners, and collaborative communities of technology and social science. Researchers and other members of the stakeholder NHERI community are encouraged to reference the Grand Challenges and Key Research Questions when submitting proposals to NSF and other agencies that support natural hazard research for earthquake, tsunamis, wind and coastal engineers and scientists.

CENTRAL SCHEDULING

The NCO developed, with input from the Experimental Facility (EF) sites and the UF, a protocol to standardize the scheduling of NHERI projects. This protocol prioritizes NSF-funded research projects and facilities, which can be accessed by these research teams at heavily discounted rates. It is composed of six phases through which each approved NHERI project will progress. The first two phases involve training of researchers in the utilization of a facility's equipment and the development of a detailed experimental plan for how the facility's equipment will be used. These phases are scheduled at the discretion of the researchers and EF site staff. Phases 3–6 involve the real-time use of the facility; the scheduling of these portions of a project are managed centrally by the NCO's dedicated Facility Scheduler and Operations Coordinator to fairly and efficiently share the facility resources among all. **Figure 3** summarizes the scheduling process, while the following sections describe each phase in more detail.

Phase 1: User Training

During the first phase, EF sites coordinate with researchers to ensure that every participant in the project is properly trained for safety within the facility and near the test equipment.

Phase 2: Planning and Experimental Design

The second phase of each project is to produce a detailed document, called the experimental test plan, of the experiments to be performed. This important document ensures that researchers and site personnel each have a full understanding of the work to be performed on the site equipment during the scheduled time within the facility, as researchers will not be directly operating the test equipment. The researchers and site personnel work together to ensure the test plan is realistic to the site's equipment capabilities and that an adequate amount of time within the facility has been allotted to the project.

Phase 3: Specimen Construction and Instrumentation

This phase marks the beginning of the project time inside the EF site work area and the first phase to be strictly scheduled by the NCO. At this point, test specimens will be constructed for the experiments to be performed. Some EF sites have an area where this construction can be performed away from the actual test equipment, but it may be necessary that test specimens be constructed directly on the testing area due to the layout of the EF site or the specifications of certain experiments.

Phase 4: Testing

This phase is when the actual experimentation is executed. Each facility offers researchers a different level of access to operate the equipment based upon local policies for safety and liability. Some facilities allow researchers to operate test equipment after appropriate training, while other sites restrict researchers to directing how site personnel should operate the equipment to perform the experiments. These details are established for each project during the development of the experimental test plan in Phase 2, which ensures the role of each participant is clear.

Phase 5: Transferring Raw Data

This phase marks a milestone where ownership of the experimental data transfers from the facility to the researchers for analysis. Raw data from the test equipment is uploaded to NHERI data storage servers, operated by the DesignSafe Cyberinfrastructure team. Each experimental facility has local procedures in place for performing this file transfer from their unique equipment setup to the NHERI servers. Some sites perform this data transfer during the testing phase while other sites allow the data transfer to happen simultaneously with the following demolition phase. Any analysis and results of the experiments are not captured within the scheduling protocol, as they do not require any use of the EF site and fall outside the scope of the management of facility equipment utilization.

