SimCenter NHERI
Center for Computational Modeling and Simulation

SimCenter tools for simulated ground motion utilization

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University of California, Berkeley

CMMI 2131111

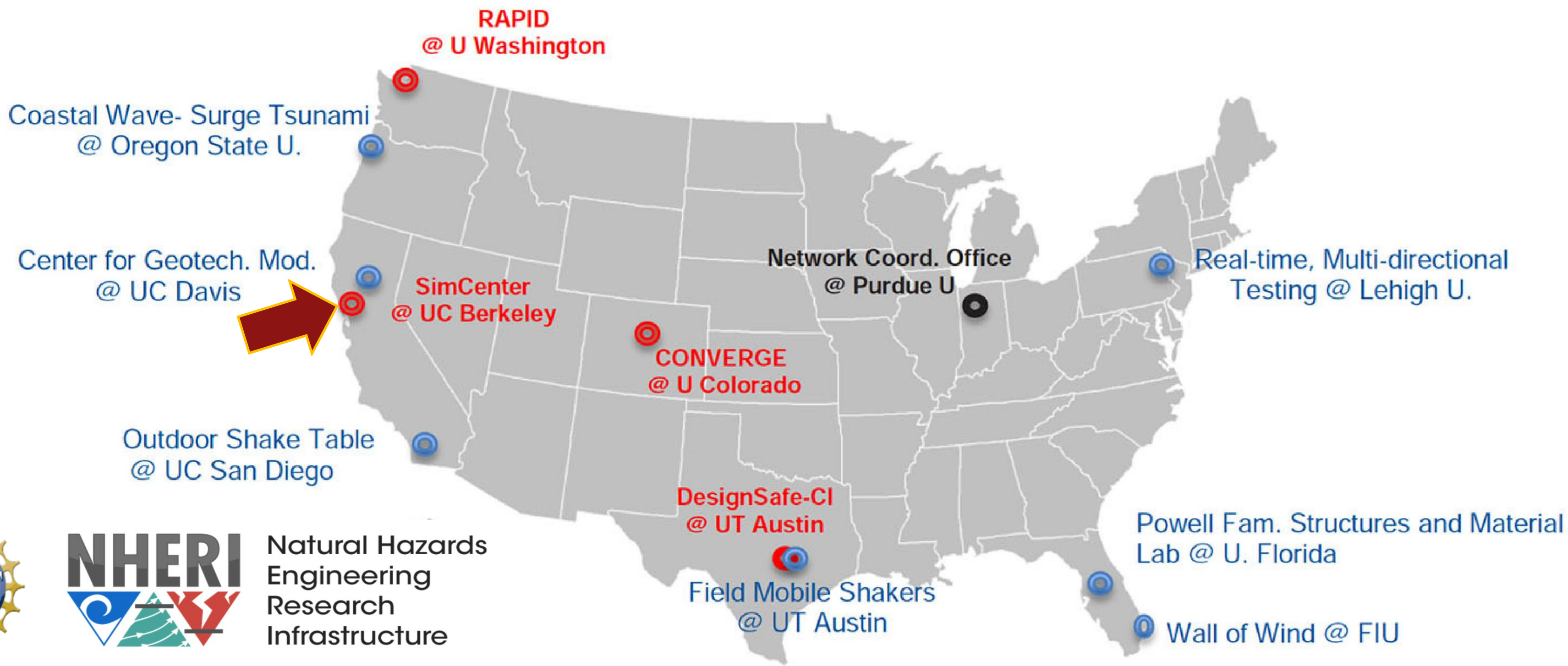
SimCenter Role:
Provide tools to allow researchers / practitioners to feasibly make use of simulated ground motions in computational workflows

Feasible = Easy access to:

- simulated ground motion data
- simulation models
- HPC resources

NSF NHERI – Large-scale Collaboration

- Experimental facilities (7), Cyber-infrastructure, Field Reconnaissance, and Simulation Software
- Current project period: 2014-2025; future initiative (2026-2035) under development



NHERI Natural Hazards Engineering Research Infrastructure

Computational Modeling and Simulation Center

Advance the Nation's capability to **simulate the impact** of natural hazard events on structures, lifelines, and communities.

Create an open-source and extensible application framework, integrate existing tools and data, and develop new software to provide the **next-generation of regional disaster simulation tools**

Support researchers and practitioners with **education and training**, and connect them with high-performance computing resources.

The SimCenter Team

Directors
- Matthew DeJong
- Gregory G. Deierlein

Senior Management
- Frank McKenna
- Matthew Schoettler
- Adam Zsarnoczay

Co-PIs
- Ahsan Kareem
- Laura Lowes
- Satish Rao

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- Sina Naeimi Dafchahi
- Jinyan Zhao

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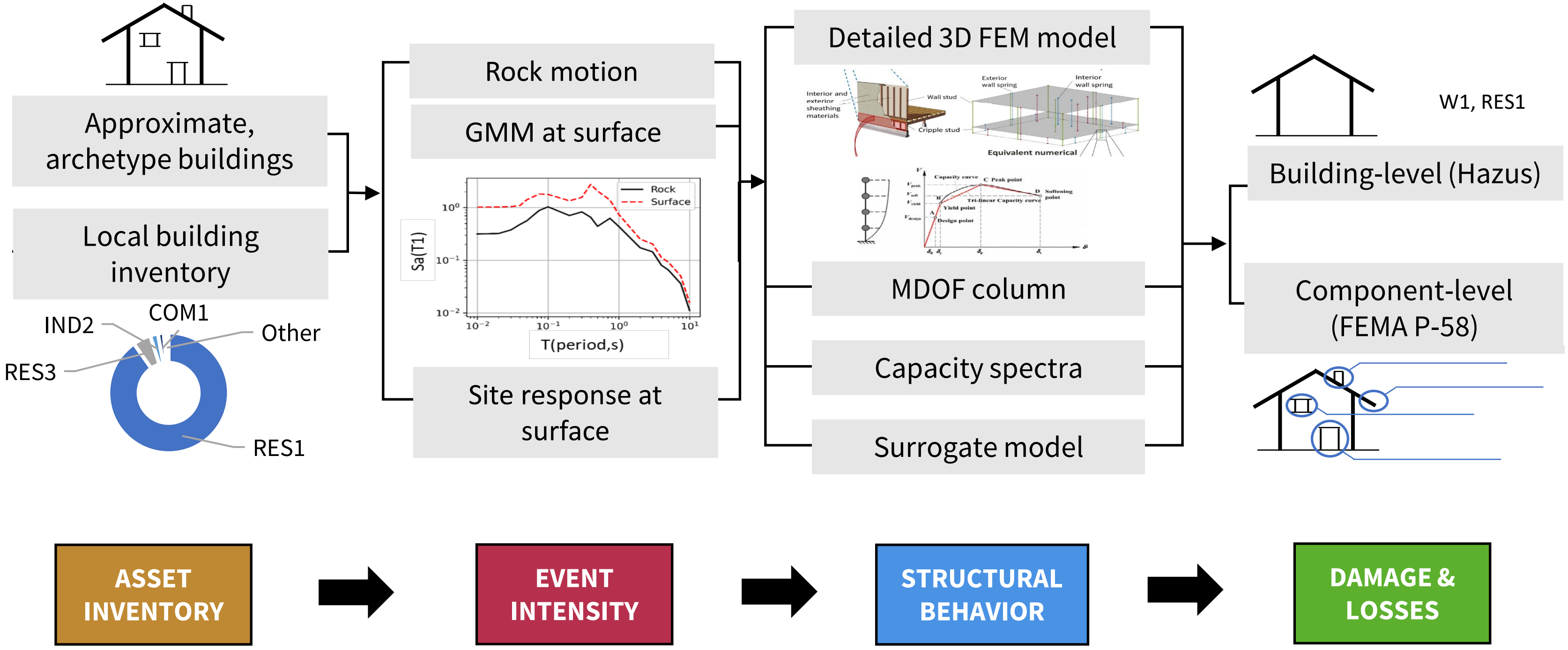
- Jack Baker
- John Bray
- Henry Burton
- Joel Conte
- Rachel Davidson
- Ann-Margaret Esnard

Faculty Domain Experts cont.
- Dimitris Giovanis
- Cathernie Gorle
- Sanjay Govindjee
- Andrew Kennedy
- Tracy Kijewski-Correa
- Patrick Lynett
- Peter Mackenzie-Helnwein
- Michael Motley
- Kenichi Soga
- Michael Shields
- Seymour Spence
- Alexandros Taflanidis
- Ertugrul Taciroglu
- Stella Yu

Unifying Simulation Platform

Foster large-scale collaboration in the Disaster Science community

Facilitate transition from local to regional scale, multi-hazard studies



SimCenter Application Framework

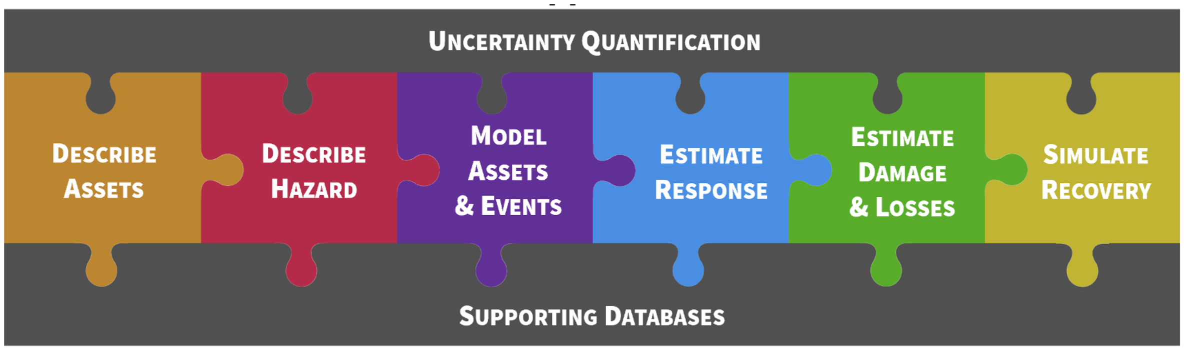
Foster large-scale collaboration in the Disaster Science community

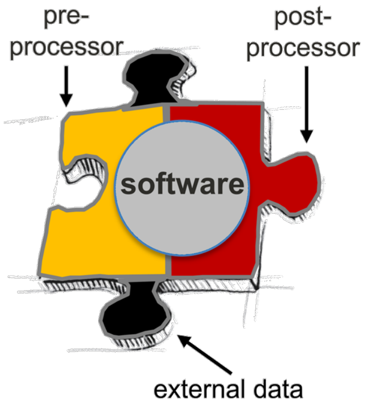
Facilitate transition from local to regional scale, multi-hazard studies

