SimCenter NHERI

Center for Computational Modeling and Simulation

SimCenter Tools for Next Generation Regional Natural Hazard Engineering

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NSF award: CMMI 1612843

SimCenter Mandate

To produce Extensible Software that Researchers in Natural Hazards Engineering can use in their research

- Develop an **open-source computational framework** for **building workflow applications** to support decision-making to enhance community resilience to natural hazards **in the face of uncertainty**;
- **Design a framework** that is sufficiently **flexible, extensible, and scalable** so that any component of it can be enhanced to improve the analysis and thereby better meet the needs of the community;
- **Seed the framework** with enough **data** and **interfaces to existing simulation tools** so that it can be employed in the near-term;
- **Release tools/applications built using this framework** that meets the computational needs of researchers in natural hazards engineering;
- **Provide an ecosystem** that fosters collaboration between scientists, engineers, urban planners, public officials, and others who seek to improve community resilience to natural hazards.

NHERI SimCenter

"Transforming the nation's ability to understand and mitigate adverse effects of natural hazards on the built environment **through computational simulation**"

SimCenter NHERI
Center for Computational Modeling and Simulation

- **Cloud-enabled research tools, scalable to run on HPC**
- **Emphasis on uncertainty quantification**
- **Educational resources**

Front-end

SimCenter Research Tools

QUO FEM | EE UQ | WE UQ | PBE | RDT

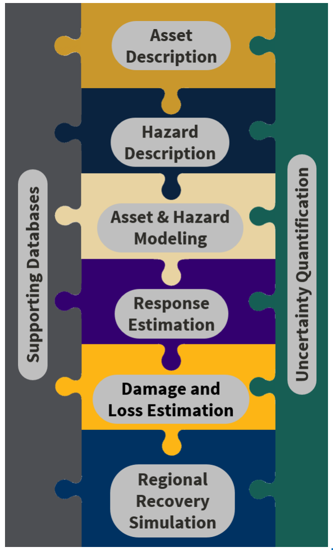
Agave Platform

DESIGNSAFE-CI
NHERI: A NATURAL HAZARDS ENGINEERING RESEARCH INFRASTRUCTURE

- Data storage and HPC access

Back-end

SimCenter's Application Framework



rWhale
BRAILS
Pelicun

quoFEM (v2.0)

quoFEM (Quantified Uncertainty with Optimization for the Finite Element Method) is a tool that combines finite element applications with uncertainty quantification (UQ) applications behind a simple user interface (UI).

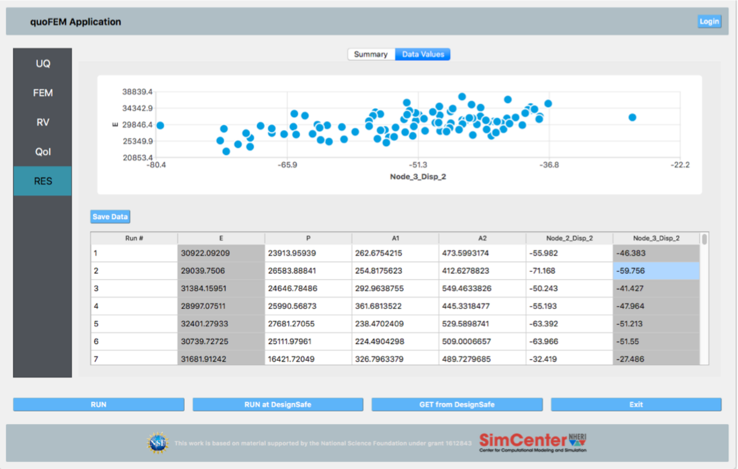
Capabilities

(1) Forward problem: Monte Carlo (MC), Space filling (LHS) Variance Reduction, Importance Sampling Variance reduction, MC using surrogate models -Gaussian Processes (GP) or Polynomial Chaos Expansion (PCE), density approximation using samples

(2) Inverse Problem: Parameter Estimation (MLE/MAP) and simulation of samples from posterior using Metropolis-Hastings (MH) variants (MH with delayed-rejection, adaptive MH)

(3) Reliability Analysis: FORM and SORM adopting local or global search schemes for most probable point (MPP) and further leveraging surrogate models for efficient MPP identification

(4) Global Sensitivity Analysis: MC or PCE based estimation



Year 4 updates will incorporate:

(1) Online parameter estimation

(2) Integration of hierarchical models and coupled with Multi-fidelity Monte Carlo simulation

(3) Design under uncertainty problems (RBDO)

(4) Extension of interface to allow easy integration of algorithms beyond DAKOTA capabilities (→)

(5) High efficiency techniques for global sensitivity analysis

(6) Design of Experiments for global surrogate modeling

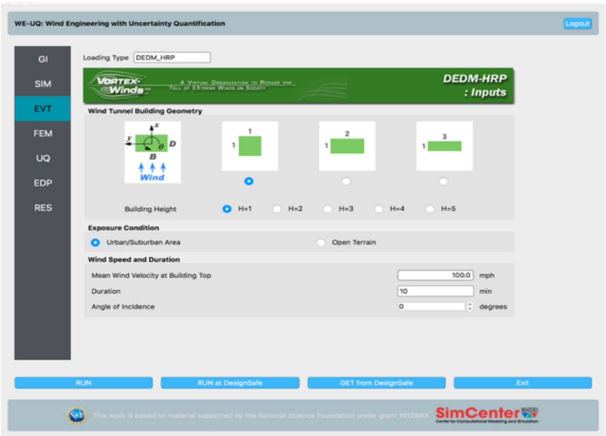
(7) Rare event MC-based reliability analysis

WE-UQ (v2.0)

Wind Engineering with Uncertainty Quantification (WE-UQ) is an application to determine the response of a structure to wind loading. The tool focuses on providing different wind loading options (including options to integrate with CFD simulations), structural model generators, and UQ methods. It allows users to run computations on HPC resources.

Capabilities

Loading options: (1) stochastic wind load generation; (2) database-enabled options utilizing Vortex-Winds; (3) uncoupled CFD simulations incorporating TInF option for inflow; (4) Tokyo Polytechnic University's (TPU's) low-rise wind tunnel datasets; and (5) user-provided wind tunnel test data for rectangular buildings.
UQ methods: Forward Problem methods from quoFEM
Model Generators: Nonlinear (NL) shear models and detailed OpenSees building models



Year 4 updates will incorporate:

(1) Coupling of CFD-FEM simulations.
(2) Surrogate Modeling options.
(3) Additional Low Rise Roof Shapes and TPU datasets.
(4) New UQ features made available through quoFEM, including Sensitivity and Reliability Options.
(5) Model Generators including Expert System.

EE-UQ (v2.0)

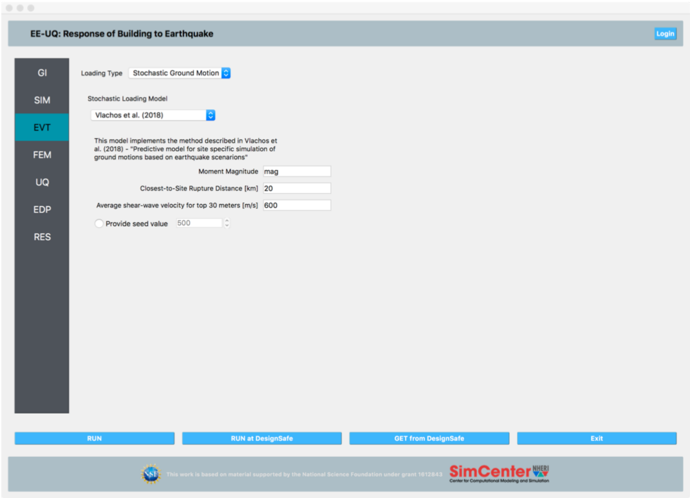
Earthquake Engineering with Uncertainty Quantification (WE-UQ) is an application to determine the response of a structure to earthquake loading. The tool focuses on providing different earthquake loading options, structural model generators, and UQ methods. It allows users to run computations on HPC resources.

