

# **NCST Technical Investigation of Hurricane Maria (Puerto Rico)**

## **Performance of Critical Buildings Project**

**Project Leaders:** Joseph Main and Marc Levitan

**Objective:** To characterize the performance of critical buildings in Hurricane Maria by evaluating damage and loss of function for representative hospitals, schools, and storm shelters with respect to the hazards they experienced, including an evaluation of selection criteria and design requirements for storm shelters.

# Background and Motivation

Engineered buildings with good structural performance suffered significant ***damage to building envelopes***, and penetration of rainwater resulted in extensive ***nonstructural damage*** and ***loss of function***:

- roof covering and rooftop equipment damage from wind and windborne debris;
- window and door damage caused by wind and windborne debris;
- rainfall ponding on the roof due to excessive rainfall rates and debris blocking drains; and
- wind-driven rain penetration through undamaged cladding, such as windows and doors.



Loss of power and failure of backup generators also disrupted the function of some critical buildings, including hospitals, schools and storm shelters

# Project Plan: Data Collection (1/2)

**Initial Data Collection:** Coordinate with Puerto Rico government agencies, federal partners, and others to identify and collect relevant existing data:

- characteristics and performance of hospitals, schools, and shelters
- shelter program information, including selection criteria and facilities used

**Sample Selection:** Select representative hospitals and schools/shelters for detailed evaluation, considering characteristics of buildings, hazards, other factors

**Facility Evaluations:** Collect information for selected critical facilities to document:

- **Phase 1:** initial document collection and review
- **Phase 2:** interviews, additional document collection (and field investigation)

**Wind Tunnel Testing:** Test scale models for a subset of the selected buildings

- building models will be extensively instrumented to measure wind loads
- effects of surrounding topography and buildings will be considered

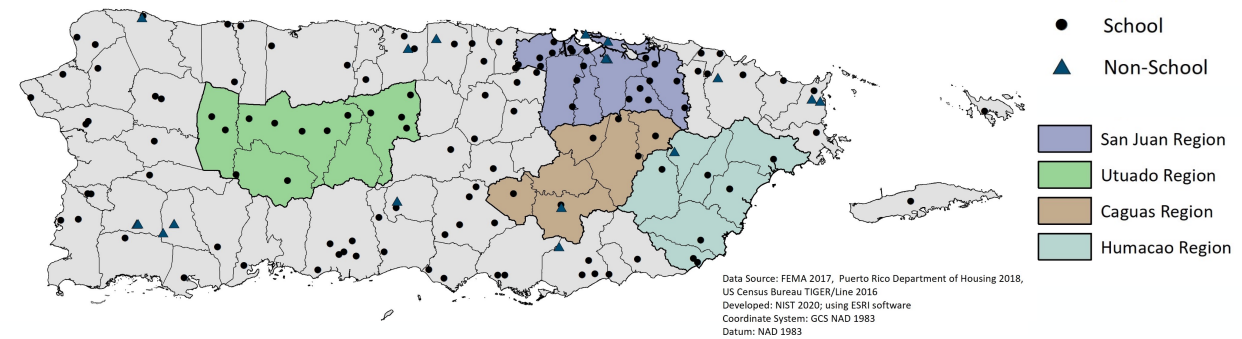
# Project Plan: Data Analysis (2/2)

- Evaluate the performance of selected critical buildings with consideration of:
  - wind loads and other hazards encountered during Hurricane Maria
  - damage to buildings and impacts on function of buildings and life safety of occupants, including operational challenges encountered
  - adequacy of existing codes, standards, and practices
- Evaluate shelter selection criteria, design criteria, and operational guidance for the larger population of shelters with consideration of:
  - hazard levels encountered at shelter sites and damage to shelter buildings
  - shelter population per site over time, including relocation of occupants
  - adequacy of existing selection criteria, design criteria, and operations plans
- Develop findings and recommendations, as necessary, for specific improvements to building codes, standards, and practices based on the findings, including consideration of seismic hazards