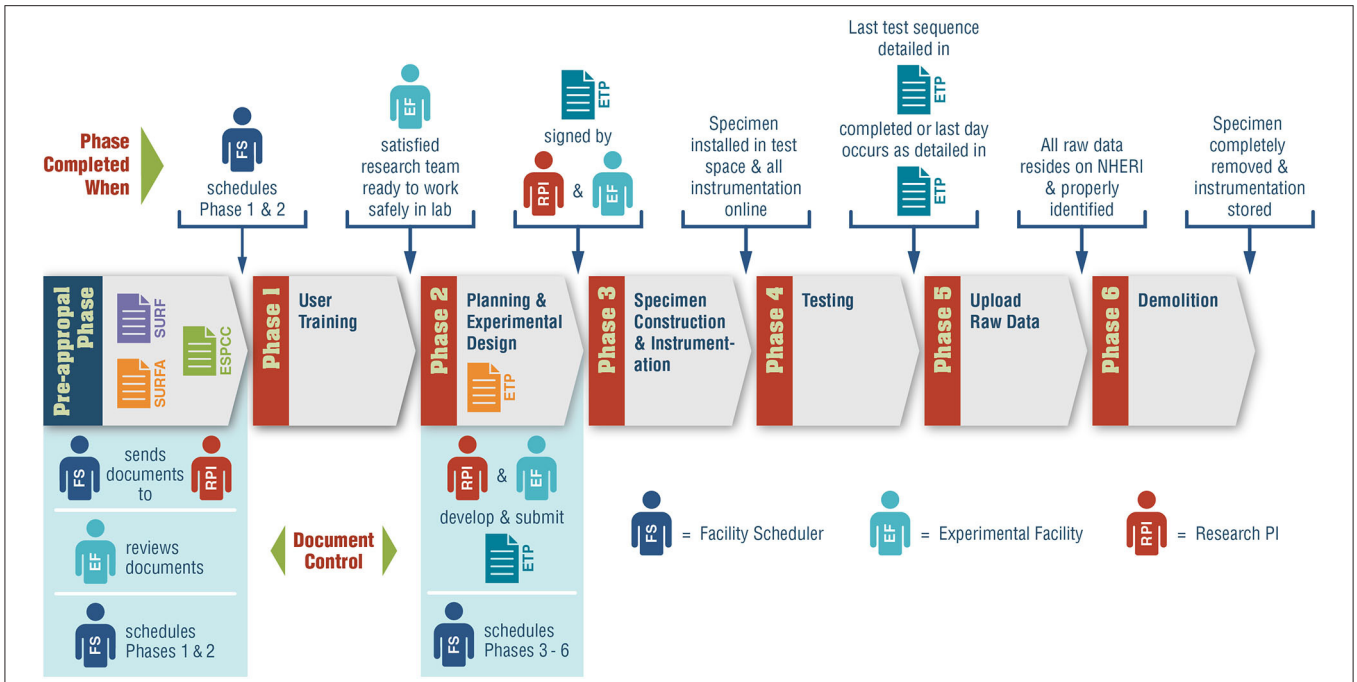

FIGURE 3 | Conceptual diagram of the NHERI central scheduling process.

Phase 6: Demolition

The final stage of each NHERI project is to remove any leftover test equipment from the EF site equipment so it can be prepared for the next project entering the space. If multiple rounds of testing are prescribed by the experimental test plan, some demolition may have occurred previously at the discretion of the EF site personnel once the use of each test specimen has ended. By the end of this phase, however, all test rigging from all experimental rounds is demolished and removed from the work area.

Using the above protocol for the experimental facilities has allowed the NCO to facilitate and support the scientific mission of each facility and support the research community with clear, equitable access to the resources needed to complete their funded projects.

NHERI Network Metrics

The Facility Scheduler and Operations Coordinator is also charged with recording and updating the metrics of the NHERI network. The current metrics for the network include: Number of NSF Awards, Days of Utilization, results from User Satisfaction Surveys, Number of Safety Recordable Incidents, and Duration Variance. Within our cooperative agreements, NSF defines utilization as the ratio of actual days of equipment utilization by NSF-supported projects to total planned days of utilization, as included in the approved final Annual Work Plan and accounting for days planned for routine equipment maintenance and calibration.

The NCO and the experimental facilities are in the process of adopting a uniform set of metrics to demonstrate throughput at the EFs that can be used to reflect level of engagement or research impact. These include metrics defined using days of use, similar to the structure reported by the NSF-sponsored Academic Research Fleet. For example, a large number of science days would intuitively reflect that the equipment facility is being commonly used in science applications and would be a useful evaluation. The metric could not be used to demonstrate utilization as a percentage of capacity, and would not reflect the efficiency of use.

Furthermore, NHERI plans to adopt a uniform practice of reporting utilization as throughput divided by capacity using local definitions of throughput and capacity. A uniform set of categories may be possible, so, for example, equipment facilities could report X% supporting the science of project A, Y% in maintenance, Z% administration, etc. The utilization percentage would be comparable across sites by category, but the raw throughput and capacity numbers likely would not be.