Capabilities

Loading options: (1) Stochastically generated motions Vlachos et al. and Dabaghi & Der Kiureghian; (2) PEER .AT2 files; (3) interaction with PEER NGA WEST database; (4) Site Response (soil column: Elastic, PM4Sand/Silt, PDMY02, etc.)

UQ methods: Forward Problem methods from quoFEM

Model Generators: Nonlinear (NL) shear models and detailed OpenSees building models



Year 4 updates will incorporate:

(1) Random Fields in Site Response
(2) Incorporate Domain Reduction Method
(3) Coupling with NGA East
(4) Surrogate Modeling options
(5) Incorporate Reliability and Sensitivity from quoFEM
(6) Hierarchical models and multi-fidelity MC
(7) Model Generators including Expert System

PBE (v2.0)

The Performance Based Engineering (PBE) Application is an extensible workflow application to perform PBE computations for various hazards. The current release provides researchers a tool to assess the performance of a building in an earthquake scenario. The application focuses on quantifying building performance through decision variables.

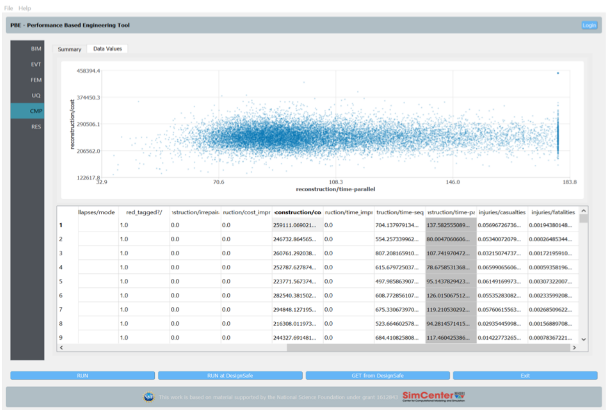
Capabilities

UQ methods: As per EE-UQ

Event-loading options: As per EE-UQ

Damage and loss (D&L) assessment: FEMA P58 and HAZUS D&L functions

User configuration options: Define D&L models



Year 4 updates will incorporate:

(1) An extension to include wind events (HAZUS D&L)

PELICUN (v2.0).

PELICUN stands for Probabilistic Estimation of Losses, Injuries, and Community resilience Under Natural disasters. The HAZUS and FEMA P58 methods in PELICUN provide multi-hazard and multi-fidelity damage and loss modeling capabilities.

Capabilities

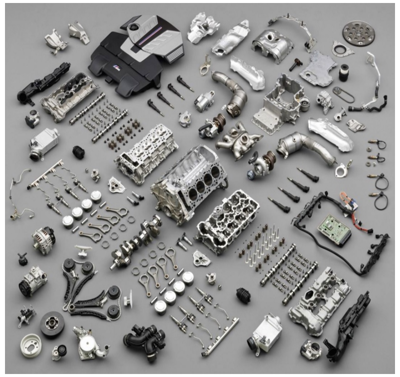
FEMA P58 and HAZUS-based methods to estimate damage and losses under earthquake and hurricane wind.

(1) uncertainty in structural response;

(2) time-based assessments;

(3) user friendly input and output

(4) auto-population feature for regional simulations



Year 4 updates will incorporate:

(1) Methods and configuration data for damage and loss assessment in storm surge and tsunami events.
(2) Higher fidelity models for lifeline damage and loss assessment.
(3) Enhanced auto-population methods for damage and loss models.
(4) Efficient structural response estimation without simulation.

Tools to Study Effects of Regional Hazard

Emphasis in 2020 is on **RDT**, rWhale, PELICUN, BRAILS to allow researchers to study Effect of Natural Hazards on the Regional Scale

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Front-end

SimCenter Research Tools

RDT

Agave Platform

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NHERI: A NATURAL HAZARDS ENGINEERING RESEARCH INFRASTRUCTURE

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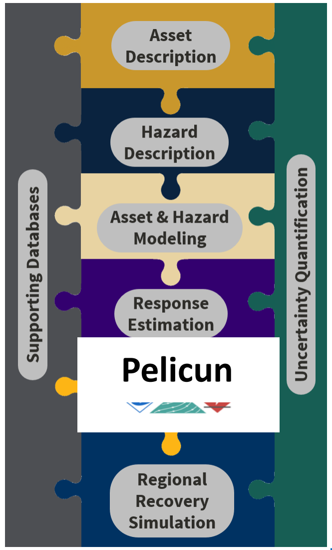
BRAILS