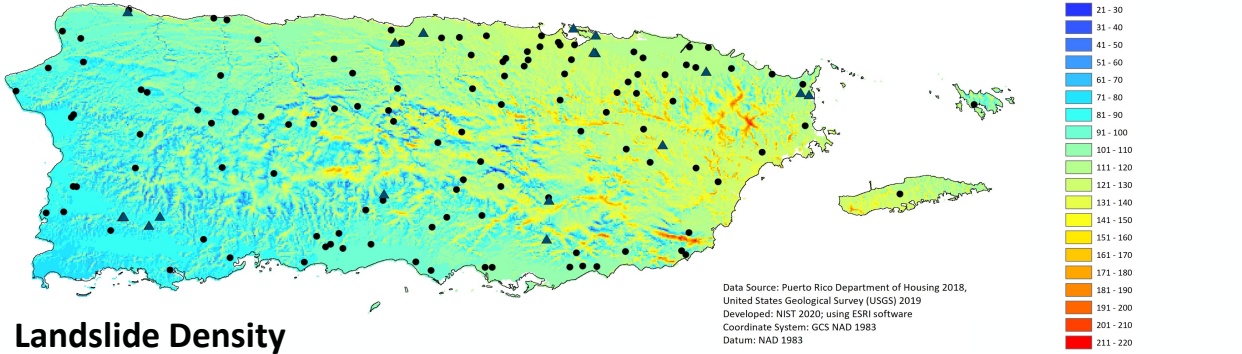
# Recent Progress: Initial Data Collection and Sample Selection

- Relational databases developed for linking various sources of information for hospitals and schools/shelters:
  - hazard exposure at facility sites
  - building characteristics
  - reported damages
  - shelter population over time
- Set of 10 “linking” hospitals selected to facilitate coordination across projects; five hospitals from this list selected for detailed evaluation
- Sampling strategy for schools/shelters is currently in development using information from database queries