EDUCATION AND COMMUNITY OUTREACH

The Network Coordination Office's Education and Community Outreach (ECO) component extends the impact of the natural hazards engineering research community by engaging NHERI sites in educational and outreach activities. The main goal of the ECO is to broaden participation in natural hazards engineering research, especially within diverse groups of individuals in K-12 education, undergraduate and graduate school, and early career faculty members. To facilitate activities relevant to multiple hazards, the ECO Committee includes representatives from

all NHERI sites. The committee plans, and also strategically assesses, two flagship programs: the Research Experiences for Undergraduates program and the Summer Institute. Both are described later in this section. The committee also collects, analyzes, and reviews information from each program to understand and improve the educational and outreach experiences, and to improve the overall impact associated with broadening participation in the NHERI community.

In order to engage a diverse team of multi-hazards researchers, the ECO Committee established a common vision and related goals around educational objectives within the first grant year. The team considered research-based educational best practices as well as innovative ways to engage and leverage the various networks available to each hazard group. Team science research helped build a cohesive team within the ECO Committee (Bennett et al., 2018). Throughout the first year, continuous communication and transparency of decision-making and challenging issues helped build trust among representatives in the group. Members were encouraged to provide feedback throughout the planning and evaluation phases, and complete participation was key for the success of all educational activities.

From the start of NHERI, a committee of members representing each of the components was selected by each awardee to serve on the ECO Committee. As more awards were announced, new members to the ECO Committee were added. These individuals serve on the ECO Committee throughout the life of the grant, which helps to build rapport and establish and maintain expectations. The ECO representatives are a steering committee that strategically decides important elements of the education and community outreach components for the entire NHERI network and maintains a dynamic evaluation process.

ECO Strategic Activities

The ECO Committee plans strategic, research-based educational programs that help to connect the NHERI network with young scholars. The Research Experiences for Undergraduates (REU) summer program brings together cohorts of diverse undergraduates to conduct scholarly research, while the Summer Institute focuses on preparing early-career faculty and senior-level doctoral students to collaborate on proposals for federal funding that utilize NHERI resources in multi-disciplinary ways. Meanwhile, lesson plans for K-12 education aim to enlarge the next generation of natural hazards scholars and practitioners.

Research Experiences for Undergraduates

The NCO, through the ECO Committee, organizes a summer REU program that places talented undergraduates with senior research faculty and staff at each of the NHERI components. Starting with recruitment, the NCO through the ECO leads the dissemination of best practices in recruiting diverse students to the NHERI REU program, with the secret to success being personal communications from faculty members teaching relevant undergraduate coursework. Webinars are held to guide students through the application process, as well as to help them learn more about expectations for the summer research program. Because a large part of the mission of the ECO is to broaden participation among women, as well as racial and ethnic minority students, recruitment also involves connecting to minority-serving institutions, especially those with civil engineering, environmental engineering, and computer science degree programs. The ECO Committee has established a list of high-leverage recruitment groups to disseminate information, such as Pathways to Science, where students can learn more about NHERI and the REU program.

Because several universities operate on a quarter system while others are on a semester academic calendar, the ECO coordinates two REU blocks that intersect for a maximum number of weeks during the blocks' 10-week durations; this ensures that students across the two REU blocks can interact and build working relationships across the sites. Students in different locations use videoconferencing to learn about each other's work. They attend guided research meetings across the distributed NHERI sites to discuss individual components of peer-reviewed publications. These meetings, held on a weekly basis, allow students to share details of their research, challenges they are confronting, and successes worth celebrating.

Mentorship is a big part of the REU student experience (**Figure 4**). All students are assigned a faculty mentor, and others working at each site serve as informal mentors and guides for the students. Educational best practices are used to help guide mentors (Handelsman et al., 2005), and student researchers are also encouraged to engage with mentors in meaningful ways throughout the summer.

In order to record work produced by NHERI-REU undergraduate students, the NCO serves as a central place for deliverables to be submitted. Through the DesignSafe-CI website, the NHERI cyberinfrastructure facility archives recruitment communication, participant information, and published papers. The site serves as a focal point to easily access data, publish student-authored manuscripts, and quickly disseminate information to other stakeholders.

Summer Institute

The second flagship educational program, the NHERI Summer Institute, helps prepare early career faculty for writing collaborative research proposals within an interdisciplinary, multi-hazards research community. Each year, ∼20 participants from multiple disciplines—tenure-track assistant professors, post-doctoral fellows, and senior-level graduate students—are offered travel awards to participate in the 2.5-day Summer Institute.