Building Information Models

Back-end

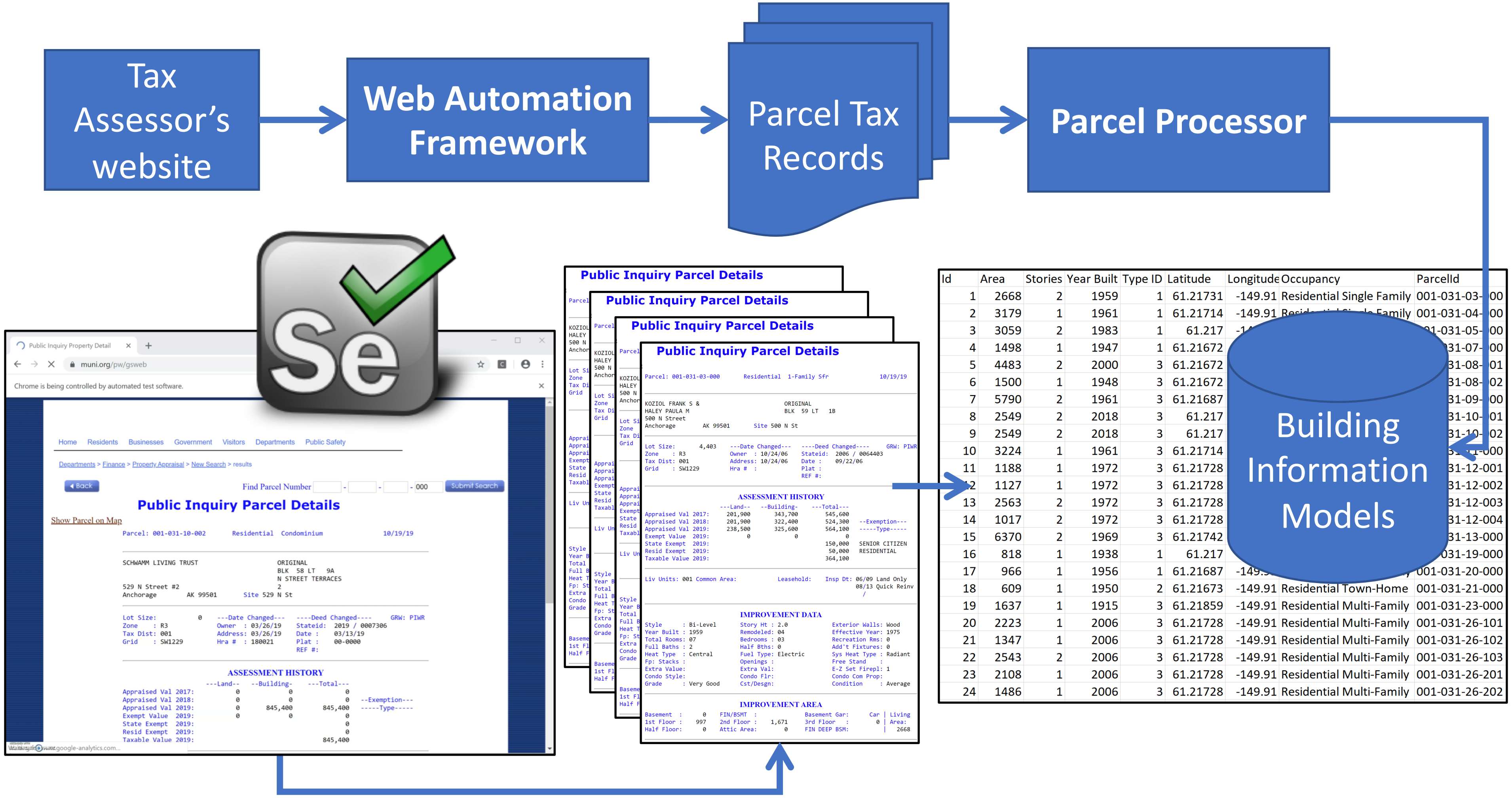
rWhale

SimCenter's Application Framework



Buildings Inventory

- **Buildings Inventory Development using Web Automation**



BRAILS (v1.0)

The Building Recognition using AI at Large Scale (BRAILS) is a new AI-enabled tool to assist regional-scale simulations. BRAILS utilizes machine learning (ML) and deep learning (DL) to create enhanced building inventory databases of cities.

City of Interest

Metadata collection

Geocoding

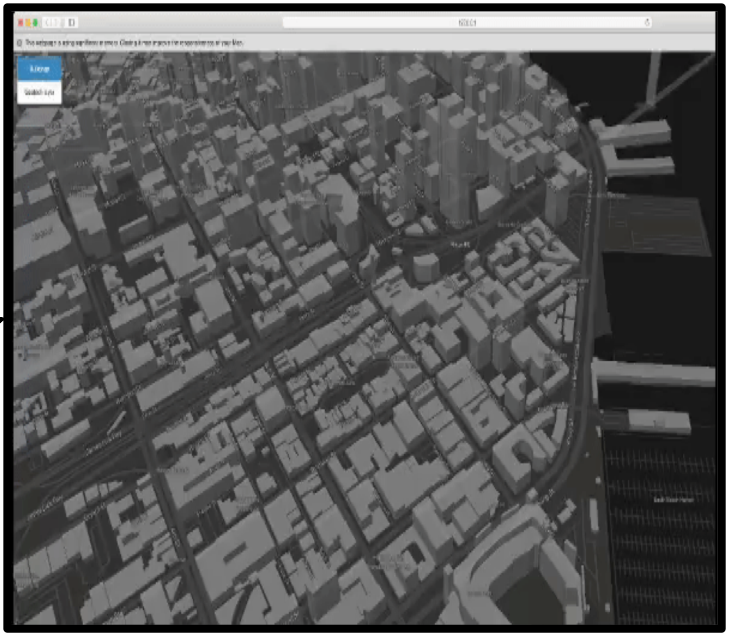
Satellite / Street Images

CNN

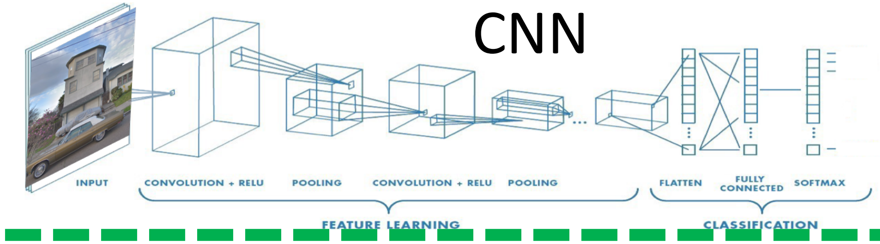
BIM For Individual Bldgs.

Uncertainty Quantification (*SURF*)

