Bracket 1

Entrant Information

I am submitting this entry as:
a team leader on behalf of my team

Big Idea Information

Title of your Big Idea
Preempting Natural Catastrophe

Upload an image to represent your Big Idea or your team.

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What are your scientific or engineering research interests or areas of expertise?
Natural hazards (wind, seismic) engineering and science

What is the compelling question or challenge?
The impact of extreme geophysical events on society is both acute and chronic. Can we reinvent design and construction to futureproof society from natural disasters?

What do we know now about this Big Idea and what are the key research questions we need to address?
More than half of a century of research in engineering and earth, ocean and atmospheric sciences has generated the knowledge to predict the effects of natural hazards on infrastructure and communities. For example, the skill of numerical weather prediction models increased by one day per decade over the last 40 years, and we can model earthquake and wind damage to complex, interdependent networks of buildings, electrical and water utilities, cyber infrastructure, and transportation services at regional scale. Coupling of physical modeling, economics, urban planning, and social science now enables the holistic assessment of community resilience.

The NSF has played a key role in driving the discoveries that led to these advances, having supported [a] research across all directorates to elucidate the phenomenology of severe weather and extreme geological events and to innovate new technologies that improve community resilience and [b] dedicated shared-use facilities (e.g., the Natural Hazards Engineering Research

Infrastructure and the Lower Atmosphere Observing Facilities programs) to accelerate research. The resulting knowledge has advanced building codes, standards, and community planning, informed industry practice, and shaped how the public and private sectors approach preparation, mitigation, response and recovery.

Despite these long-term efforts, the disruption to our nation's prosperity and welfare caused by natural hazards continues to escalate. The frequency of billion-dollar disasters caused by weather and climate alone is increasing at an average rate of 5% per year, with the US sustaining a $306B economic loss in 2017. Without a new strategy, our society will continue to be trapped in a recurring cycle of endure-and-recover, whereby humans grow accustomed to accepting that infrastructure will fail, even at below design level. The proposed idea rejects this assumed reality, positing that the architecture, civil engineering, and construction fields are primed for a major reimagining with broad input from other fields such as advanced computing, additive manufacturing, bio-inspired engineering, robotics, social and physical sciences, and the humanities.

This endeavor will introduce research questions across multiple themes. First, the current philosophy for design must evolve from meeting 'code minimums' to achieving an optimal design without violating constraints derived from limit state analysis (e.g., material yielding, structural instability) and other requirements for life safety, health, and general welfare. Second, the new framework must be interpretable by both human and machine to accommodate interaction with artificial intelligent (AI) and autonomous systems. Third, we must approach construction like advanced (precision) manufacturing. Today, robotics and autonomous systems represent a small fraction of the construction market, but it is poised to explode in the next two decades. By virtue of its mission, NSF is uniquely positioned to create fundamental knowledge about autonomous, connected systems constructing engineered systems at architectural scales. Fourth, harnessing the proposed integration of humans and automation presents new challenges for human oversight. Intensive computation cannot supplant our responsibility for ethical decision-making. Fifth, the path to accelerate research will necessitate international networks of collaboration to leverage intellectual resources and to amplify opportunities to transfer knowledge to practice.

Why does it matter? What scientific discoveries, innovations, and desired societal outcomes might result from investment in this area?

Recent experiences with Hurricanes Florence and Michael, the Joplin and Moore Tornadoes, the Thoku Earthquake have instilled in society the expectation that infrastructure and lifelines are destined to fail or lose function during or following a natural hazard event.

Rational science offers a far more promising outlook. Creating hazard resistant infrastructure is feasible by modern engineering standards, but scalability is constrained by inefficiencies in our human-heavy approach to design and construction. Absent a new approach, the growth of hazard prone communities will continue unabated in a manner inconsistent with risk, accelerating vulnerability. Investment by NSF will foster convergence between diverse disciplines and strengthen inter-governmental efforts by FEMA, NIST, and others to reduce the loss of life and property. These agencies have a vested interest in seeing machine learning, remote sensing, robotics, VR/AR, and other technologies be adapted into the tools that preempt disaster.

As one example (inspired by the second theme), consider the long-term benefits of NSF-led research in human-computer interaction to [a] conceptualize design schematics/renderings from multimodal input (e.g., natural speech, gaze, gestures, haptic feedback) and [b] use virtual/augmented reality or holography to project an optimized design with estimates of cost, construction scheduling, and the bill of materials, while using advanced informatics to access critical information not usually available until the design is complete (e.g, locally availability of materials to improve sustainability or a probable maximum loss to project underwriting cost).