During the Summer Institute workshop, participants learn about the NHERI Science Plan and also provide feedback on it. Speakers from each of the NHERI components present an overview of the various facilities and resources available for early-career professionals' research use. An NSF Program Director also typically presents a workshop geared toward providing valuable information about submitting grant proposals to NSF. A separate workshop speaker presents information about the NSF CAREER program[3]. Successful NSF and CAREER awardees also share their experiences in a panel, answering participants' questions and providing useful perspectives on the proposal process.

[3]https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503214

FIGURE 4 | NHERI REU students form close relationships with peers and mentors.

Throughout the Summer Institute, funded participants work in interdisciplinary teams to propose solutions to the Grand Challenges posed by the NHERI Science Plan (**Figure 5**). These groups are challenged with building a collaborative proposal concept, taking into account multiple hazards and innovative research methods. Additionally, the teams of attendees have valuable opportunities to network in formal and informal ways; the workshop agenda includes networking luncheons, time to interact with the NHERI Program Director and presenters, and an excursion to the city's most popular tourist sites.

K-12 Lesson Plan Development

Through both flagship activities, participants in the REU summer program as well as the Summer Institute also develop K-12 lesson plans, which are tested by teachers with their students and submitted to TeachEngineering for publication. Guided by a K-12 educational specialist, participants in both programs learn about engaging young scholars to build their experiences in providing broader impacts to the community. These valuable experiences give researchers an important perspective on the significance of developing working relationships with educators. Both educators and researchers gain valuable perspective about the importance of motivating young learners into natural hazards engineering careers.

Strategic Activity Outcomes

The ECO Committee engages in formative evaluation of the strategic programs; pre- and post-assessments collected for both the REU and the Summer Institute inform changes to the programs. Analyses are compared on a yearly basis and give the ECO Committee information about the successes and challenges of the intended goals for each program. Additionally, the committee collects longitudinal data to review the success of the programs after participants complete the program. From this initiative, the entire NHERI community has learned about the impact of the network's educational objectives. At the time of this publication, 22% of senior-level graduate students and post-doctoral fellows who attended the Summer Institute have secured tenure-track appointments, and 23% of early-career faculty have secured competitive federal grant funding as Principal Investigators (PI) or co-PIs, with an average award of $263K, including two CAREER award winners. Undergraduate students who complete the NHERI REU program ($N = 45$) reported exceptional retention in their engineering and science majors: All REU alumni respondents ($N = 42$) remain in their major or have graduated from their STEM degree program. Of those who graduated, 39% are continuing on to graduate studies immediately after completing their undergraduate degree, with five students (11% of NHERI REU alumni) already continuing for PhD work.

INTERNATIONAL PARTNERSHIPS

As evidenced by events such as New Zealand's Canterbury earthquake swarm; Japan's Tohoku tsunami; hurricanes Katrina, Sandy and Maria; and the 2011 Joplin tornado in the United States, communities can take years to recover from widespread infrastructure failure and damage associated with natural hazards. To mitigate the consequences of these kinds of events, many nations have put forth significant efforts toward improving the resilience of their infrastructure. The NHERI network, and similar networks around the globe, significantly enhance natural hazards research, facilitating studies previously presumed impossible (e.g., large-scale hybrid simulations of earthquake effects on structures). These natural hazards networks—recognizing complementary resources—have also formed bi-lateral partnerships with counterparts in other nations to enable access to facilities and data. For instance, the United States' Network for Earthquake Engineering Simulation (NEES, 1999–2014) established strong ties with the European Union's Seismic Engineering Research Infrastructures for European Synergies (SERIES) network through joint activities. This led to the CELESTINA project for shared access to a wealth of experimental data by NEES and EU researchers (Taucer and Apostolska, 2015). NEES' partnership with Japan's National Institute for Earth Science and Disaster Resilience (NIED), specifically the Miki City laboratory Hyogo Earthquake Engineering Research Center (best known as "E-Defense"), enabled several bi-national capstone experiments. These include Controlled Rocking of Steel-Framed Buildings with Replaceable Energy Dissipating Fuses (PI Deierlein, NSF 05-30756) to confirm the viability of combining conventional