Regional-scale Building Inventory



CNN

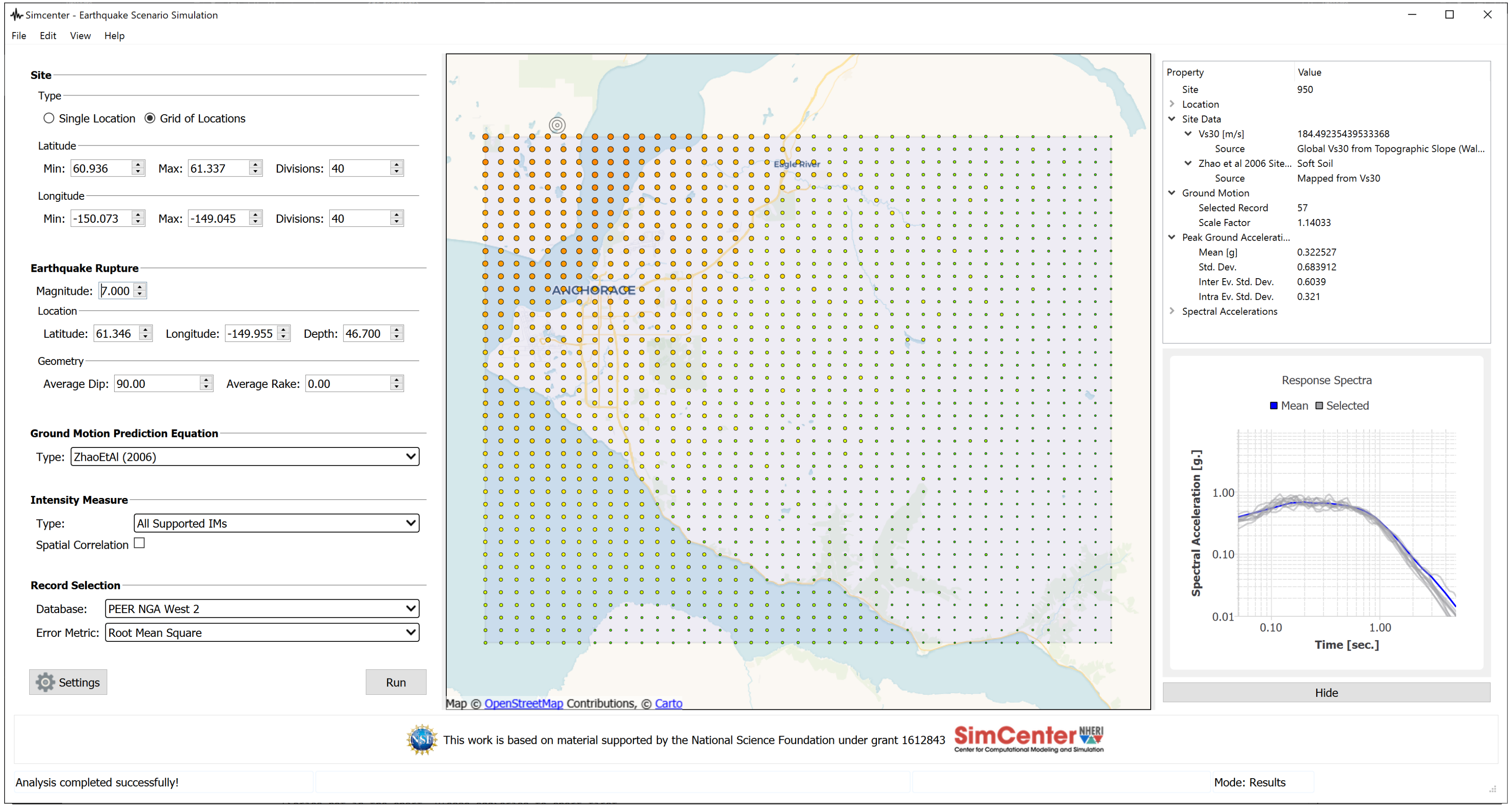


SURF

SimCenter NHERI

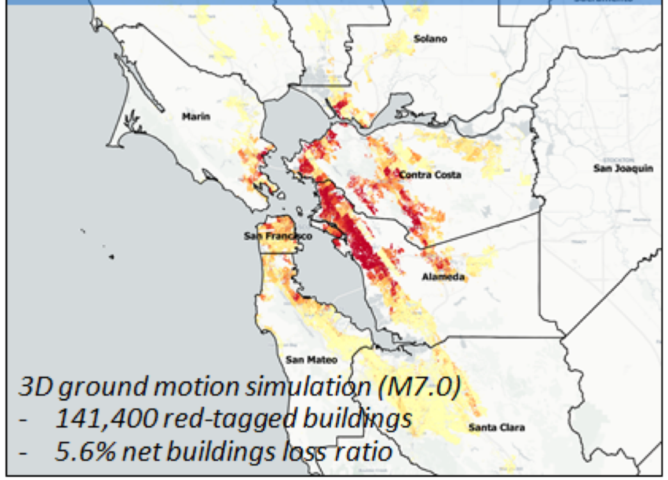
Earthquake Scenario Simulator (EQSS)

- Prototype for Scenario-based Regional Seismic Hazard Analysis and Ground Motion Records Selection/Scaling