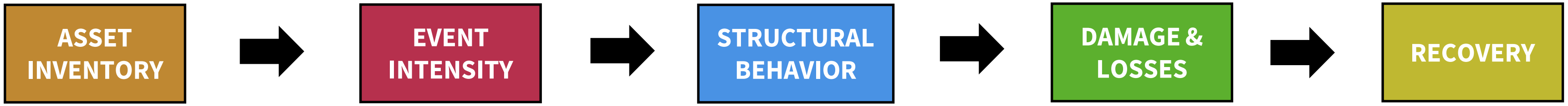
Open Source

Multi-Fidelity

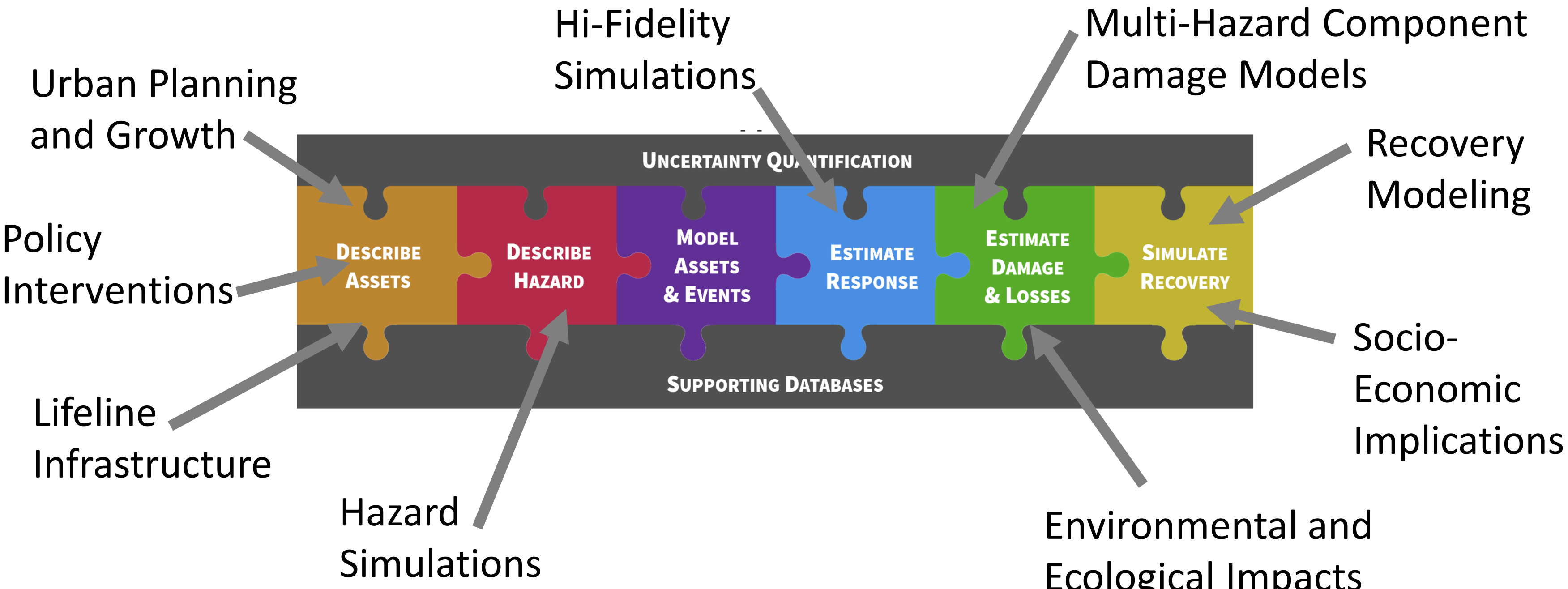
Multi-Hazard



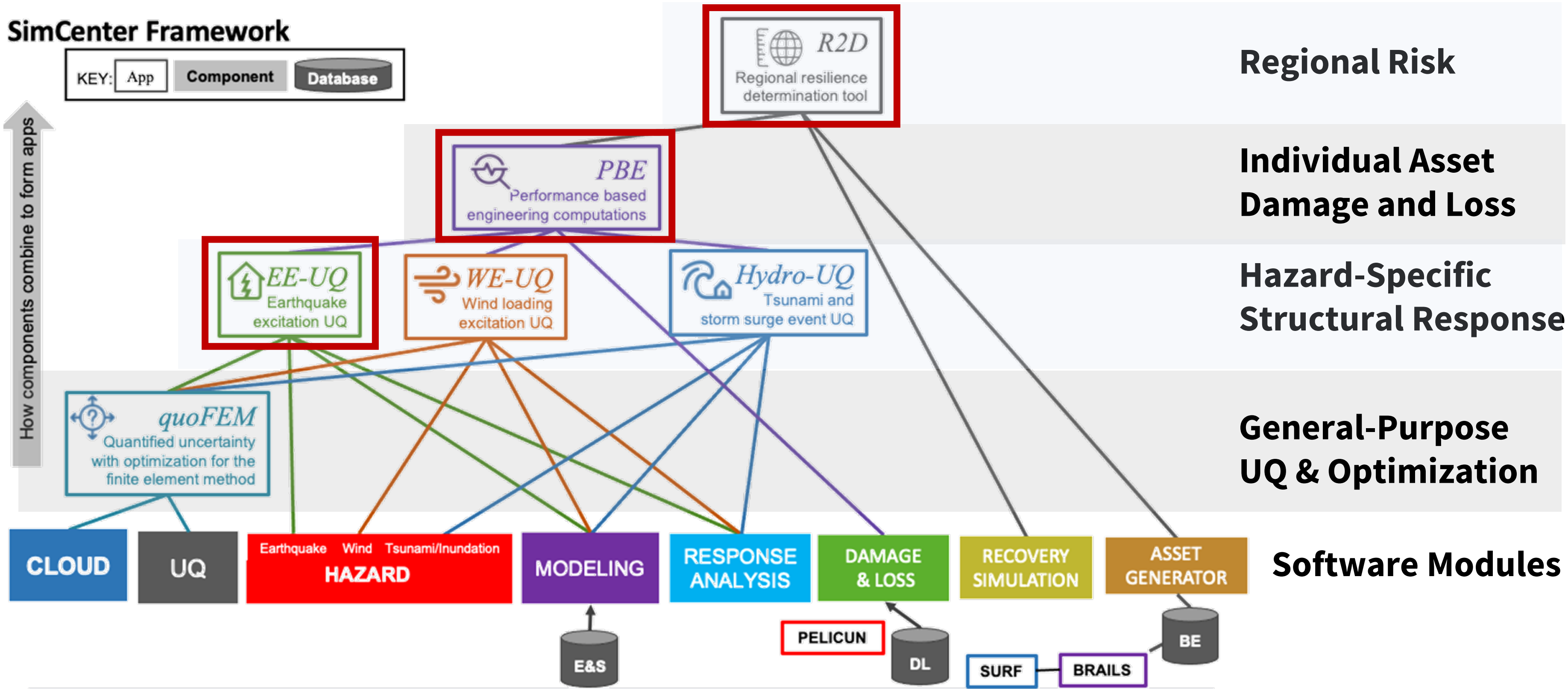




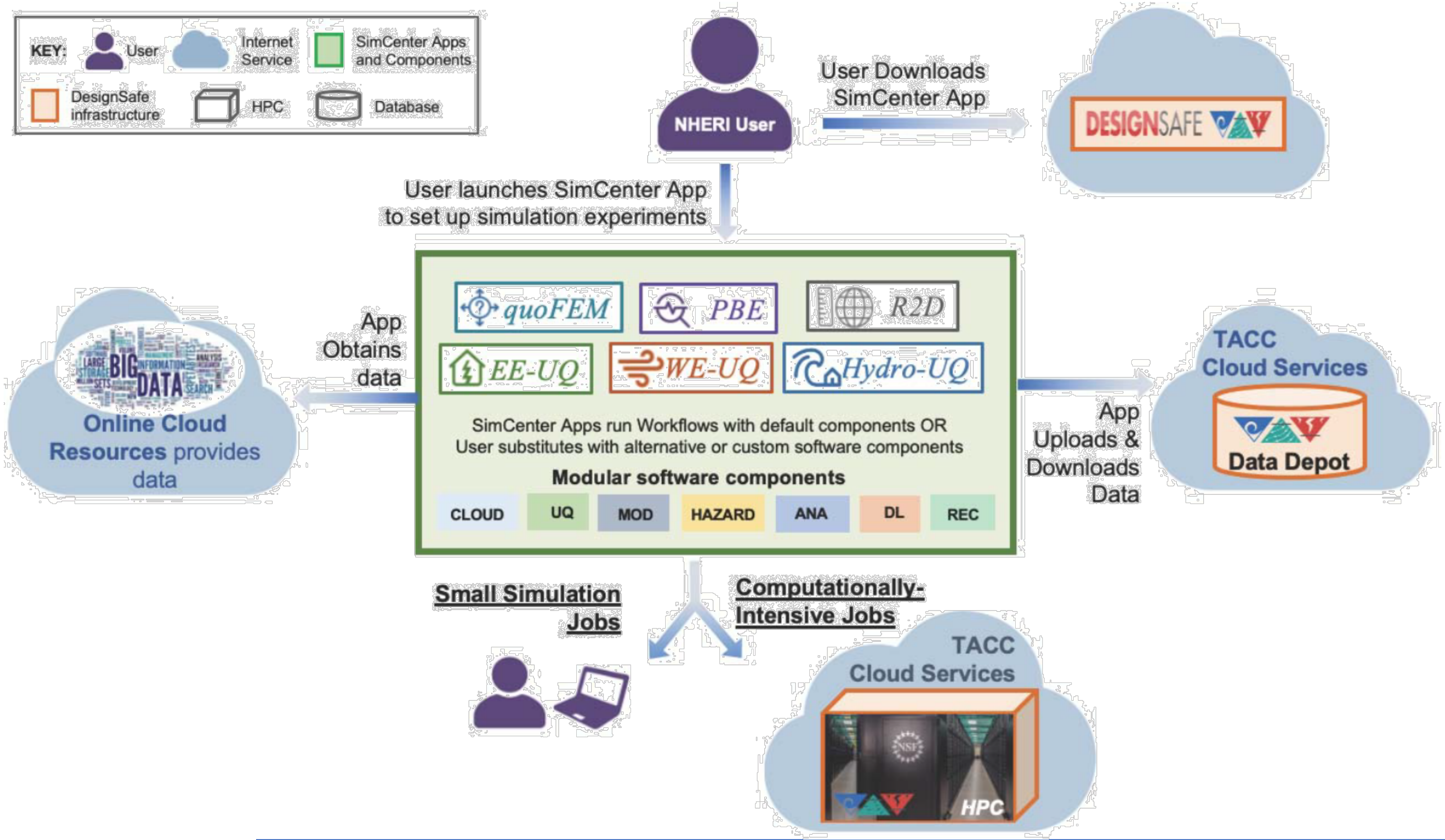
Framework for Multi-Disciplinary Collaboration



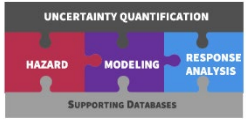
SimCenter – Desktop Applications



Integration with Online Resources



Desktop Application for Earthquake Engineering (EE-UQ)



EE-UQ V3.2

Integrates UQ applications of quoFEM, Earthquake Loading Applications, Building Model Generators with analysis application to determining response of building to earthquake loading

UQ Problem Types:≈

Sampling **Sensitivity** **Reliability**
Surrogate Modeling (new features)

Hazard (Earthquake):

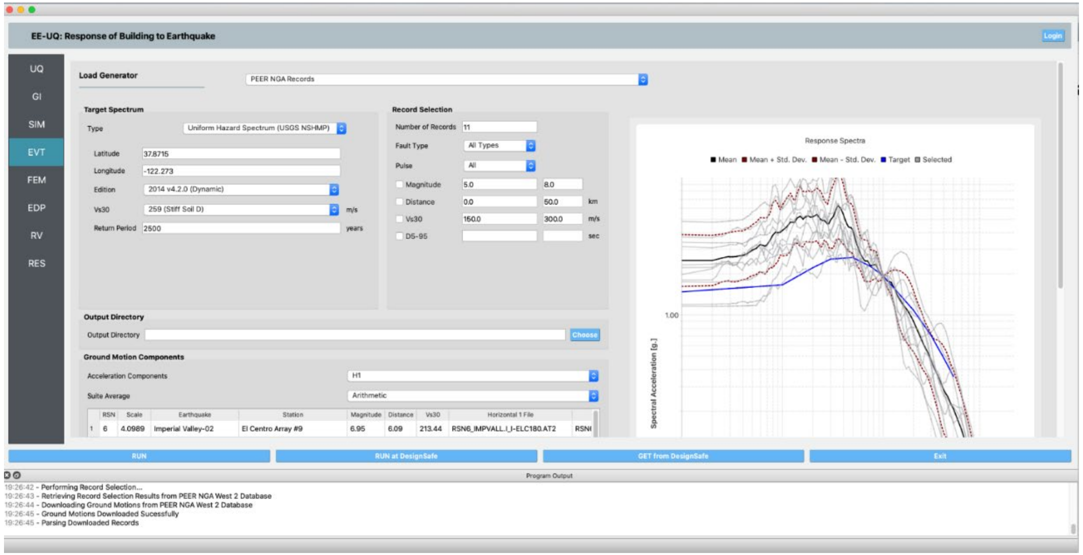
Stochastic Motions
PEER NGA Search with target spectrum
Site Response with Random Fields

Modeling (Building):

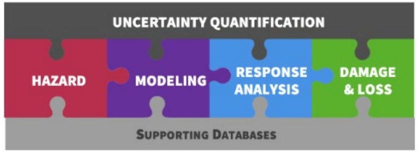
OpenSees
Nonlinear Shear Spring (MDOF)
Steel Building Design & Build (AutoSDA)
Concrete Building Design & Build
Multi-Model Surrogate

Response:

OpenSees
Multi-Model



PBE Desktop Application for Performance Assessment



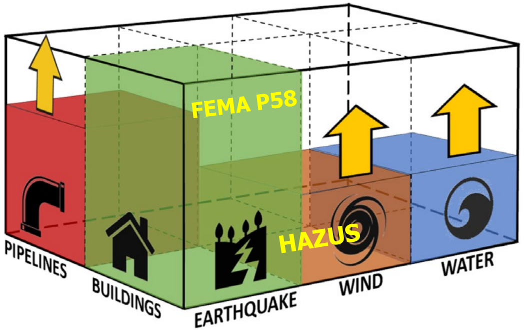
PBE v3.0

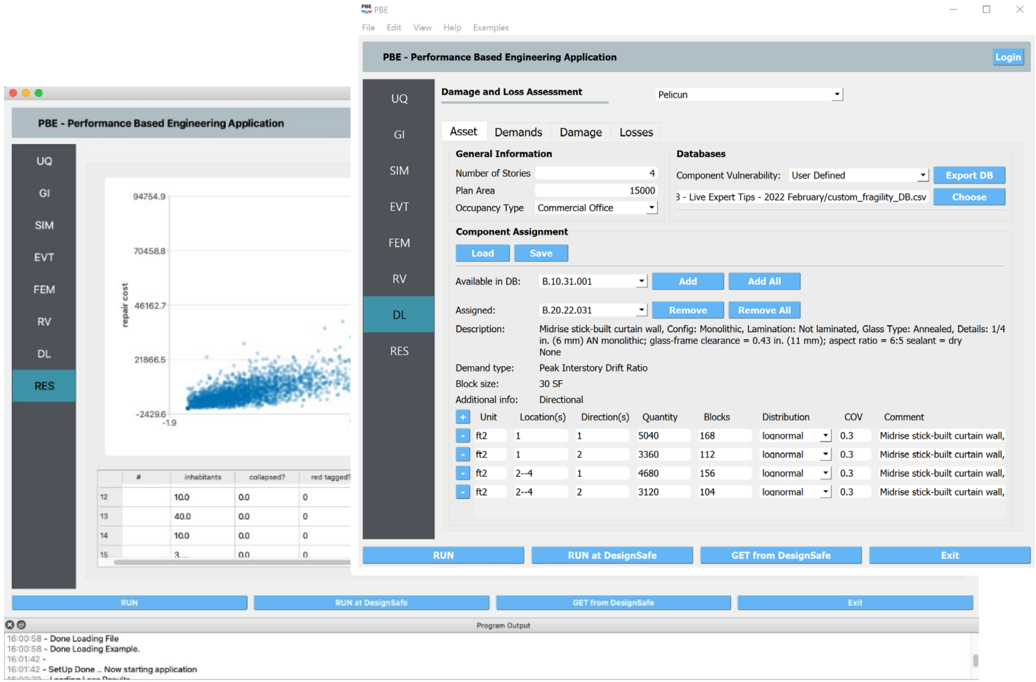
Performance-Assessment of Buildings and Infrastructure Components

Multi-Hazard and Multi-Fidelity (PELICUN library of damage and loss models)

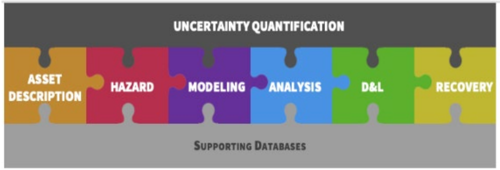
Damage & Loss (using PELICUN):

- Building-level assessment (e.g., HAZUS)
- Component-level assessment (e.g., FEMA P58)
- Supports external response estimation
- Customizable damage & loss models





R2D Desktop Application for Regional Simulation



R2D V2.1

Create and run complex workflows for regional simulation of natural hazards to facilitate research in disaster risk management and recovery.

Asset definition

csv files
GIS files

Hazard definition

Regional Site Response
User-supplied earthquake and hurricane grids
Raster-defined earthquake, hurricane, and tsunami intensity fields
Earthquake scenario simulation
Hurricane wind field simulation

Response, Damage and loss

FEM simulations of response
HAZUS and other fragility models
User-provided fragility functions

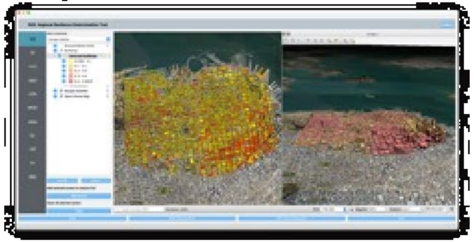
Multiple Hazards

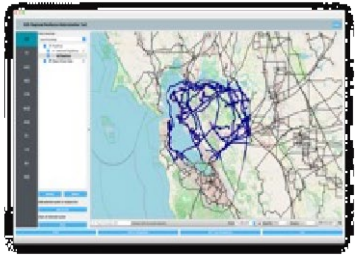

Earthquakes


Hurricanes

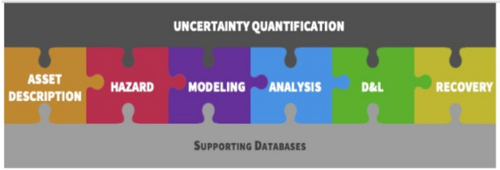

Tsunamis

Multiple Assets


Buildings


Lifelines

R2D Desktop Application for Regional Simulation



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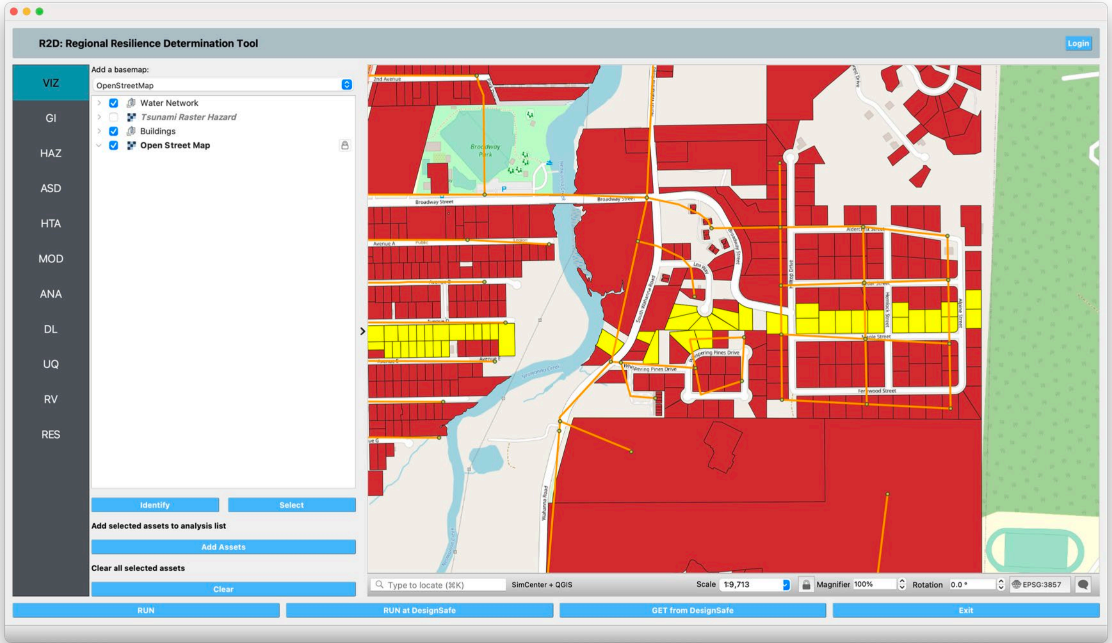
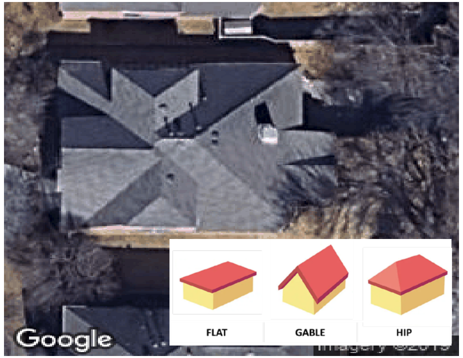


High-Res Inventories – Computer Vision – BRAILS

Elevations & Window Area

Number of Floors

Occupancy Class

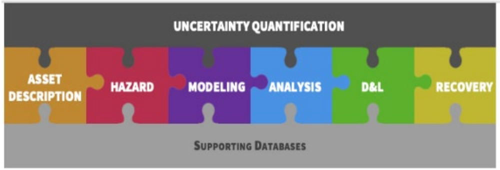


Roof Shape

BRAILS: Building Recognition using AI at Large Scale

- Detect building features
- Library of AI models and approaches
  - *semantic segmentation*
  - *classification (multi-class transformer)*
  - *object detection*
- Seeded with trained models for several common building features.
- Validated with field reconnaissance and ZTRAX

Desktop Application for Regional Simulation



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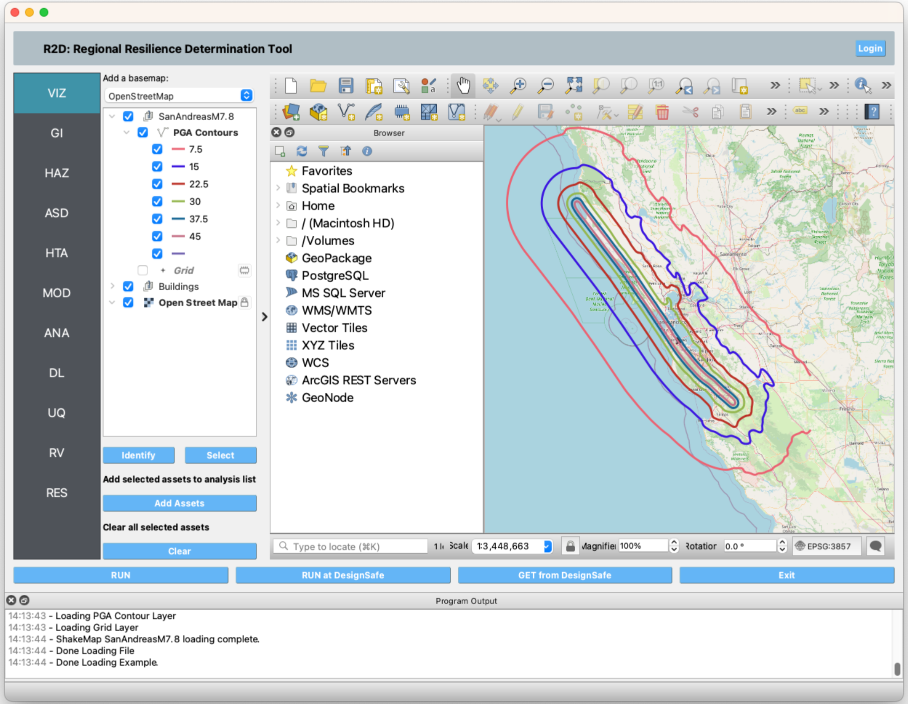

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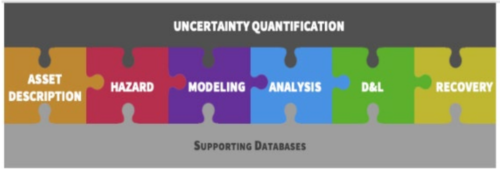