FIGURE 5 | Summer Institute early career faculty work in interdisciplinary teams with NHERI researcher mentors.

steel-braced framing with rocking-mobilized energy-dissipating shear fuses; Tools to Facilitate Widespread Use of Isolation and Protective Systems, a NEES/E-Defense Collaboration (PI Ryan, NSF 07-24208/11-13275) to evaluate knowledge gaps and design assumptions in base isolation technology with special attention to non-structural content protection; and NEESWood: Development of a Performance-Based Seismic Design Philosophy for Mid-Rise Woodframe Construction (PI van de Lindt, NSF 05-29903) to develop a performance-based seismic design approach to enable mid-rise wood frame construction.

NHERI was established by NSF to inform the broader global vision of earthquake, wind, and coastal inundation risk mitigation. As such, the NCO has worked to secure similar commitments from leading earthquake, wind, and coastal engineering organizations in Japan, Korea, China, and Europe for the purposes of research collaboration, access to facilities, data exchanges, assessment of post-event damage to civil infrastructure, and to conduct educational and outreach activities. The NCO also explores new collaborations with partners in Europe, Central and South America, and Asia on topics such as elaborating a research roadmap to promote collaboration of research infrastructures in multi-hazard engineering, post-disaster data collection, and new instrumentation and sensor techniques. These partnerships will identify priority topics for transnational access to large-scale research infrastructures. They will also facilitate development of innovative technologies for efficient use of research infrastructures, including robotics and real-time hybrid simulation.

In July 2017, a new phase of research collaboration on earthquake engineering between the US and Japan broke ground with the signing of a Letter of Agreement between NHERI and the National Research Institute for Earth Science and Disaster Resilience (NIED) on earthquake engineering research, using E-Defense and NHERI facilities. The First Planning Meeting discussed the details of a new research collaboration, identifying both the scope of the first research collaboration under the framework of NHERI and NIED agreement, and the process for research collaboration over the coming years. Reports from collaborative planning meetings between the organizations are hosted on DesignSafe-CI[4], with the most recent meeting held in December 2019. In February 2018, with support from the RAPID facility, Texas A&M professor Maria Koliou and her team collected data on two full-scale, three-story wood-frame buildings (NSF project #1829433, funded under the NHERI-NIED/E-Defense research collaboration) (**Figure 6**).

The National Center for Research on Earthquake Engineering (NCREE) was officially established in 1990 through a joint effort of the Ministry of Science and Technology and the National Taiwan University. NCREE became a non-profit organization under the supervision of the National Applied Research Laboratories in 2003. NCREE currently operates two laboratories (Taipei and Tainan) and is able to conduct long-stroke, high-velocity shake-table tests, and cyclic quasi-static tests under extreme high axial loads. NCREE and NHERI signed a Letter of Agreement in August 2017 during a tour by NHERI representatives of the NCREE Tainan facility. The mission of NCREE is aligned with NHERI and includes the promotion of international research on earthquake hazard mitigation and emergency responses to pre-quake preparation and post-quake recovery.

The third NHERI international agreement, signed in July 2018, is with the EUCENTRE Foundation. The European Centre for Training and Research in Earthquake Engineering of Pavia, Italy (EUCENTRE), has developed and constructed an array of experimental laboratories focused on seismic simulation of earthquake effects on full-scale structures and non-structural elements, which include a high-performance uniaxial shake table, a multiaxial shake table, a bearing tester system for full-scale testing of isolation devices, a damper tester system for tests

[4]https://www.designsafe-ci.org/facilities/nco/partnerships/nied

FIGURE 6 | Full-scale test of two wooden houses at E-Defense.

on dissipative devices, and a system for hybrid simulation and pseudo-static tests.

TECHNOLOGY TRANSFER

The NHERI NCO sponsors a Technology Transfer Committee (TTC) composed of a group of ∼20 volunteer practitioners and decision makers. The committee works to strengthen ties between NHERI researchers and the implementers of NHERI–developed technology. Members are experienced in contributing to the development of design guidelines, technical briefs, building/infrastructure codes and standards and technical seminars regarding earthquake, wind, tsunami and storm surge, and geotechnical issues. Although code committees and other implementation groups are often generally aware of ongoing applicable research, it is less common to see a coordinated, systematic review of all natural hazards risk-reduction research for the potential for practical implementation.