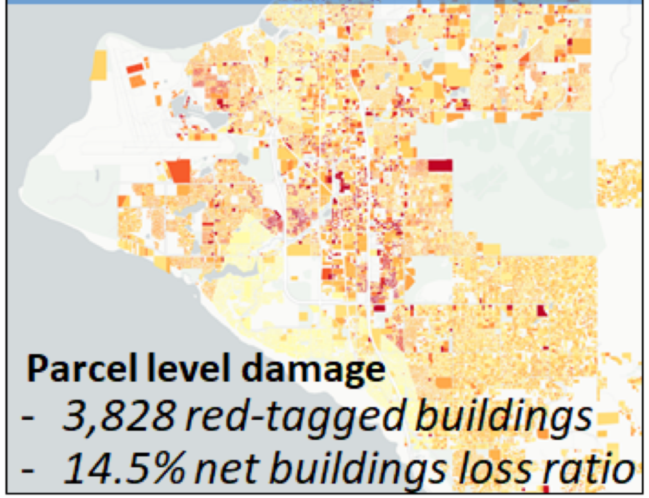


Regional Simulations Testbeds to Verify the Software

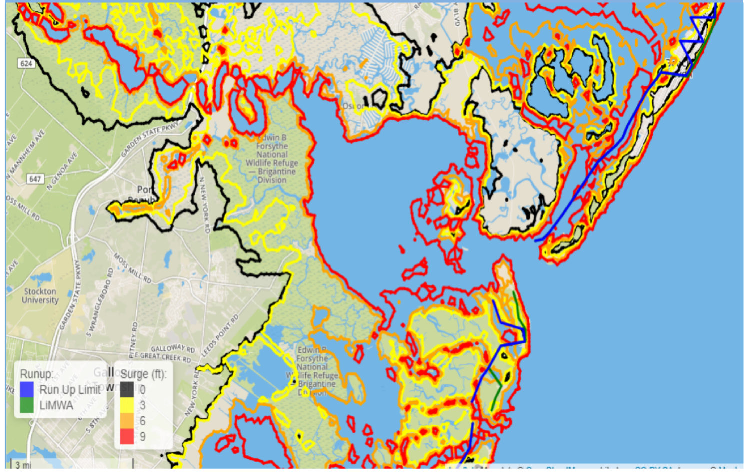
San Francisco Bay Area Testbed



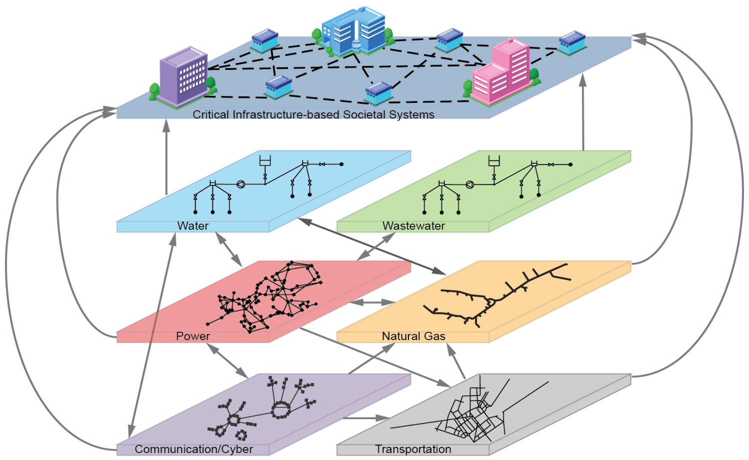
Anchorage, Alaska Testbed



Atlantic City, NJ Storm Testbed

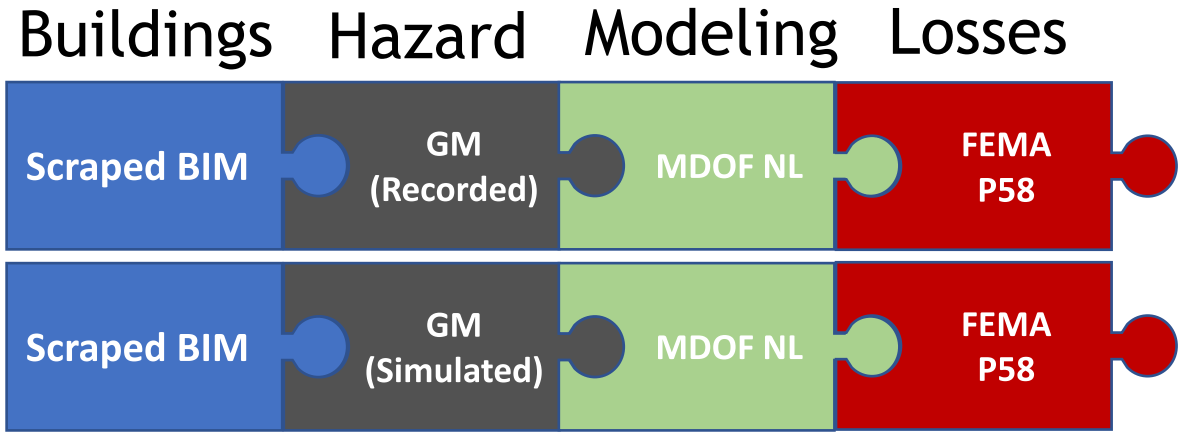


Memphis, TN Lifelines Testbed

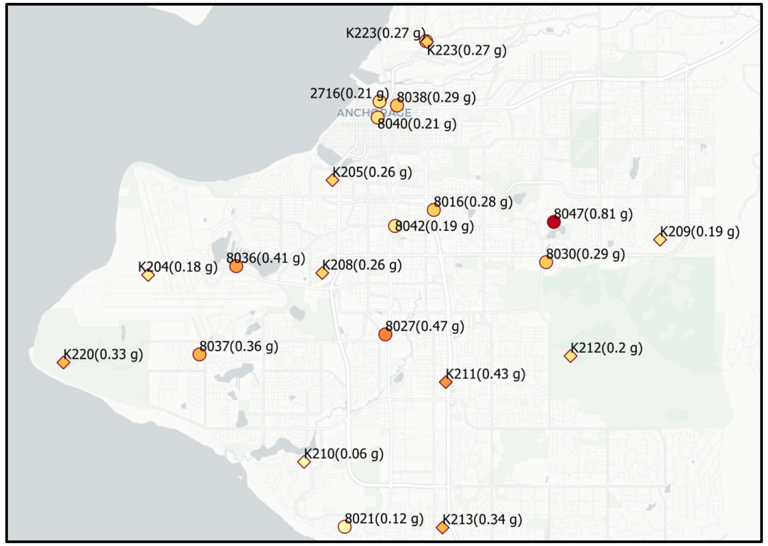


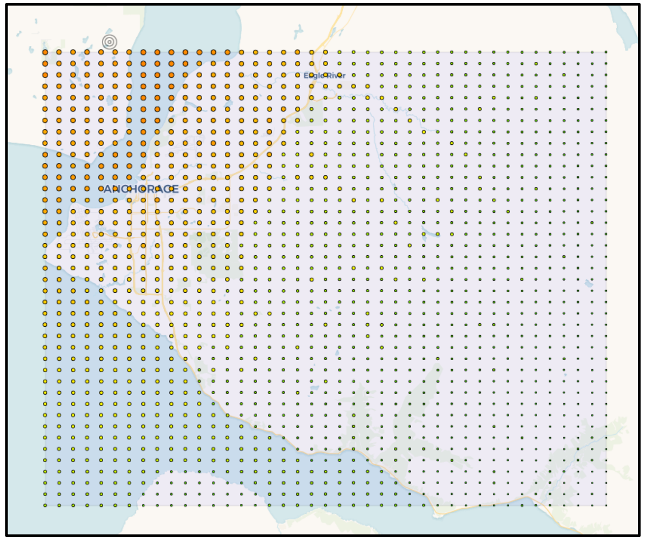
Anchorage Testbed: Workflow Configurations

- Two different rWHALE configurations to characterize ground motions



Recorded Ground Motions





Simulated Ground Motions

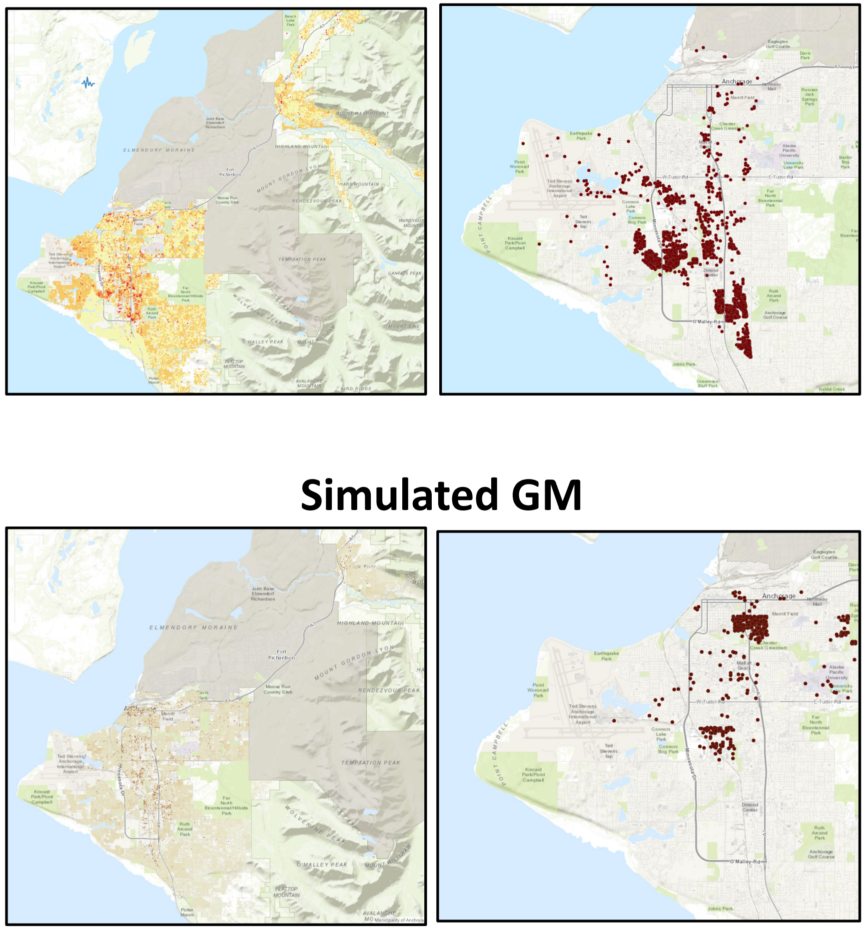
Anchorage Testbed: Results: Validation

- Estimated Losses

	Recorded GM	Simulated GM
Repair Cost [$Billion]	7.5	7.3
Red Tags	3800	626
Loss Ratio [%]	14.5	12.5

- City of Anchorage identified more than 750 homes and buildings that suffered substantial damage
- Research opportunities to calibrate, verify and validate computational models