Putting this information at the 'fingertips' of the design team will enable them to focus on maximizing building function, efficiency, and aesthetics, while the AI system ensures the underlying engineering is in place. This approach will reduce design and construction errors, produce better designs at less cost, and enable designers to boldly push the envelope of infrastructure performance. It will also open a pathway to diversify the disciplinarity of a fairly monolithic workforce. Expertise in social science, human factors, and human behaviors (e.g. preparation and response to hazards) will be more loudly heard, as will the purely artistic/creative minds seeking to promote ingenuity in design.

As a second example (inspired by the third theme), consider construction automation. Conventional methods are reaching an end, and the unoccupied innovation space is vast. NSF can drive the use of autonomous systems forward, leveraging ongoing investments in third wave AI, human-robot interaction, data fusion, IoT, cybersecurity, among other technology thrusts. The timing is ideal to creating a rallying point for researchers and industry partners to reinvent the process; further, the large commercial potential will create many opportunities for NSF’s industrial innovation and partnerships programs.

If we invest in this area, what would success look like?

Short-term success will look like the first building codes written to be interpretable by both human and machine, signaling the acceptance of AI and robotics as integral technologies for design and construction. Codes will then evolve from a broad collection of minimum requirements for safety, health, and general welfare into frameworks to optimize complex, interdependent systems while incorporating sound engineering principles. Ultimately, success will look like the first community emerging from an extreme event dominantly unscathed and without major disruption to its commerce and functioning. That moment will be when history records a change in human perception of hazard vs. catastrophe. This experience will inspire other countries to adopt similar mindsets, eventually reducing the impact of local disasters on the global economy.

Success will also take the form of a revitalized and upskilled workforce encompassing architecture, civil engineering, and construction. Future workers will be adept at interfacing with soft/hardware through hybrid virtual systems, haptics, holography and other technological modalities and communicating with AI agents that control aspects of the design (e.g., structural and geotechnical engineering, architecture and mechanical functions). The time required to produce a complete design will reduce from months to a few sessions lasting a few hours, and include a more skill-diverse workforce. Designs will be optimized based on constraints customized to regional risk, intended function, green considerations, and the interdependent infrastructure. Builders and contractors will become experts in human-robotic interaction, using these technologies to reduce errors, increase productivity and improve safety to levels unattainable in today's paradigm.

Why is this the right time to invest in this area?

The US urgently needs to accelerate research to make infrastructure investments more affordable without causing a tradeoff in their ability to withstand natural hazards. Severe weather and geological events are increasingly disrupting the prosperity of communities worldwide, particularly in the US, which has high population and infrastructure densities in hurricane and earthquake prone areas. Within 50 years, the US population will increase by 100 million people. Evacuation and refuge will not be options for many, especially for those who are more socioeconomically vulnerable to natural hazards. Exacerbating this issue are emerging national crises around the rising cost of materials and a shortage of skilled construction labor. Economic growth will ultimately be limited by the efficiency, quality and hazard resilience of our infrastructure. The current system is doomed to repeat an unacceptable cycle absent the proposed investment to separate the catastrophe from the hazard.

Please give us three key words describing the Big Idea.

Natural hazards, optimal design, automated construction

Publication/Citation References (optional)

In the boxes below, you may list up to 3 publication/citation references, either by text or link.

Reference #1

Natural Hazards Engineering Research Infrastructure Five-Year Science Plan, Multi-Hazard Research to Make a More Resilient World, National Science Foundation, July 2017.

Reference #1 URL

http://www.designsafe-ci.org/facilities/nco/science-plan/

Reference #2

NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters. 2018

Reference #2 URL
https://www.ncdc.noaa.gov/billions/
Reference #3
Bauer, P., A. Thorpe, and G. Brunet, 2015: The quiet revolution of numerical weather prediction. Nature, Vol. 525, 47-55.

Reference #3 URL
http://www.nature.com/articles/nature14956
Agreements and Validations

I consent to NSF's use and display of the submitted information and contestants' names and likenesses.
I agree

I confirm that all individual, teacher, and team entrants meet the age and citizenship/residence requirements, and agree to abide by all rules of the NSF 2026 Idea Machine as described in the
eligibility criteria and rules
.
I agree

Forms and Releases

All individual and team entrants must be at least 14 years of age as of September 1, 2018.

Individuals: If you are under 18 years of age, please upload a completed parental/guardian permission form (located in the Quick Links to your left) here.

Team leaders: Please collect the signed parental/guardian permission form for any team members younger than 18 years of age (including yourself) and combine them into one document to be uploaded here.

Teachers entering on behalf of high school classes are not required to submit parental/guardian forms on behalf of their classes.

Please upload a completed NSF1515 Form (located in the Quick Links to your left) here. Team leaders: Only one completed form is necessary for the whole team.

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