The TTC's primary task is to review the results of NHERI research projects in order to identify findings that could immediately lead to improvements in the design process resulting in mitigation of risk due to natural hazards. Another task is to educate researchers, particularly young researchers, regarding the many ways in which research in natural hazard risk reduction is implemented and the characteristics of research results that are most often implemented.

In the first 3 years of the NHERI program, over fifty NSF awards in various stages of completion have been reviewed. Several awards have been identified as having potentially implementable results. Members of the TTC have contacted the researchers in these cases and offered suggestions about implementation of the results moving forward.

The committee has published instructional material and guidelines for researchers aiming to promulgate their work into building codes and standards or to influence regulation. The document, "Mechanisms for Implementation of NHERI Research Results," is a resource to the NHERI research community (Holmes et al., 2020). It describes not only building code applications, but also other paths that can lead to improvements in design practices as a result of research. The paper is available on the DesignSafe-CI website as well as at user workshops held for potential researchers at NHERI Experimental Facilities.

In the third year of the NHERI NCO award, a one-and-one-half day meeting was held that included all members of the TTC and a representative of each NHERI facility. The meeting was both for the TTC to further discuss research awards that have been reviewed and to develop a closer relationship between the TTC and NHERI researchers. Importantly, the group defined activities that would improve the effectiveness of the TTC in future years. These improvements include wide dissemination of the "Mechanisms" paper, more direct communication with researchers, and making TTC members available to researchers interested in implementation of their research.

Based on the first few years of activity of the Technology Transfer Committee, the committee should greatly increase the practical impact of the NHERI network.

COMMUNICATIONS AND ENGAGEMENT

The primary mission of the communications and outreach arm of the NCO is to position NHERI as the nation's top source for natural hazards expertise and information. This involves promoting NHERI—its activities and accomplishments—to the external community while also unifying and informing NHERI's own network of 11 diverse, distributed facilities. The communication and outreach challenges are met through a combination of traditional digital formats, such as email and newsletters, as well as through a more dynamic social media campaign and website.

Tools of Engagement

The backbone of the network's communications tools is the NHERI cyberinfrastructure, known as the DesignSafe Cyberinfrastructure (DesignSafe-CI). DesignSafe-CI is physically based at the University of Texas-Austin, as part of the Texas Advanced Computing Center (TACC). DesignSafe-CI not only serves as the high-performance computing resource for natural hazards researchers and home to the NHERI network's data center; it also provides an ideal communications hub for the entire NHERI network. Via DesignSafe-CI, the NCO's

communications and outreach activities provide a website and real-time communications for researchers and practitioners.

Online Communications

The NHERI DesignSafe-CI website holds key documents and information for NHERI network users, as well as anyone interested in the subject of natural hazards research. NCO communications have focused on establishing a dynamic newsroom which regularly issues feature stories, news releases, and research highlights that capture ongoing output from the NHERI facilities and their researchers. This also includes DesignSafe Radio[5], a podcast series that interviews researchers about their experiences and provides topical coverage of natural hazards news. The newsroom serves as a resource for NHERI-branded logos and a launch pad for external communications on social media platforms. The DesignSafe-CI website also enables a location for educational webinars and event registration.

All experimental facilities have template websites on DesignSafe, enabling them to showcase their products and expert personnel. Because the NCO does not control or maintain the DesignSafe-CI website, close coordination and collaboration with the Cyberinfrastructure facility within the NHERI network has been needed to add network-wide communication functionality (e.g., the newsroom, a calendar, and network logos). Furthermore, not all NHERI facilities have trained communicators who can readily update and manage their NHERI website presence, so the NCO works to coordinate and encourage this.

The NHERI community also has access to real-time communications through an open-access Slack server hosted by DesignSafe-CI. Slack enables users to discuss their work within one of nearly 100 topical channels from anywhere around the world. The channel-specific nature of communications ensures a focused exchange of information. Consequently, heavy users have been engineering researchers involved in computational simulations and people soliciting volunteers and posting details of field work during post-disaster reconnaissance efforts.