Recorded GM

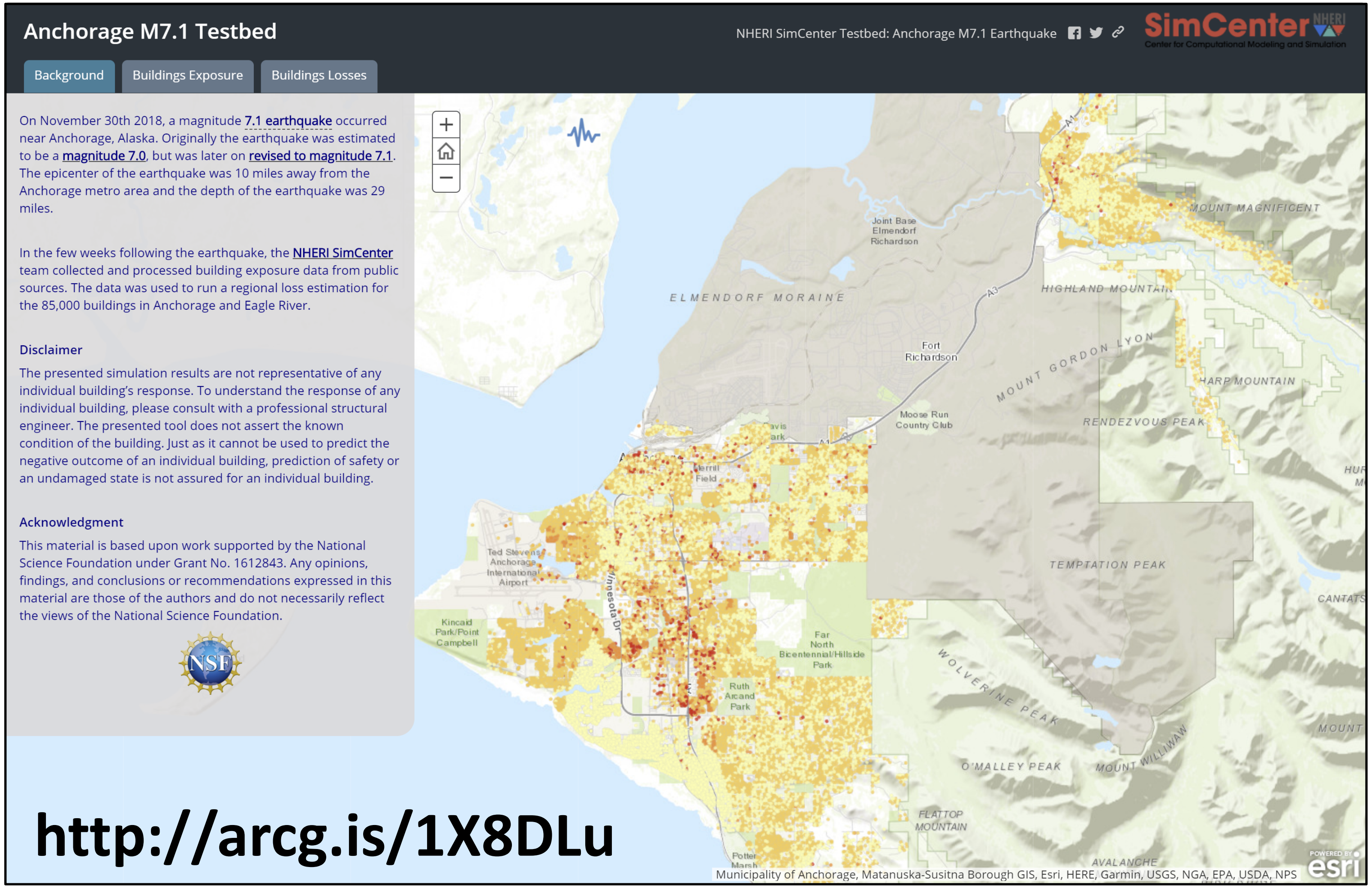


Simulated GM

Parcels Loss Ratios | Buildings Red Tags

Anchorage Testbed: Results: a Story Map

- Documents the input data, results and process



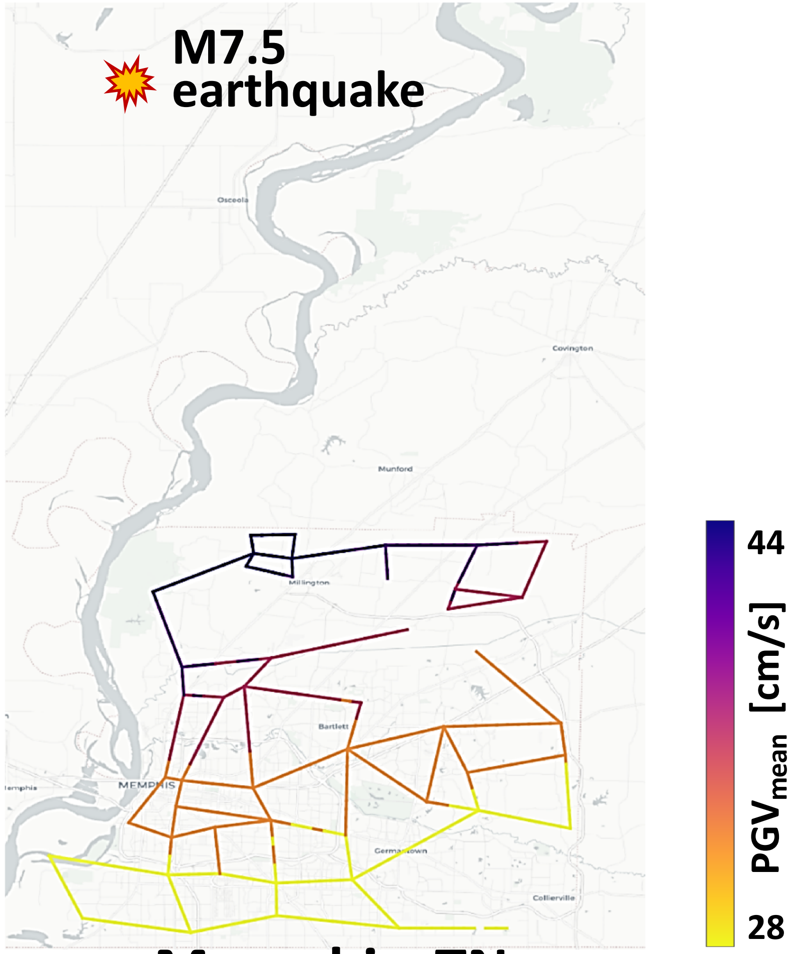
http://arcg.is/1X8DLu

Memphis Testbed: Potable Water Network

SimCenter Memphis (TN) testbed
E. Month (SimCenter REU, Cornell); C. Lee, I. Tien (GeorgiaTech)

- use rWHALE for estimation of damage and repair times
- unprecedented fidelity in damage and loss estimates
- support Bayesian approach to describe interdependencies

- extended damage and loss models to support non-building assets
- extended rWHALE to preserve spatial correlation in lifeline performance estimates



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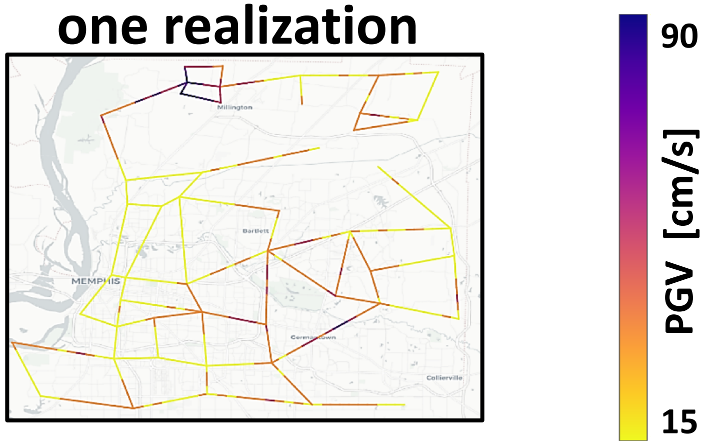

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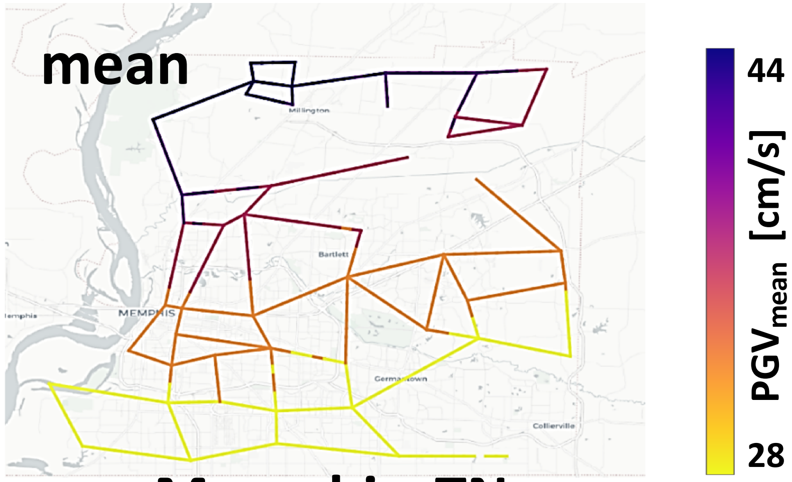