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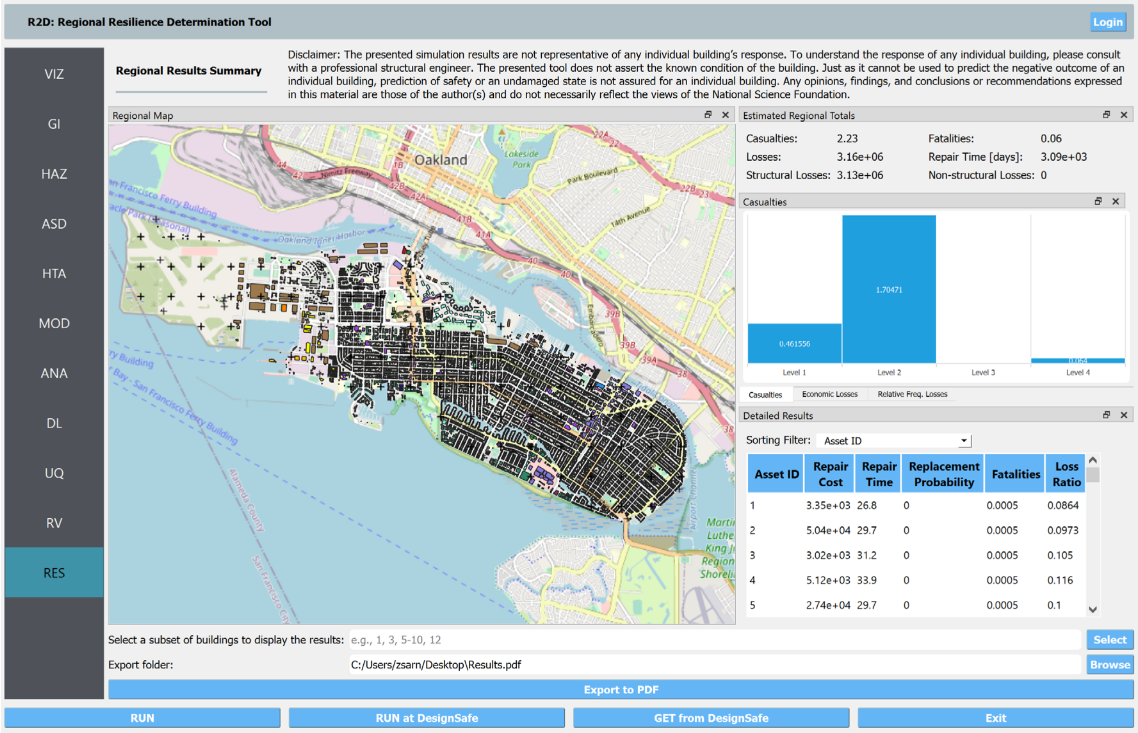
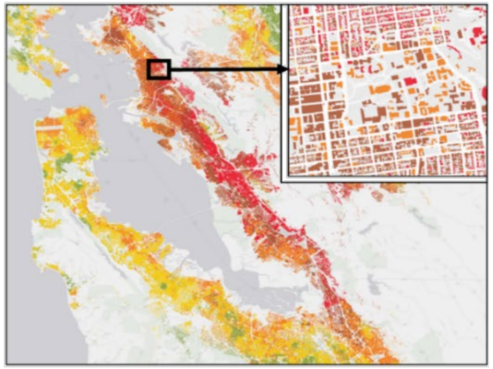
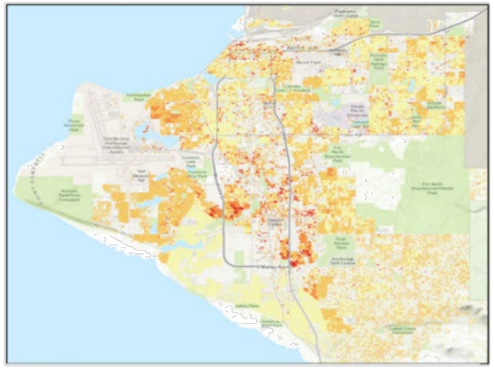


SimCenter – Regional Testbeds

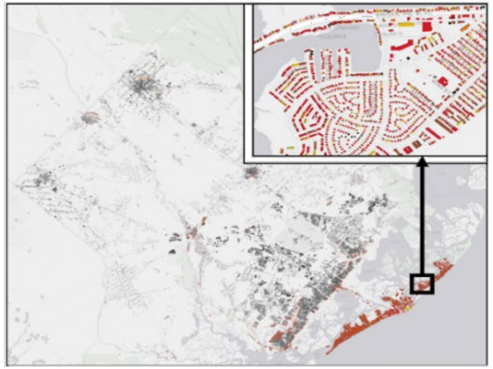
- Proof of concept
- Benchmark & verify methods
- Engage researchers and users
- Identify gaps & opportunities
- Establish data standards



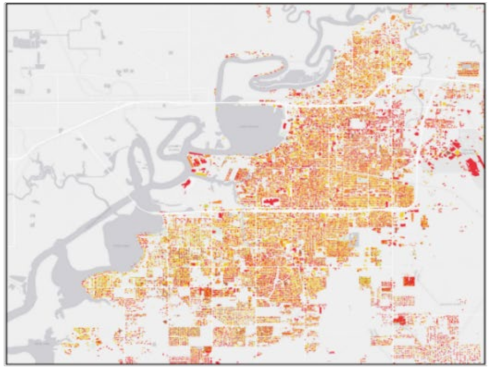
SF Bay Area – EQ Scenario



Anchorage – EQ Hindcast



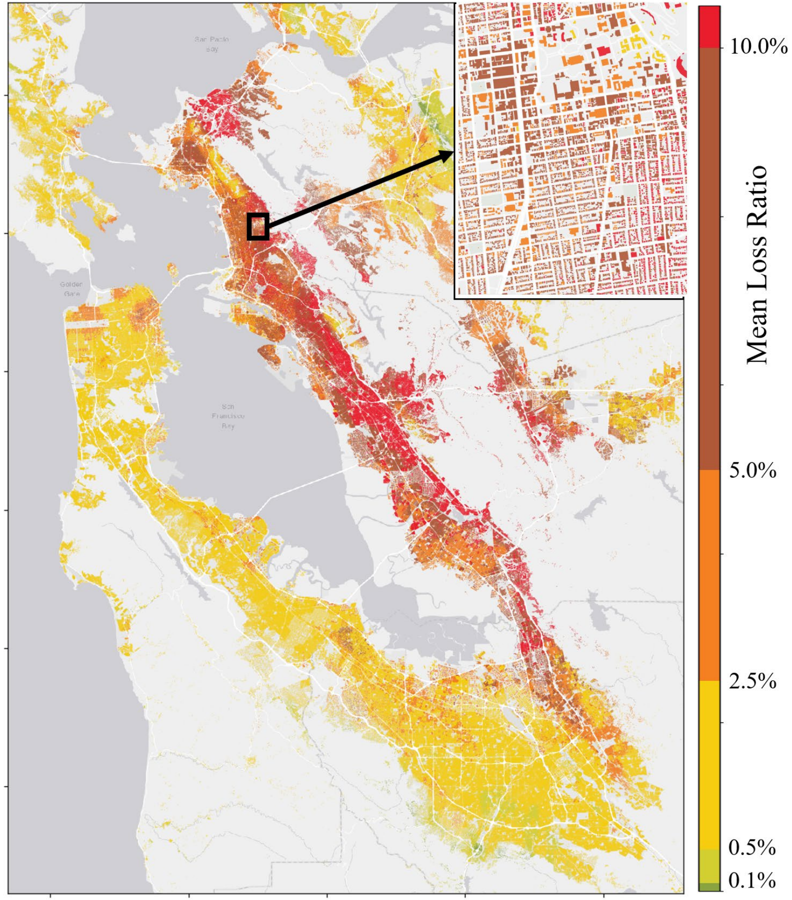
Atlantic City – Hurricane Scenario



Lake Charles – Hurricane Hindcast

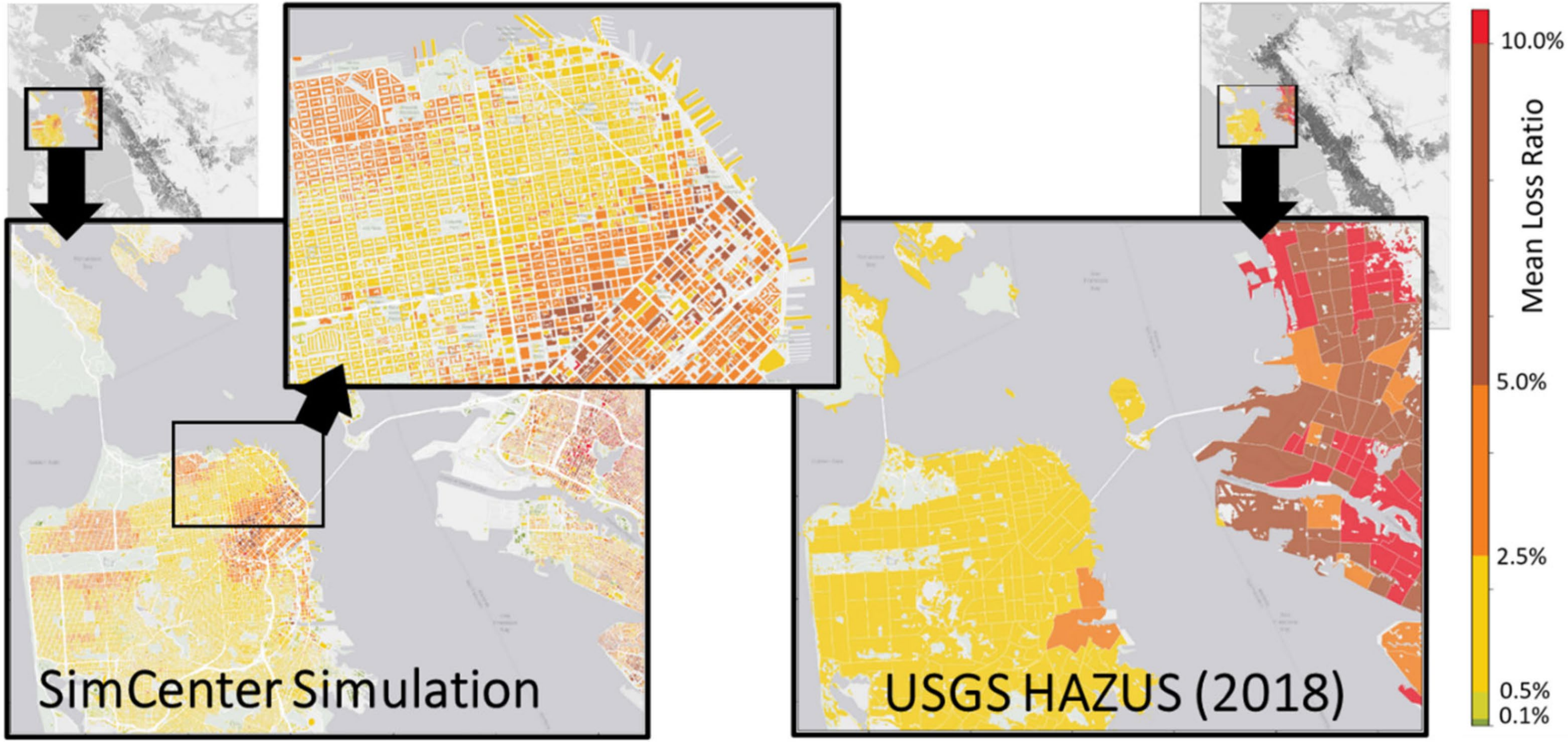
San Francisco Bay Area M7.0 Earthquake Testbed

- **M7.0 earthquake in the SF Bay Area**
  Hayward fault – physics–based simulation (LLNL-SW4)
- **High-resolution building inventory**
  1.84 million buildings with footprint & main features
- **Building-specific structural analyses**
  OpenSees idealized MDOF response models
  Hazus earthquake damage and loss models
- **Uncertainty Quantification**
  uncertainty in buildings, damage, and losses
  25 realizations capture possible outcomes
- **High-Performance Computing**
  DesignSafe HPC (Stampede2 at TACC)
  embarrassingly parallel: 2 hr runtime using 10K cores