Newsletters

For the NCO, newsletters sent via email are the primary mode of internal communications, within the NHERI network. The NCO solicits news from individual facilities to disseminate across the network in a monthly email newsletter, the "Monthly Recap." The newsletter broadcasts media coverage, new grant awards, student activities, upcoming workshops, recent successes, and any other network-wide relevant information. A second publication, "The Quarterly Newsletter," contains longer stories focused on research projects hosted at the NHERI sites. To address the challenge of convincing busy faculty researchers of the benefits of promoting their work beyond a narrow publishing community, the NCO maintains monthly person-to-person communication between an NCO member and each component's principal investigator. This often provides the inspiration for upcoming stories. NCO communications staff minimize time requirements for researchers by providing initial story copy for revision and review.

Calendar

The NCO communications staff also provide a calendar on the DesignSafe-CI webpage that tracks webinars, conferences, training, and other relevant network-wide activities. The calendar provides quick access to a centralized information source where all activities across the NHERI network can be easily found.

Branding

To be recognized as the go-to source for natural hazards engineering, a unified branding across the NHERI network is a necessity. Led by the NHERI NCO, a series of NHERI site-specific logos with a common color scheme and graphical representation were created and adopted by each NHERI site. Additionally, the NCO developed presentation templates containing proper logo branding as well as introductory slides of the NHERI network to be used by the NHERI components whenever NHERI research is presented to outside communities. Lastly, inclusion of the NSF logo has also been an important part of the branding and results in exposure to a wider community of research.

Email Subscriptions

The NCO employs external mailing lists to create and send messages and to monitor the success of our external campaigns. It disseminates information about NHERI activities to national media entities, to engineering and social science researchers and practitioners, to college students, and to government agencies involved with natural hazards engineering and social science research.

External messages take two general forms: news releases, which go out on an *ad hoc* basis to over 500 subscribers, and a curated Natural Hazards newsletter, published weekly to over 250 subscribers. News releases announce major findings and activities, while the Natural Hazards newsletter is a roundup of research papers and news stories of interest to natural hazards researchers. The biggest challenge is communicating specific research information to a broad natural hazards research audience. For example, many earthquake engineers may be uninterested in learning about successes in hurricane storm surge mitigation. Nonetheless, NHERI email communications typically generate a very high open rate of 40% or higher. By design, the NHERI network, composed of researchers studying a wide range of natural hazards, is tackling collaborative research which has led more and more researchers to see the tremendous value of sharing data, experiences, and tools across multiple natural hazards. It is anticipated that this content will continue to grow in popularity as researchers recognize the importance of interdisciplinarity and connections between best practices in different hazards.

Social Media

Once more traditional digital forms of communication were established, the NCO communications turned to establishing a robust social media presence. The platforms selected are two of the most commonly recognized across the research community: Facebook and Twitter, with over 1,500 combined followers as of

[5]https://www.designsafe-ci.org/podcast

May 2020. NHERI tweets reach over 400 impressions per day. NCO communications outreach goals outlined for the NHERI network participants are specified as follows: (i) NHERI posts and tweets should encourage followers to learn more about NHERI and consider using NHERI facilities for their research purposes, and (ii) NHERI research sites should actively engage with other components, faculty, and students. NHERI site participation involves tagging other known NHERI sites, faculty, and/or student handles in their posts. NHERI's social media campaign has seen substantial growth since becoming a major focus in the middle of 2018.

SUMMARY

As described in this article, the NHERI Network Coordination Office provides leadership and multiple services to the greater community of natural hazards researchers, practitioners, and students within the United States and internationally. Through its efforts to lead the research agenda, coordinate experimental and post-event field research, disseminate research findings, partner with international facilities, and educate and inspire the next generations of natural hazards engineers and social scientists, the NCO is an effective team to reduce risk and ensure community resilience to natural hazards for years to come.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

Written informed consent was obtained from the individuals and minors' legal guardian for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

All authors are affiliated with the NHERI NCO and listed alphabetically by surname. Each section of the manuscript was led by a particular author, with additional contributions from others. DJ compiled and edited the manuscript, with helpful revisions provided by all.

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The handling editor is currently organizing a Research Topic with JR, and confirms the absence of any other collaboration.