Memphis, TN

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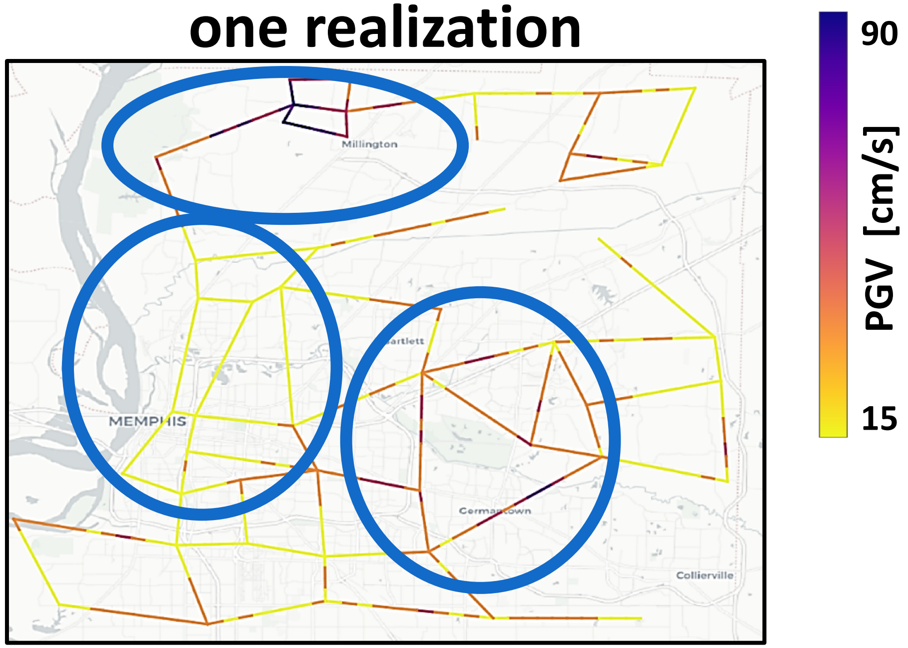
one realization



spatial correlation

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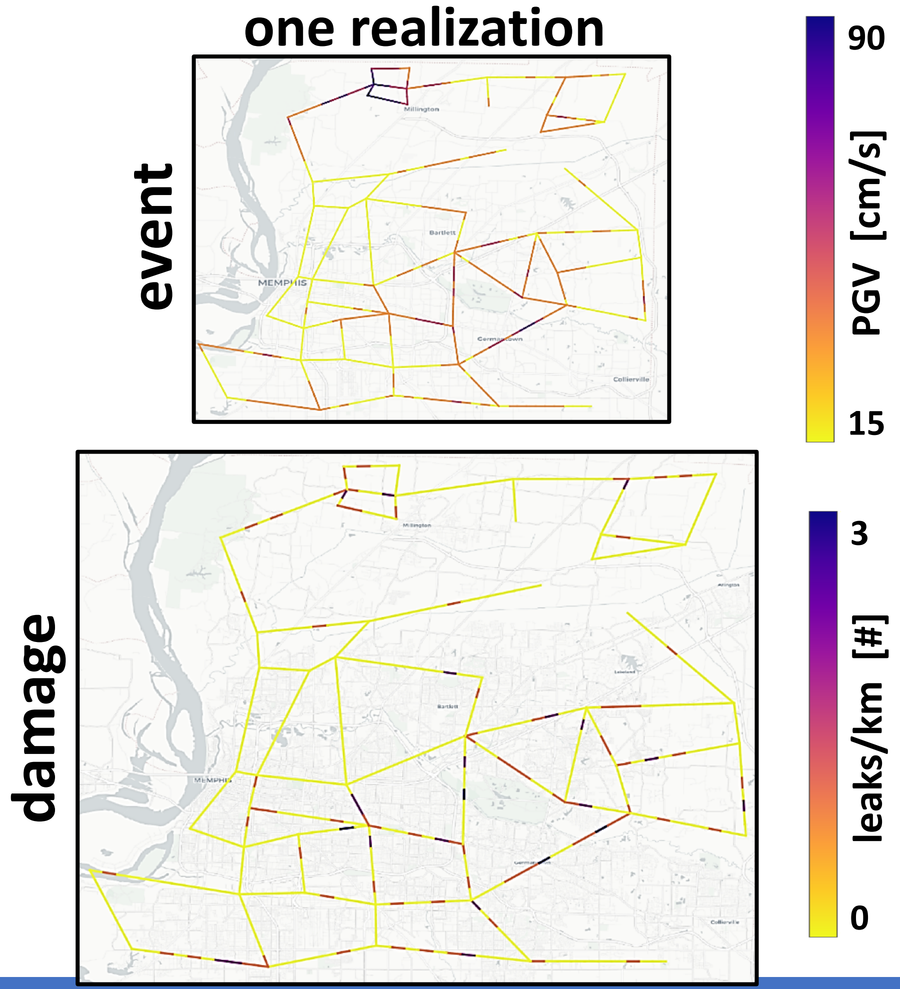

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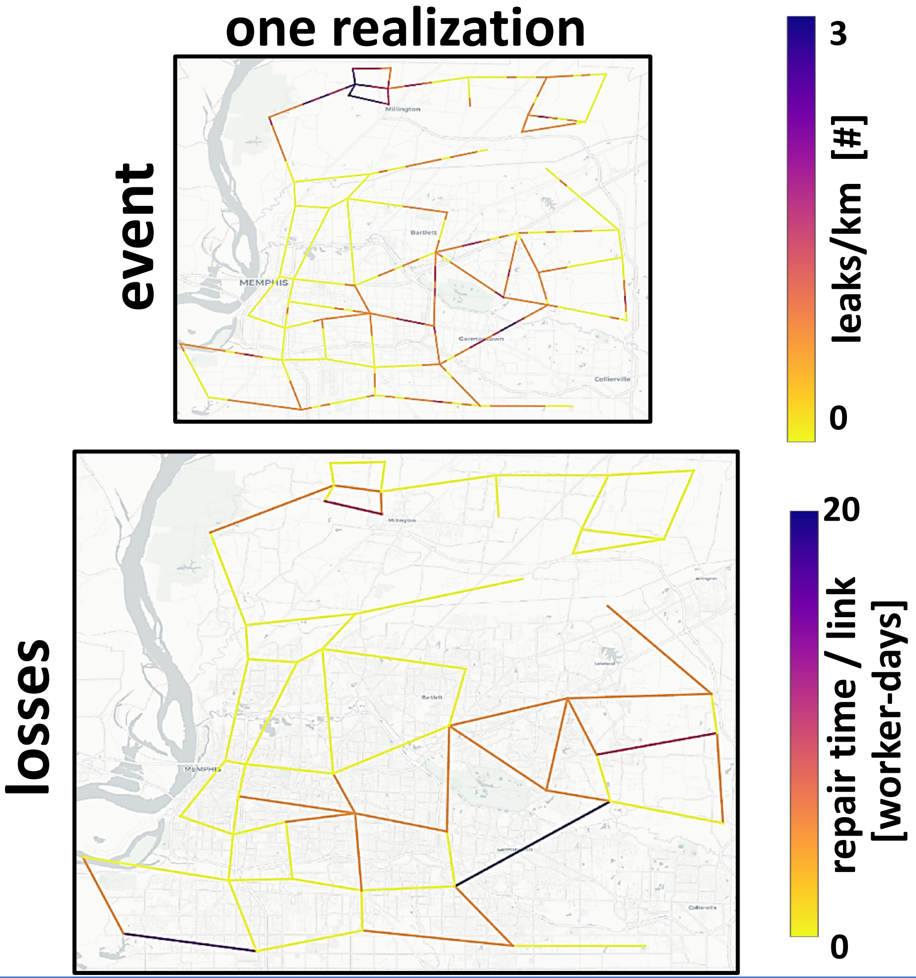