San Francisco Bay Area M7.0 Earthquake Testbed

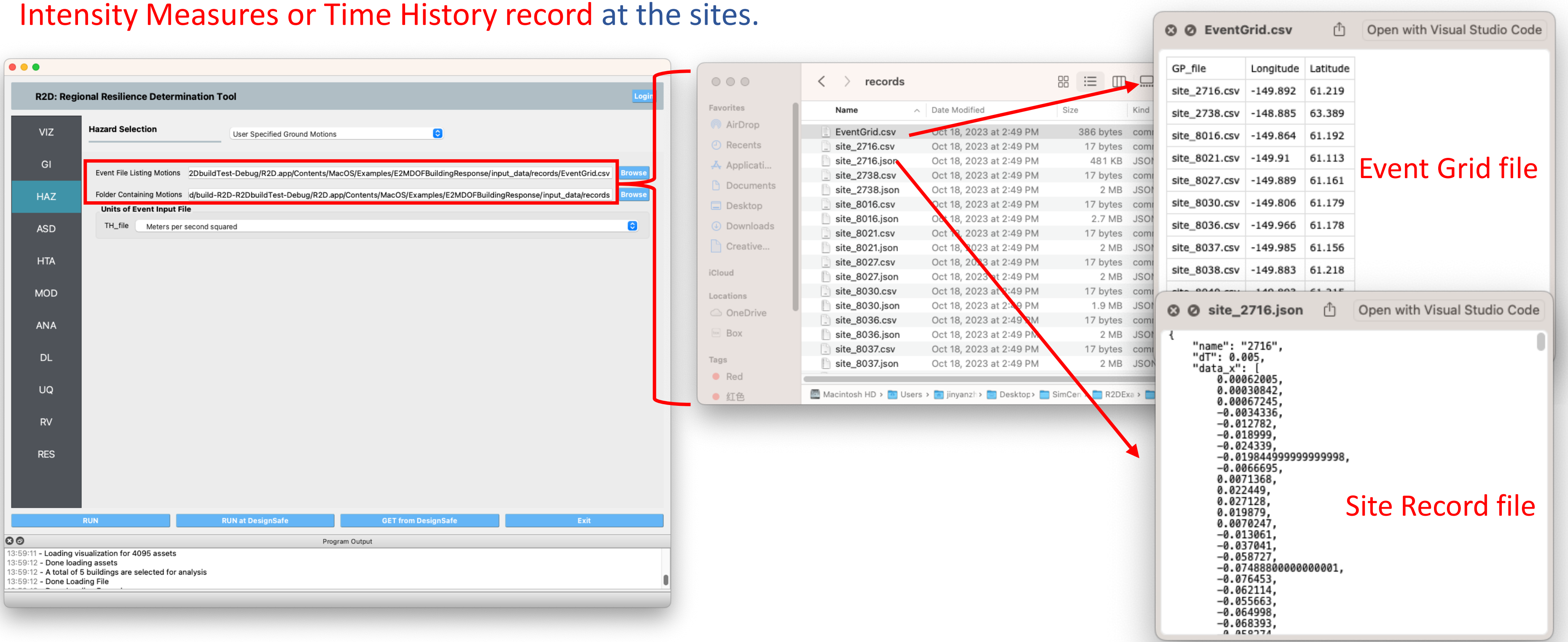
High Resolution Modeling: Parcel-level resolution enables unprecedented quantification of *engineered interventions for policy level decisions*



Earthquake hazard definition options in R2D

Option 1: User-specified ground motions

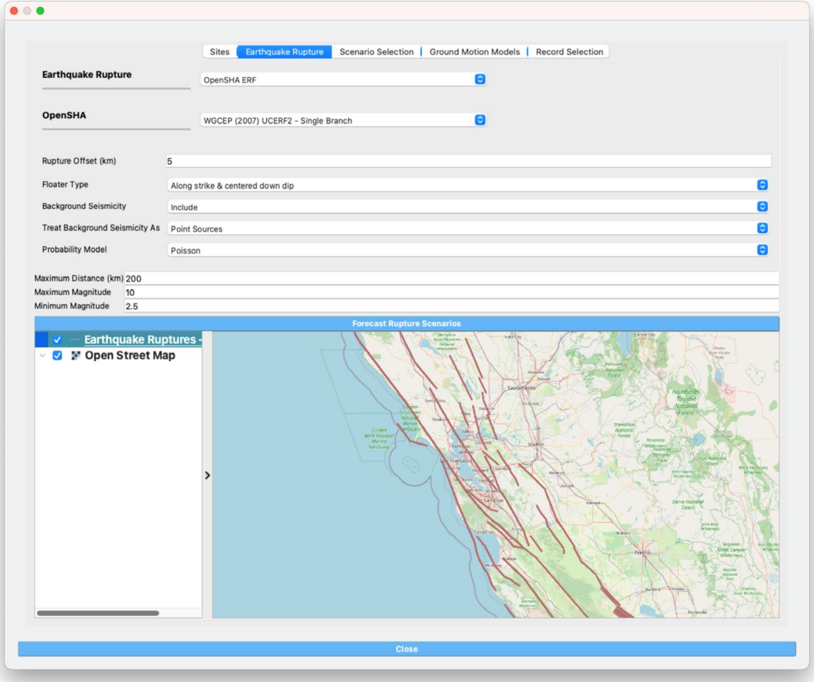
Users prepare an Event Grid file to define site locations and a group of Site Record files, which contains the Intensity Measures or Time History record at the sites.

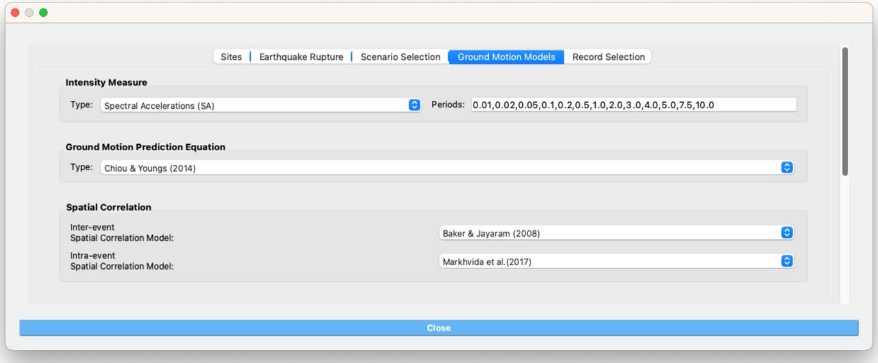


Earthquake hazard definition options in R2D

Option 1: User-specified ground motions (cont'd)

R2D has a regional ground motion simulation tool to predict ground motion maps from earthquake rupture forecasts, ground motion prediction equations, and spatial correlation models.

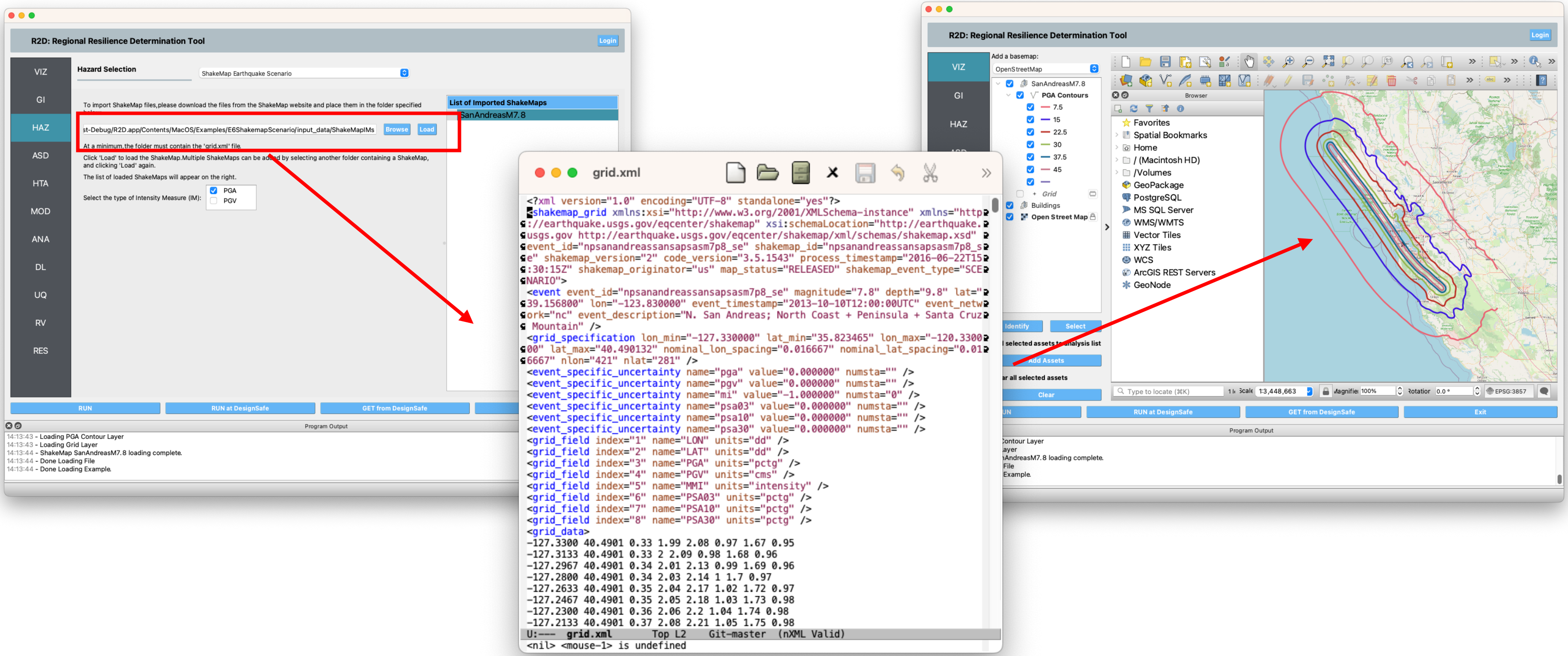




Earthquake hazard definition options in R2D

Option 2: Import from ShakeMap Scenario

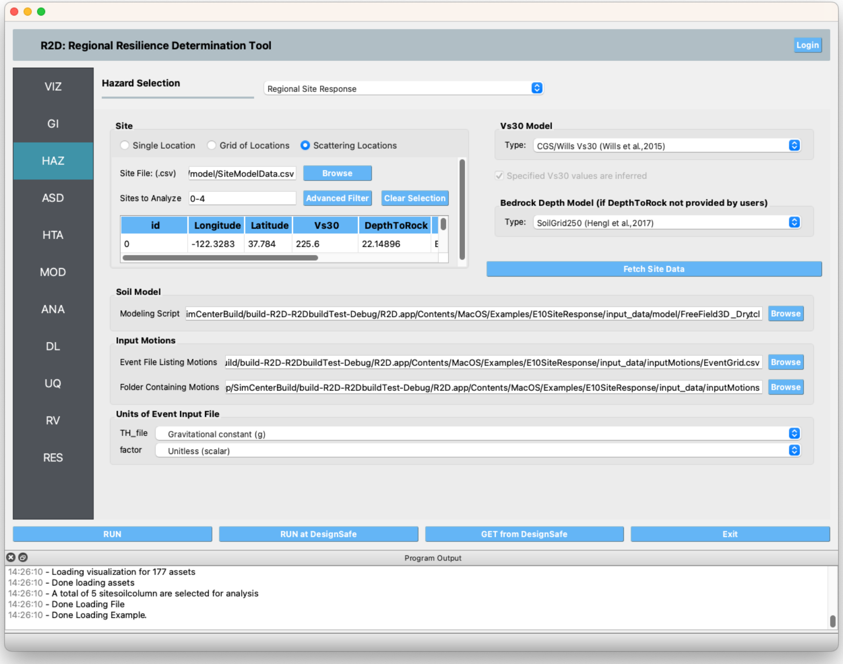
Users prepare a ShakeMap Grid (.xml) file that defines a grid and the intensity measures at each grid point.

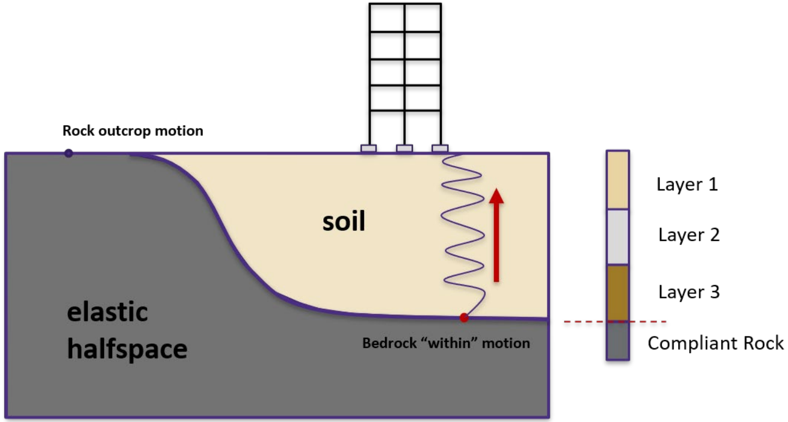


Earthquake hazard definition options in R2D

Option 3: Regional Site Response

Users provide ground motion records at the bedrock level and compute the ground surface response with one-dimensional response analyses using OpenSees.