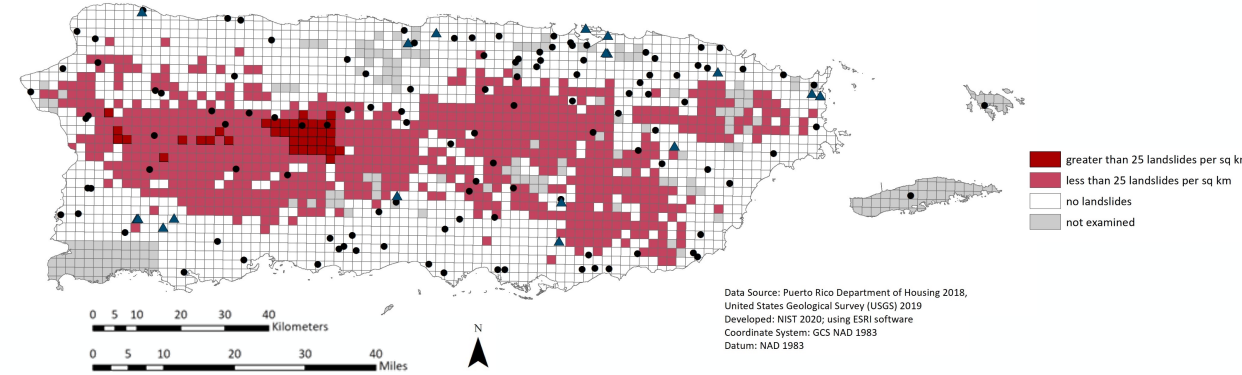
Study Regions



Peak Gust Wind Speed with Topographic Effects



Landslide Density

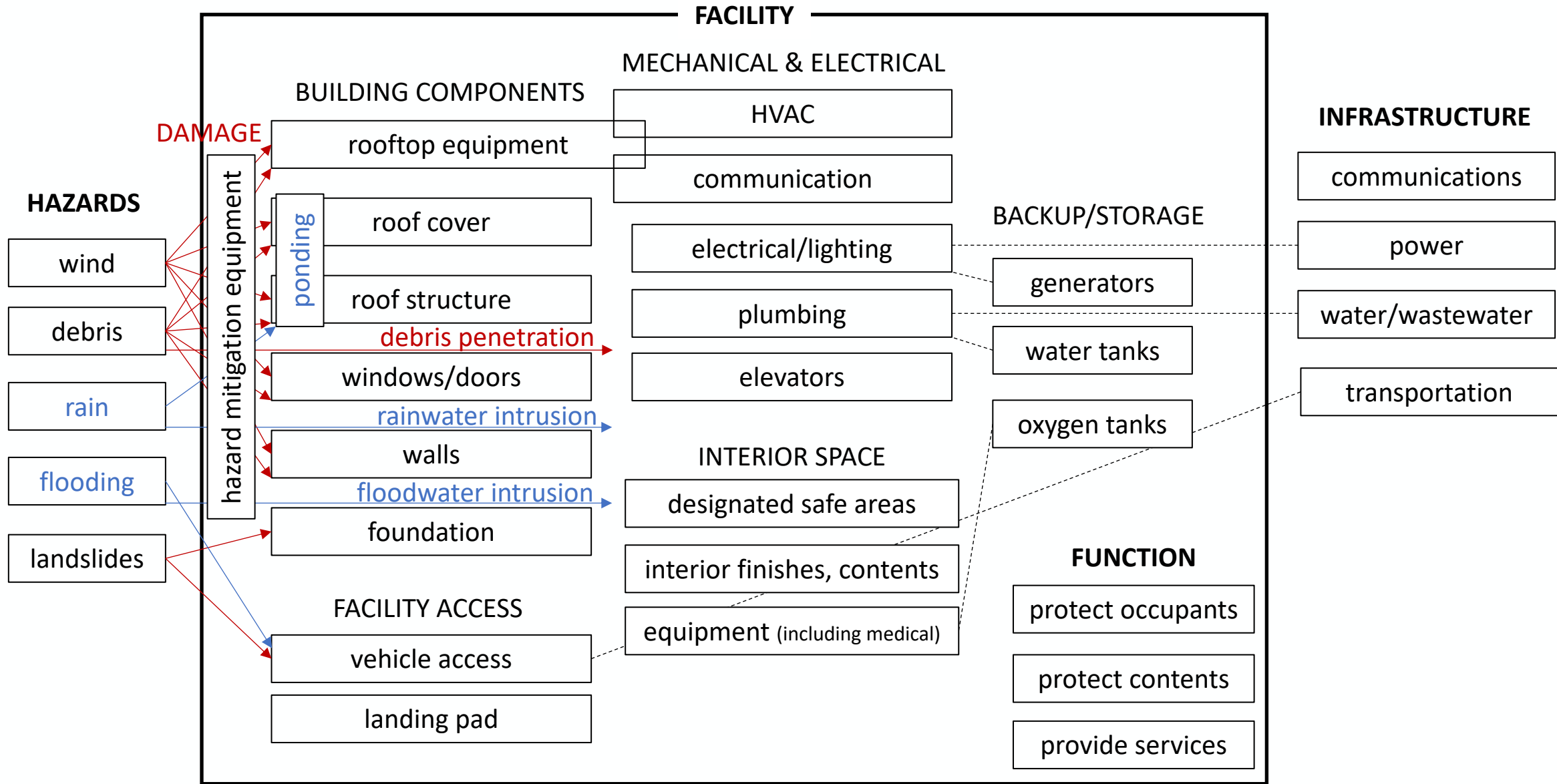


# Recent Progress: Facility Evaluations

- Subcontract through Stantec established with University of Puerto Rico at Mayagüez to support facility evaluation work
- Facility evaluations in progress at 5 selected hospitals:
  - NIST coordination with facility managers through emails and virtual meetings
  - Phase 1 evaluations **completed** for 2 of the selected hospitals
  - Phase 1 evaluations **in progress** for remaining 3 hospitals
- Initial observations from Phase 1 evaluations:
  - Significant documentation obtained on building characteristics and damages
  - Some linkages of damage to location are missing, and less information was obtained on function and operation; these items will be a focus in Phase 2
- Interview Guide for Phase 2 evaluations completed and translated to Spanish
- Project plans for evaluation of school facilities reviewed and approved by the Puerto Rico Department of Education