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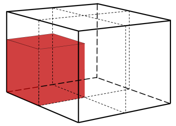

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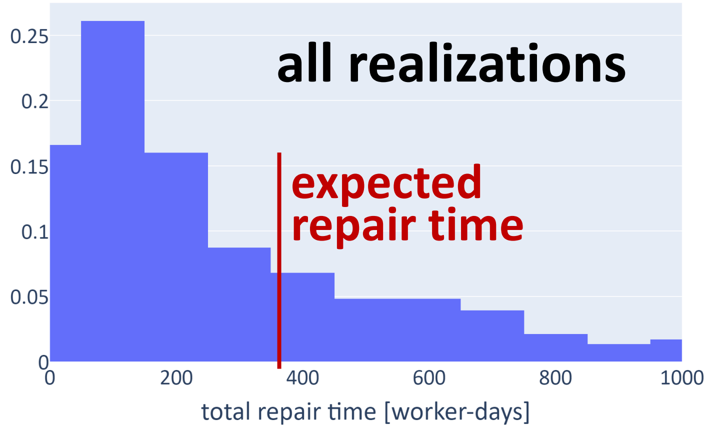

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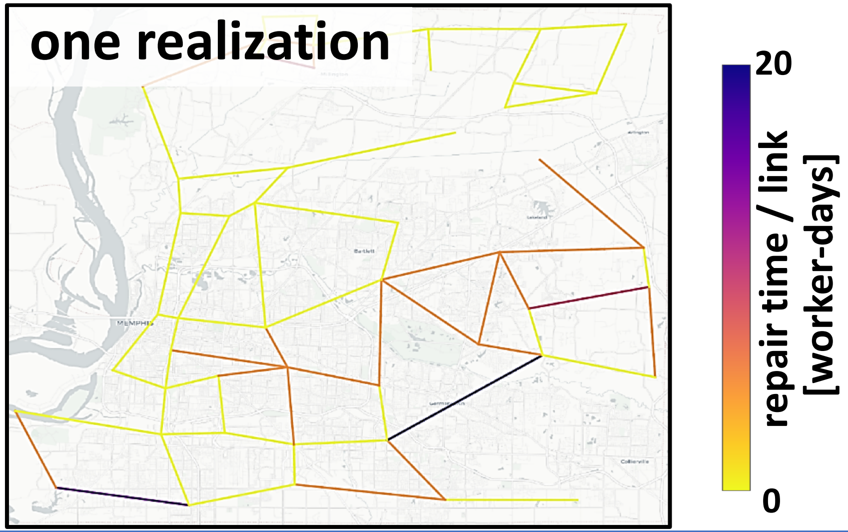
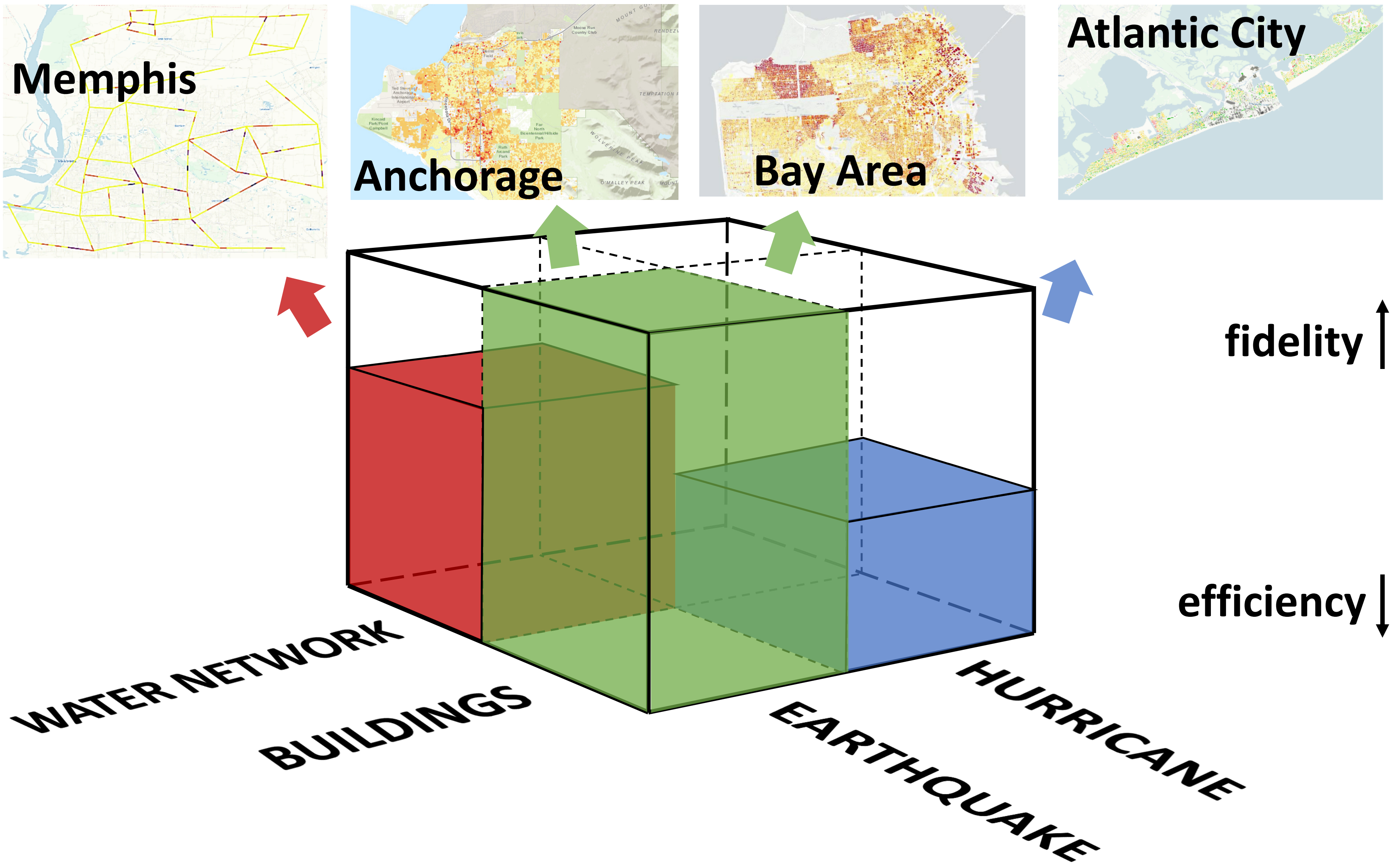


Summary


Memphis
Anchorage
Bay Area
Atlantic City
fidelity
efficiency
WATER NETWORK
BUILDINGS
EARTHQUAKE
HURRICANE

Closure

- Leveraging past PEER projects to move into the future
  - Regional simulations
  - New hazards
- All software is opensource – including building inventories
  - http://SimCenter.DesignSafe-CI.org
  - http://github.com/NHERI-SimCenter
- The Center is open for collaborations: Looking to facilitate research
- Open job opportunities for postdocs interested in hazards and programming
- Follow us on Twitter & Facebook. Subscribe to our newsletter. Come to our workshops. Attend our webinars. Most importantly contribute.