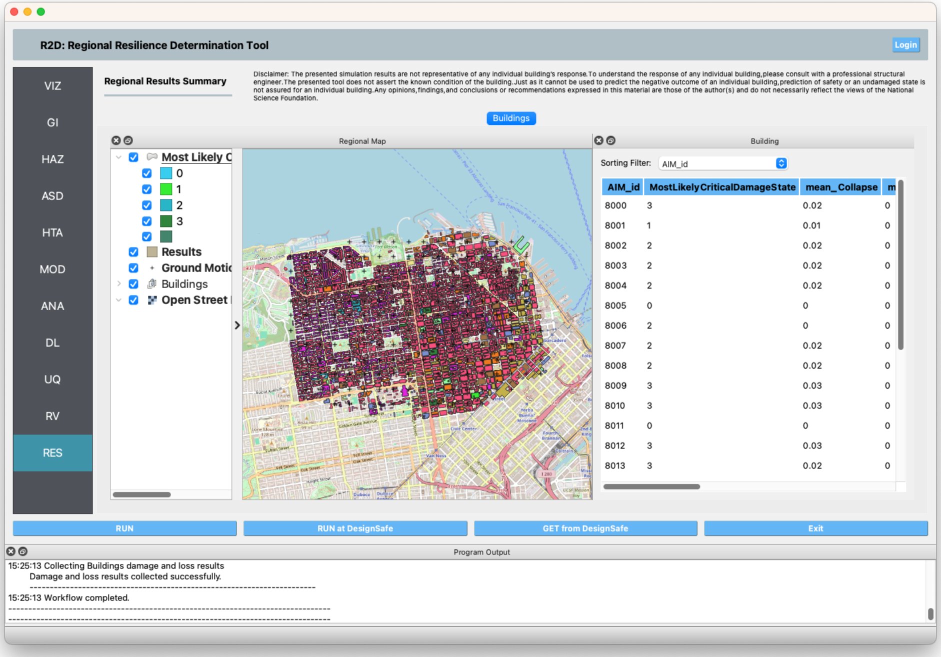


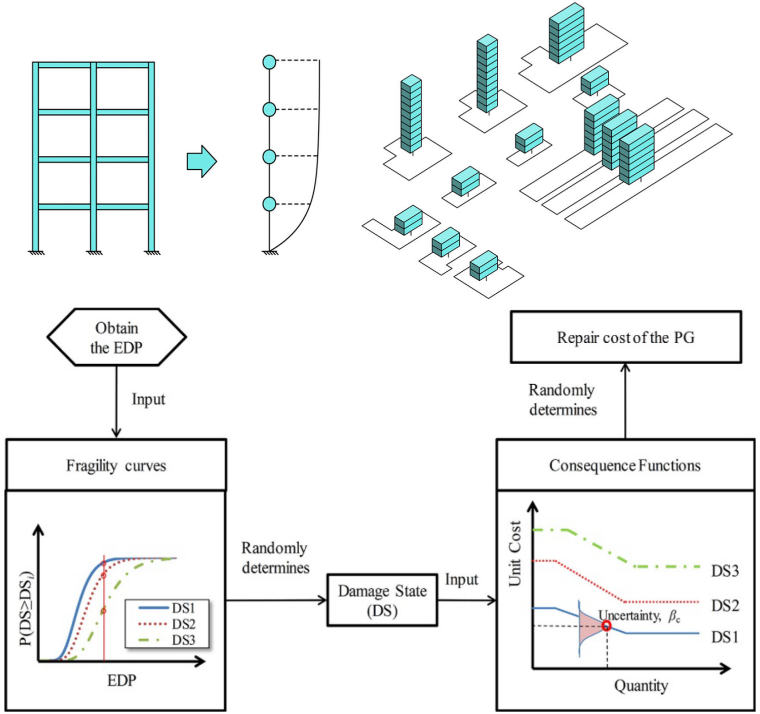


Application of the ground motions

Application 1: Building safety assessment

Building level performance assessment using Intensity Measures or story level performance assessment using multi-degree of freedom OpenSees models and ground motion Time History records.



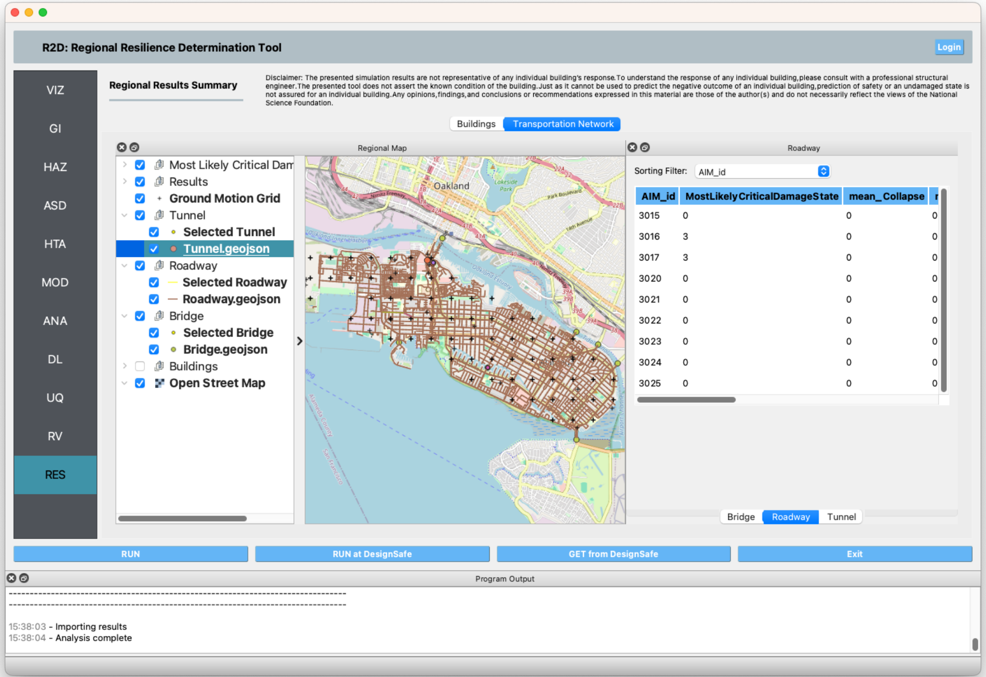


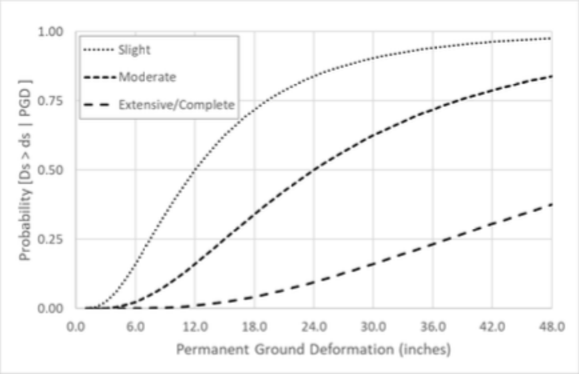
R2D

Application of the ground motions

Application 2: Transportation infrastructure safety assessment

High-level performance assessment using ground motion Intensity Measures and FEMA's Hazus fragility curves for highway bridges, tunnels, and roadways.





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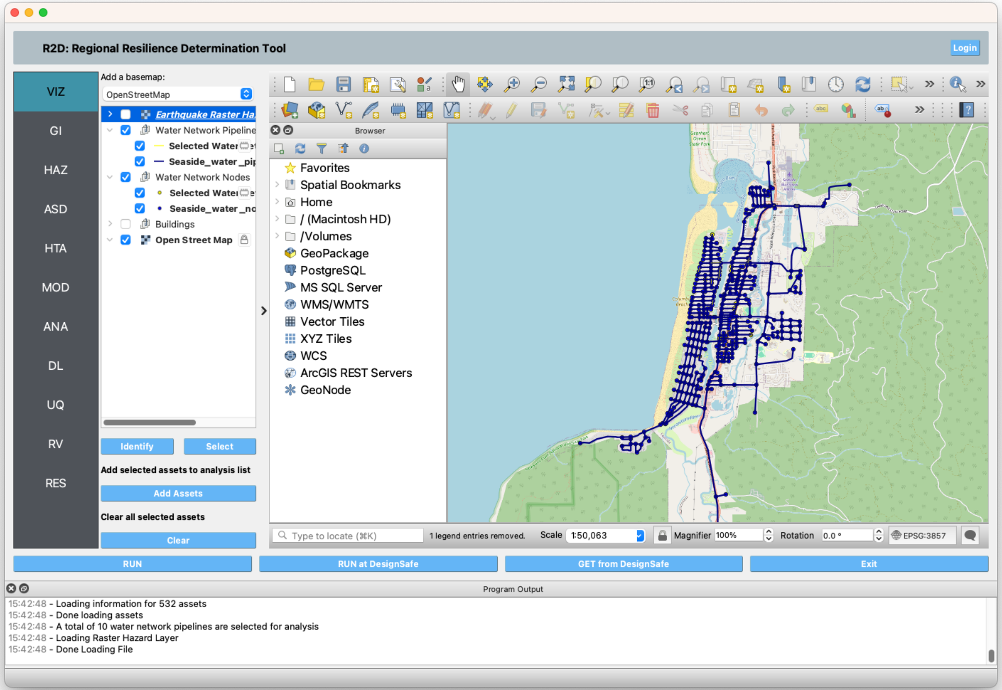
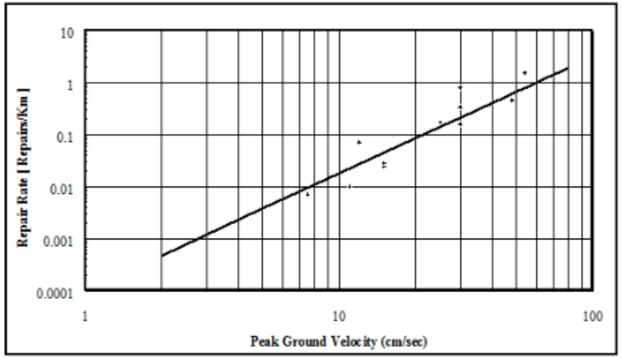
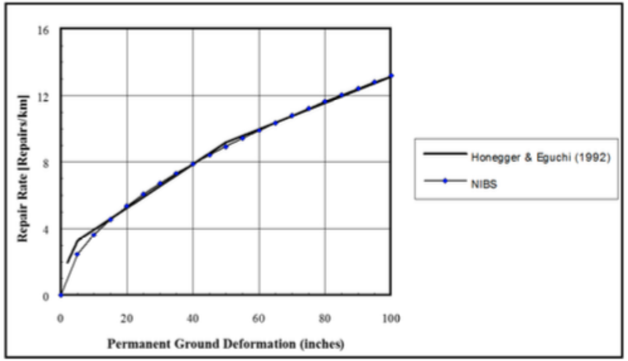
Application of the ground motions

Application 3: Water pipeline infrastructure safety assessment

High-level performance assessment using ground motion Intensity Measures and FEMA's Hazus fragility curves for water pipeline, pumps and tanks.



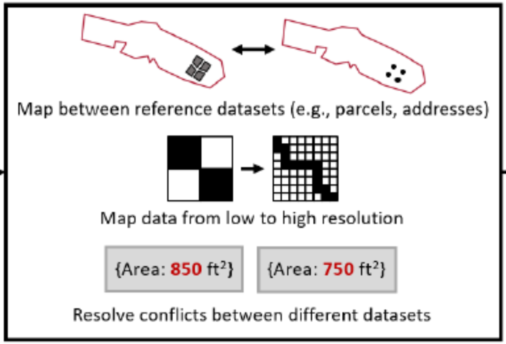


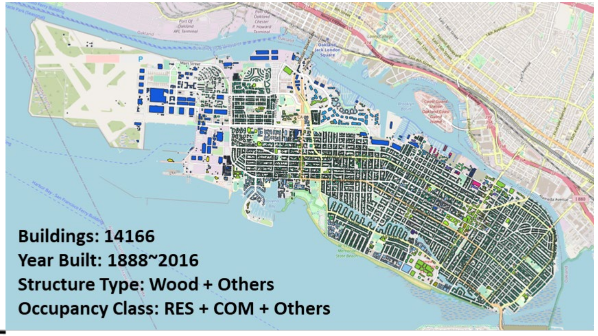


Interdependency - Alameda Case Study

High-Fidelity Building Inventory

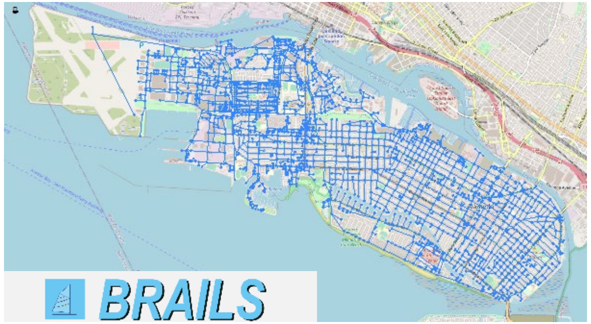
Publicly available datasets



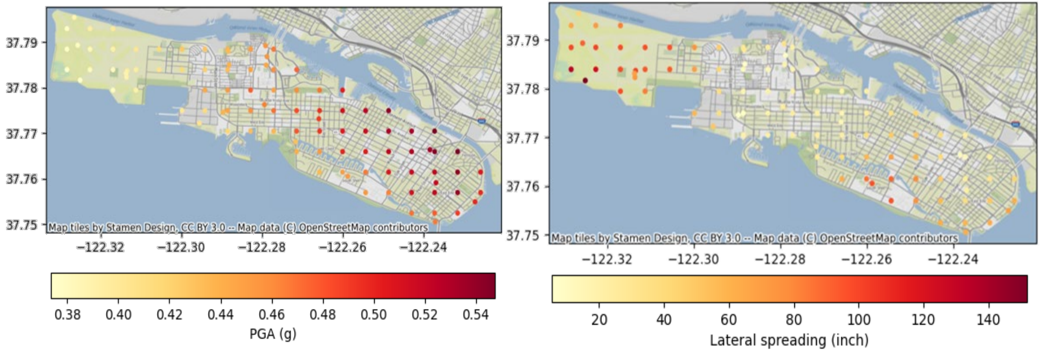


Bassman T.J., Zsarnóczay A., Saw J., Wang S., Deierlein G.G., *"High-Fidelity Testbed Development for Regional Risk Assessment in Alameda, California"*, 12th NCEE, 2022