# Recent Progress: Facility Evaluations

## Scope of Data Collection



# Recent Progress: Facility Evaluations

- Drone photography completed at two hospitals selected for wind tunnel testing:
  - Hospital Bella Vista
  - University Pediatric Hospital
- 3D point cloud models generated from drone images to support fabrication of wind tunnel models



Hospital Bella Vista Point Cloud Model



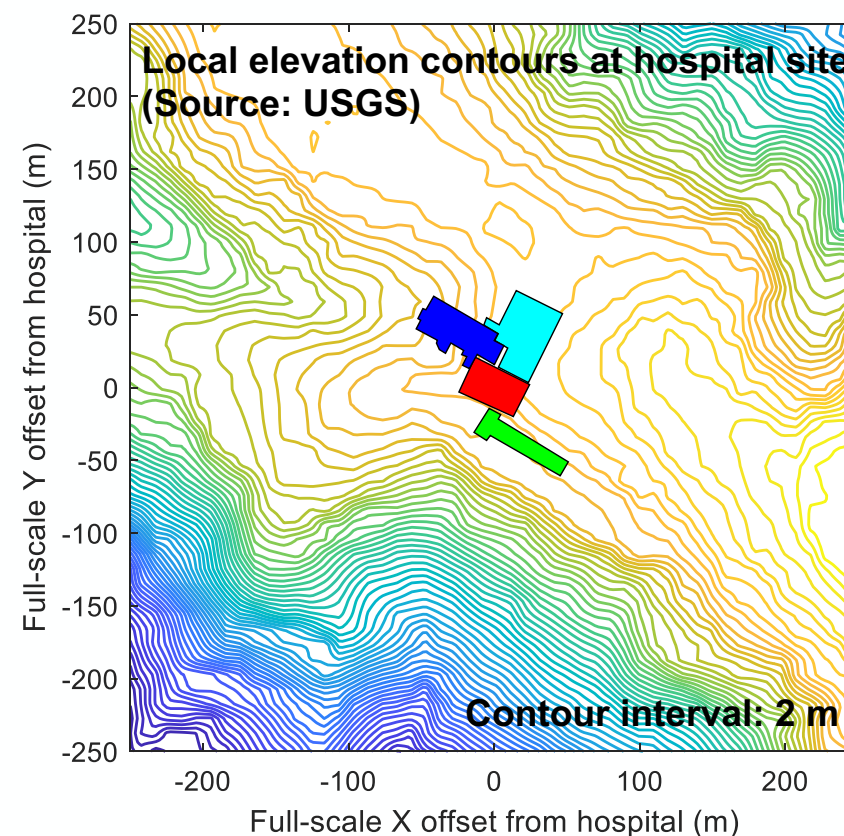
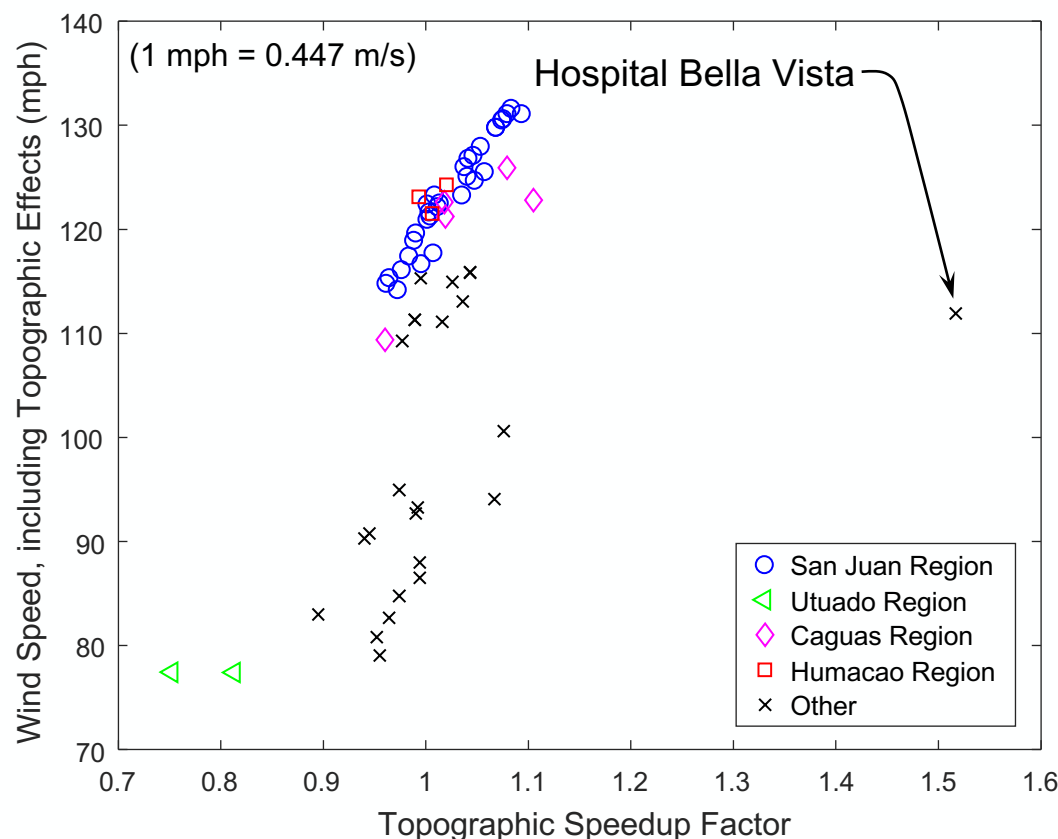
University Pediatric Hospital Point Cloud Model