Transportation & Water Infrastructure

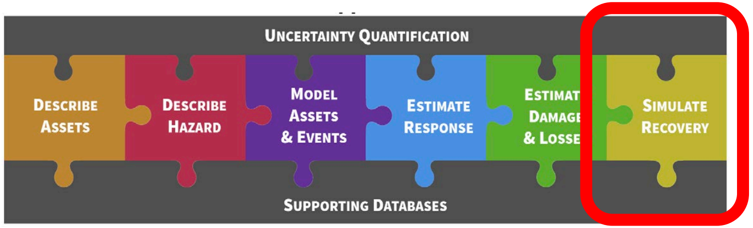


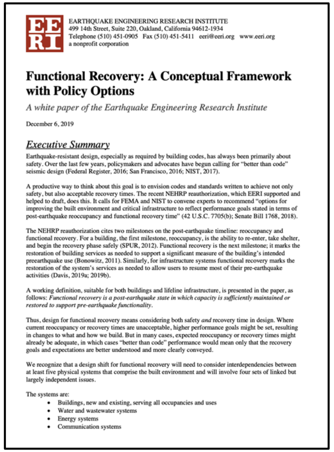
Inventory Generation Tools

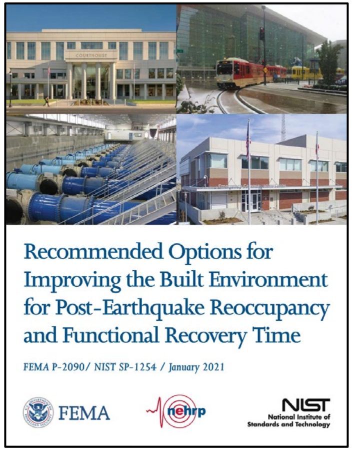


Ground Shaking and Permanent Deformation

Modeling Functional Recovery







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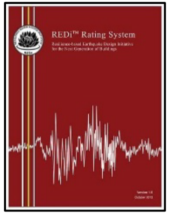


ARUP

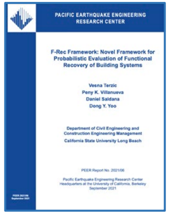
TREADS

Molina Hutt et al.

ATC-138

FEMA, ATC

F-Rec



Terzic et al.

- Opportunities for comparisons and benchmarking
- Recognize and leverage synergies in future development
- Open-source code supports both research and practice

GOAL: D/L+R+UQ+Interdependencies

- Tool to allocate resources post-event based on both certain and uncertain data and uncertainty in other parameters (i.e. known pipe/valve break) **+ OTHER INFRASTRUCTURE DAMAGE DATA**

Building damage
Road closures

R2D

Damage & Loss

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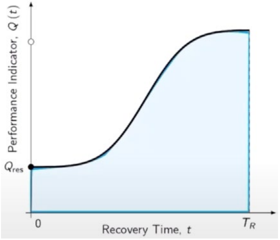
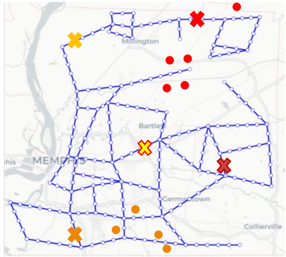
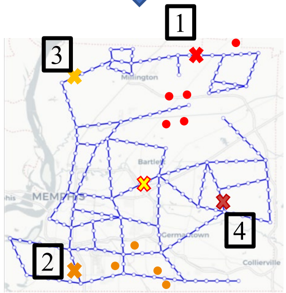


Recovery (based on simple recovery curves)



Uncertain & Certain Data

Bayesian Updating (update model based on UQ simulations)



Resilience using Resource Allocation (with interdependencies)

iRe-CoDeS computational workflow: physics-based and modular

Community properties

Soil type, terrain elevation, fault location, etc. → **Hazard module**

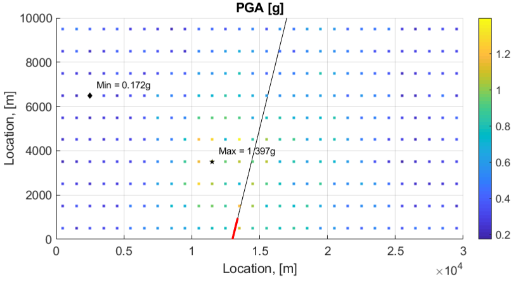
Exposure, fragility/vulnerability functions, etc. → **Vulnerability module**

Repair time, impeding factors, recovery resource supply, etc. → **Recovery module**

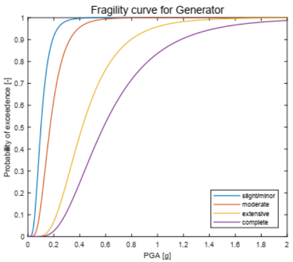
Community resilience goals → **Resilience quantification module**

Hazard module → Vulnerability module → Recovery module → Resilience quantification module

Disaster intensity measure predictions



Regional damage/loss model



iRe-CoDeS recovery model

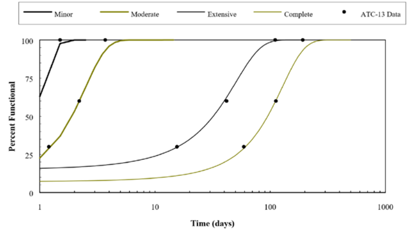
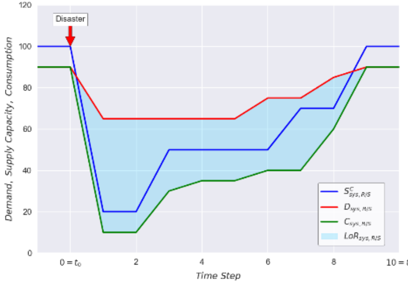


Figure 8.1: Restoration Curves for Water Treatment Plants (after ATC-13, 1985).

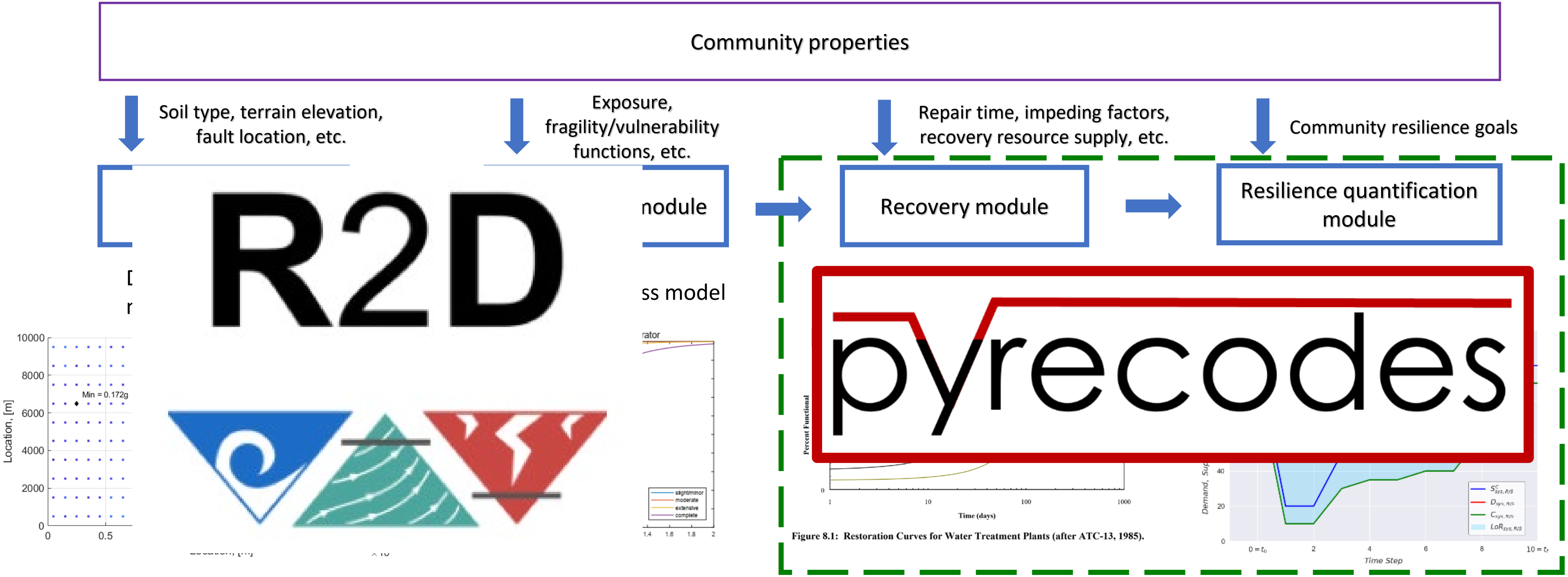
Re-CoDeS resilience assessment



Blagojević, Kipfer, Didier, Stojadinović (2020) *Probability-based Resilience Assessment of Communities with Interdependent Civil Infrastructure Systems*. Proceeding of the 17th World Conference on Earthquake Engineering. Sendai, Japan.

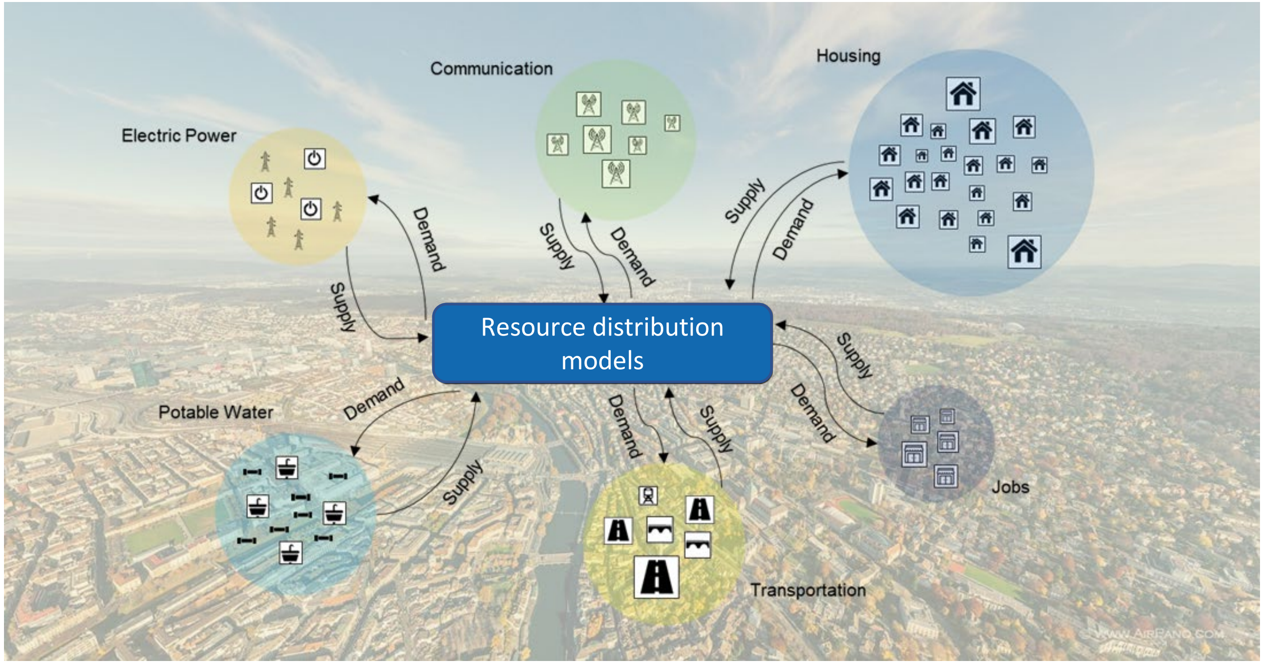
Blagojević, Kipfer, Didier, Stojadinović (2020) *Scenario-based Resilience Assessment of Communities with Interdependent Civil Infrastructure Systems*. Proceeding of the 17th World Conference on Earthquake Engineering. Sendai, Japan.

iRe-CoDeS computational workflow: physics-based and modular



pyrecodes is an open-source framework for regional disaster recovery simulation and disaster resilience assessment of interdependent systems.

Component interdependencies simulated as a flow of resources and services



Blagojević, Hefti, Henken, Didier, Stojadinović (2022) *Quantifying Disaster Resilience of a Community with Interdependent Civil Infrastructure Systems.* Structure and Infrastructure Engineering.

Regional Resilience: integration and future development

Finite-element models

Ground motion models

Fragility functions

Water: **REWET**

Transportation: **spatial-queue model**

Horizontal integration

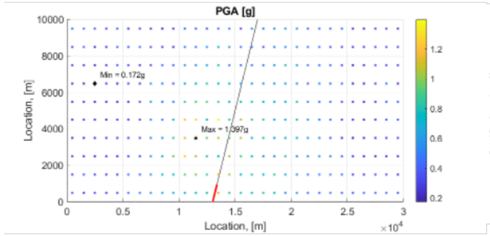
Regional risk models

Hazard module → Vulnerability module →

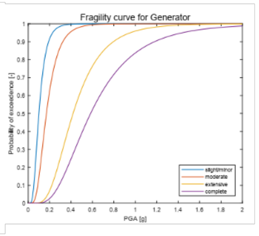
pyrecodes

Recovery module → Resilience quantification module

Disaster intensity measure assessment

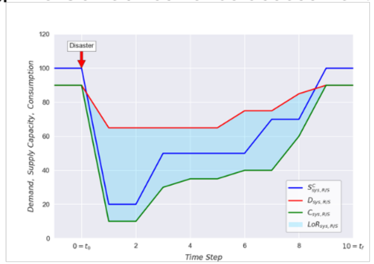


Regional damage/loss model



iRe-CoDeS regional recovery model

Re-CoDeS resilience assessment



Two Potential Workflows to integrate Simulated Ground Motions

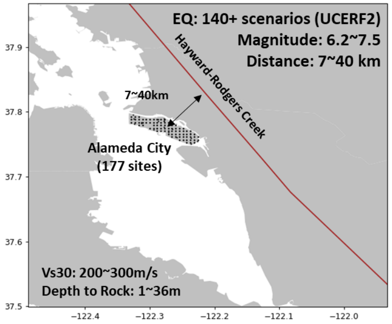
- 1D Site Response
- Domain Reduction Method (DRM)

Current R2D Worflow to include Site Response effects

- Coupling GMS, building inventory and damage and loss assessment
- Modular approach with flexible soil and structural model definition
- Conducting Risk Assessment in Research Area

Workflow using 1D SiteResponse

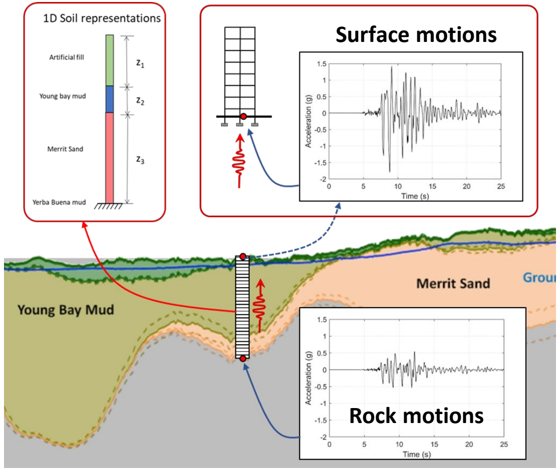
Earthquake ground motions



- **Rock motions:**

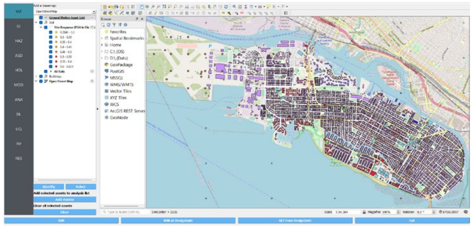
1. **GMPE w/ rock Vs30 + record selection**
2. **Physics-based earthquake records**

1D Soil layer simplification and building analysis

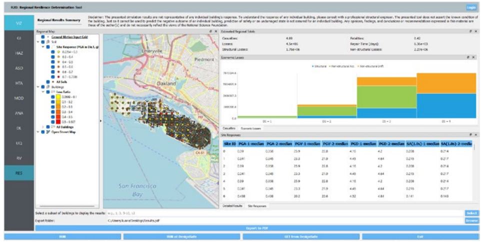


Risk Assessment(R2D)

Surface motion intensity



Building damage and loss

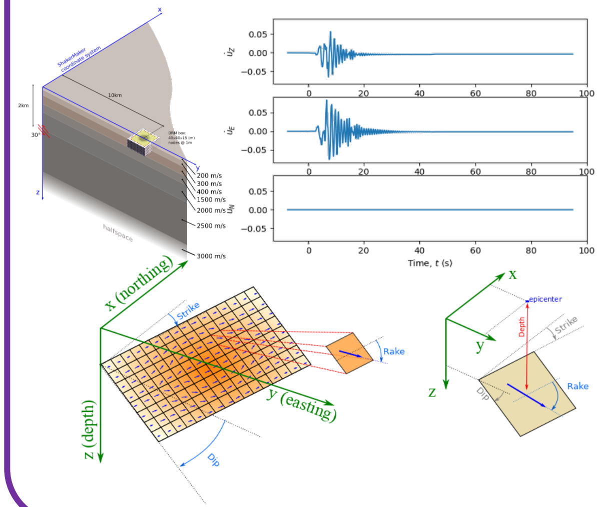


Proposed R2D Workflow to include SiteResponse effects

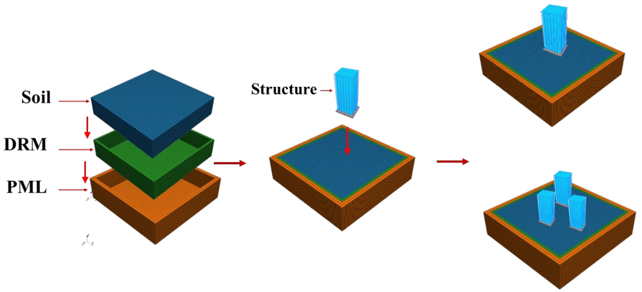
- Transition to Cutting-Edge Simulations that includes DRM and PML
- Exploring Source Rupture Modeling and Uncertainty
- Conducting Risk Assessment in Research Area

Workflow using DRM and PML

Source Modeling



State-of-the-Art Finite Element Model



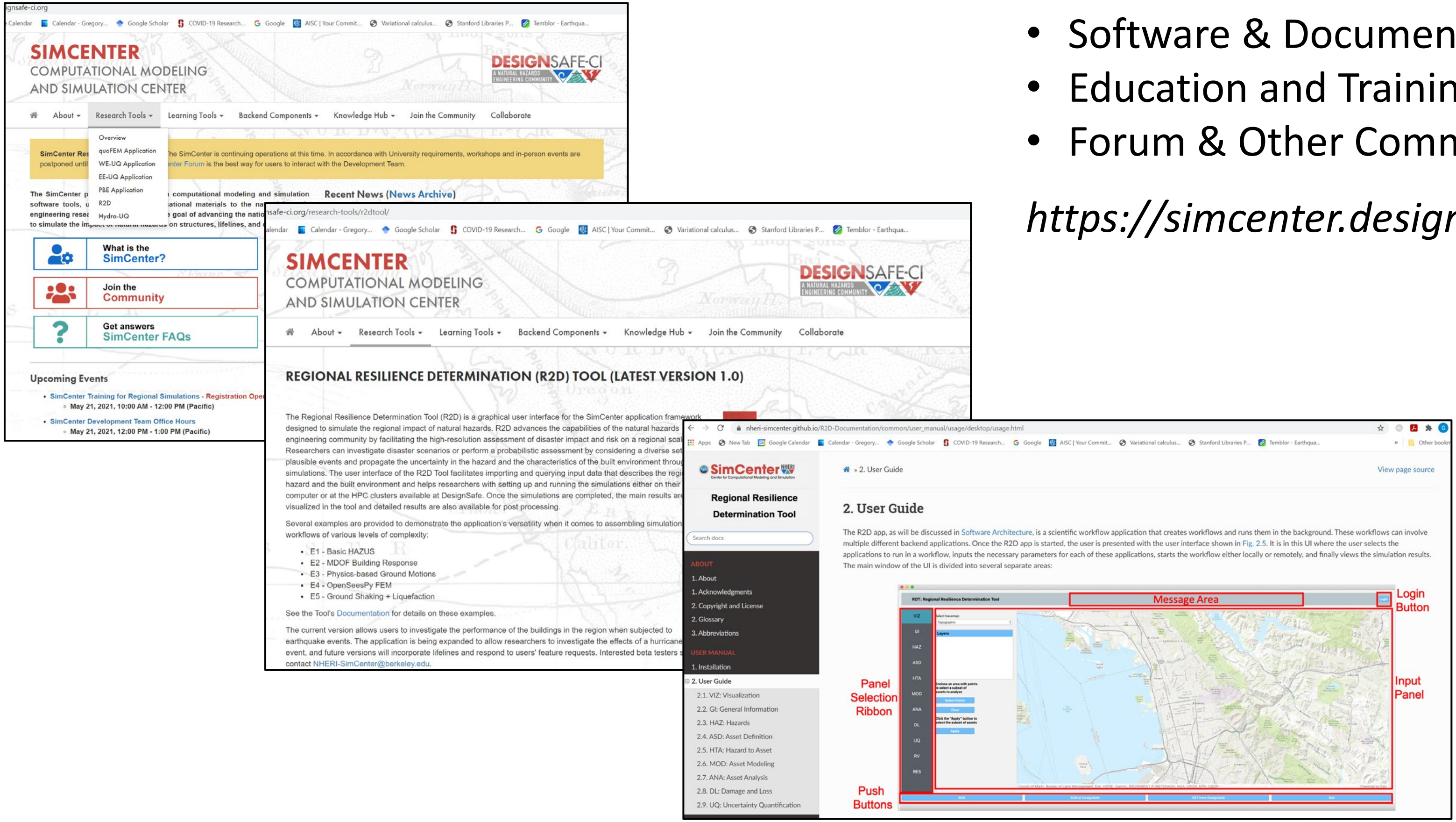
Risk Assessment(R2D)

Use Cases for Simulated Ground Motions

1. Regional impact of earthquakes
   - Broader Goal: Information for decision-making related to public policy, infrastructure operation and preparedness, retrofit mandates, urban planning
   - Simulation Goal: Regional risk, evacuation, recovery/resilience
   - Ground motions requirements:
     - Is spatially distributed mean response (PGA, PGV, PGD) enough?
     - How many simulated ground motion realizations?
   - Soil modeling requirements:
     - 1D Site Response good enough? … or just a useful first step?

2. Detailed earthquake response of specific structures
   - Broader Goal: Detailed seismic design or retrofit
   - Simulation Goal: Detailed asset performance quantification
   - Ground motions requirements:
     - Detailed time history with high spatial resolution at varying depth?
     - How many simulated ground motion realizations?
   - Soil modeling requirements:
     - Domain Reduction Method?

SimCenter Portal



- Software & Documentation
- Education and Training Webinars
- Forum & Other Communication

https://simcenter.designsafe-ci.org/

SimCenter Role:

Provide tools to allow researchers / practitioners to feasibly make use of simulated ground motions in computational workflows

Feasible = Easy access to:

- simulated ground motion data
- simulation models
- HPC resources