# Recent Progress: Wind Tunnel Testing

The objectives for wind tunnel testing of Hospital Bella Vista are to evaluate:

- effects of topography on wind loads for a site with significant topographic speedup of winds (Topographic Speedup Factor of approximately 1.5 at hospital site)
- estimated wind loading history and peak loads sustained during Hurricane Maria
- adequacy of existing standard provisions (ASCE 7) to capture topographic effects

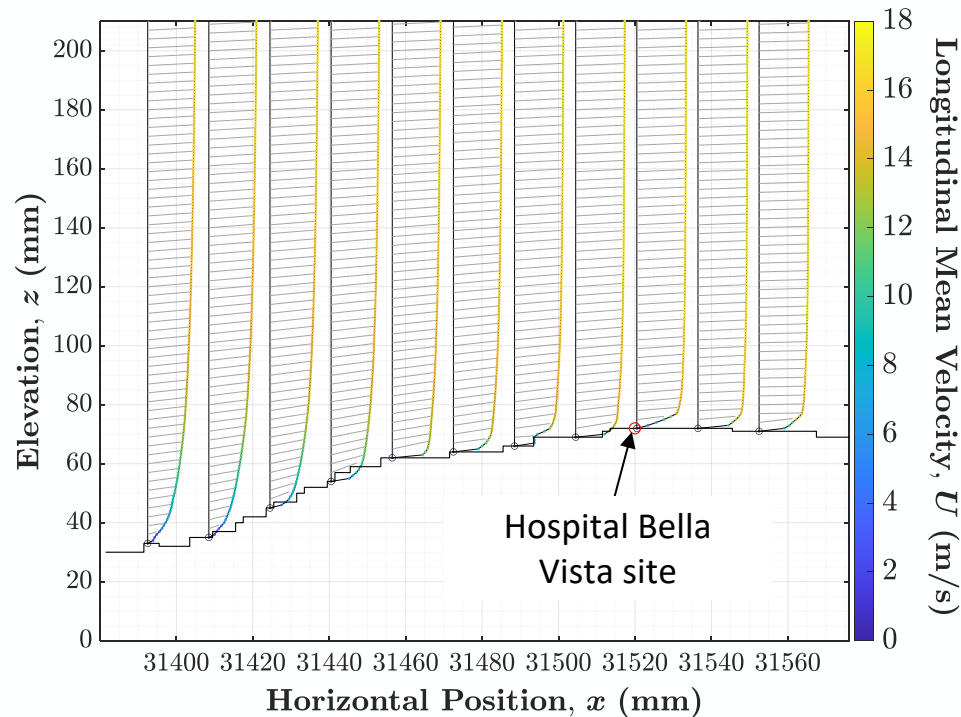


# Recent Progress: Wind Tunnel Testing

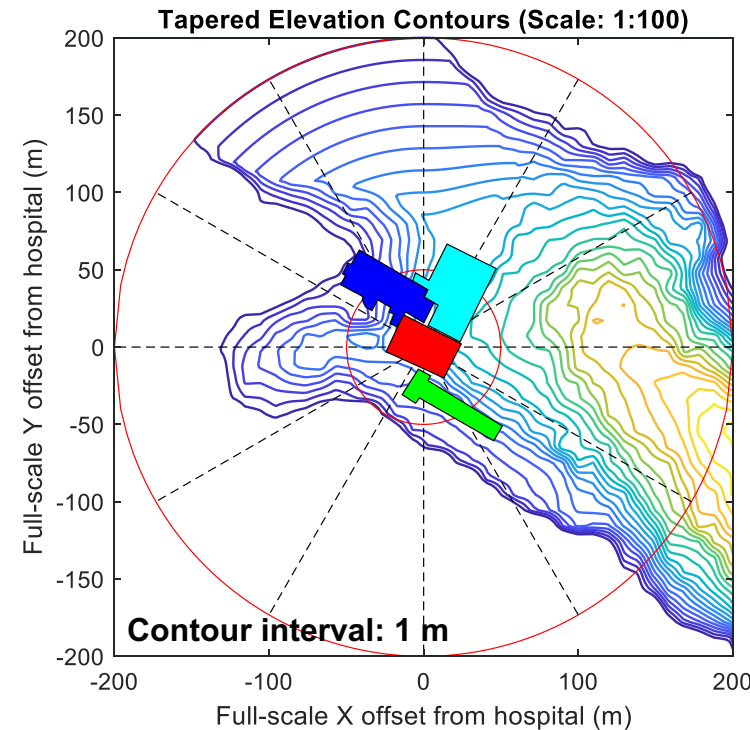
- Design completed for Hospital Bella Vista building and area model (1:100 scale)
  - Selected building (in red below) to be instrumented with pressure taps and base force balance
  - Surrounding buildings and local topography to be included in area model
  - Tests to be conducted both with and without the area model and surrounding buildings
- Measurements of approach flow velocity profiles at hospital site obtained from Mayagüez topographic model (1:3100 scale) using Particle Image Velocimetry (PIV)
- Approach flow profiles to be simulated using Flow Field Modulator



Mayagüez Topographic Model



PIV Approach Flow Measurements



Building and Area Model

# Next Steps

## Sample Selection:

- Finalize selection of representative schools and storm shelters for detailed evaluation

## Facility Evaluations:

- Complete Phase 1 evaluations of remaining 3 hospital facilities
- Initiate Phase 1 evaluations of selected schools/shelters
- Initiate Phase 2 evaluations of selected hospitals and schools/shelters
- Develop an integrated NIST/contractor database of information collected on hospitals and schools/shelters and begin data analysis

## Wind Tunnel Testing:

- Complete fabrication of building and area model for Hospital Bella Vista and perform wind tunnel testing
- Complete design and fabrication of building and area model for University Pediatric Hospital and perform wind tunnel testing
- Combine measured data from wind tunnel testing of building models with time-dependent hurricane wind-field model to evaluate wind load histories for Hurricane Maria

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**Project Team:** Jazalyn Dukes, Cynthia Rivas, DongHun Yeo, Camila Young

### **Questions?**

 **Please ‘raise your hand’ using the Blue Jeans Participant window and unmute your audio and video**