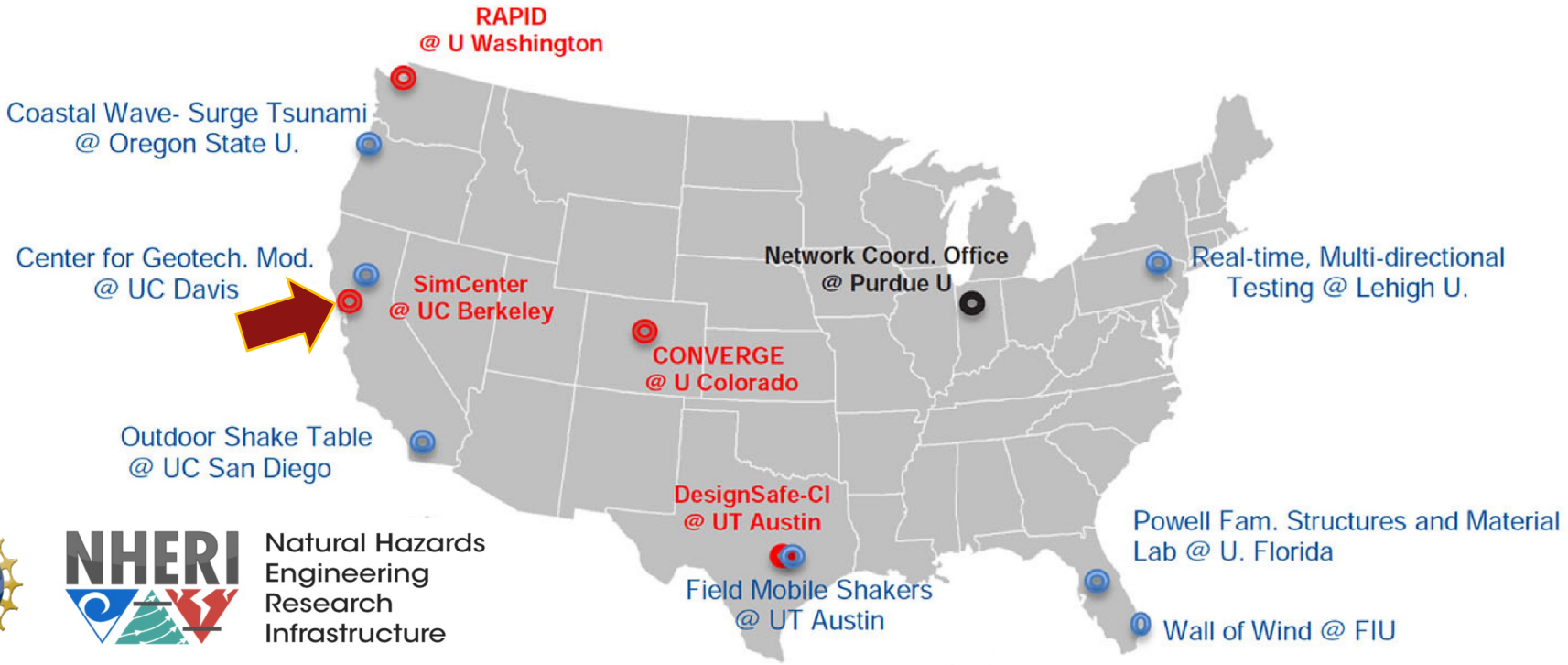
SimCenter NHERI
Center for Computational Modeling and Simulation

SimCenter tools for simulated ground motion utilization

Matt DeJong
PI & Co-Director of SimCenter
Co-Director of CSI
University of California, Berkeley

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

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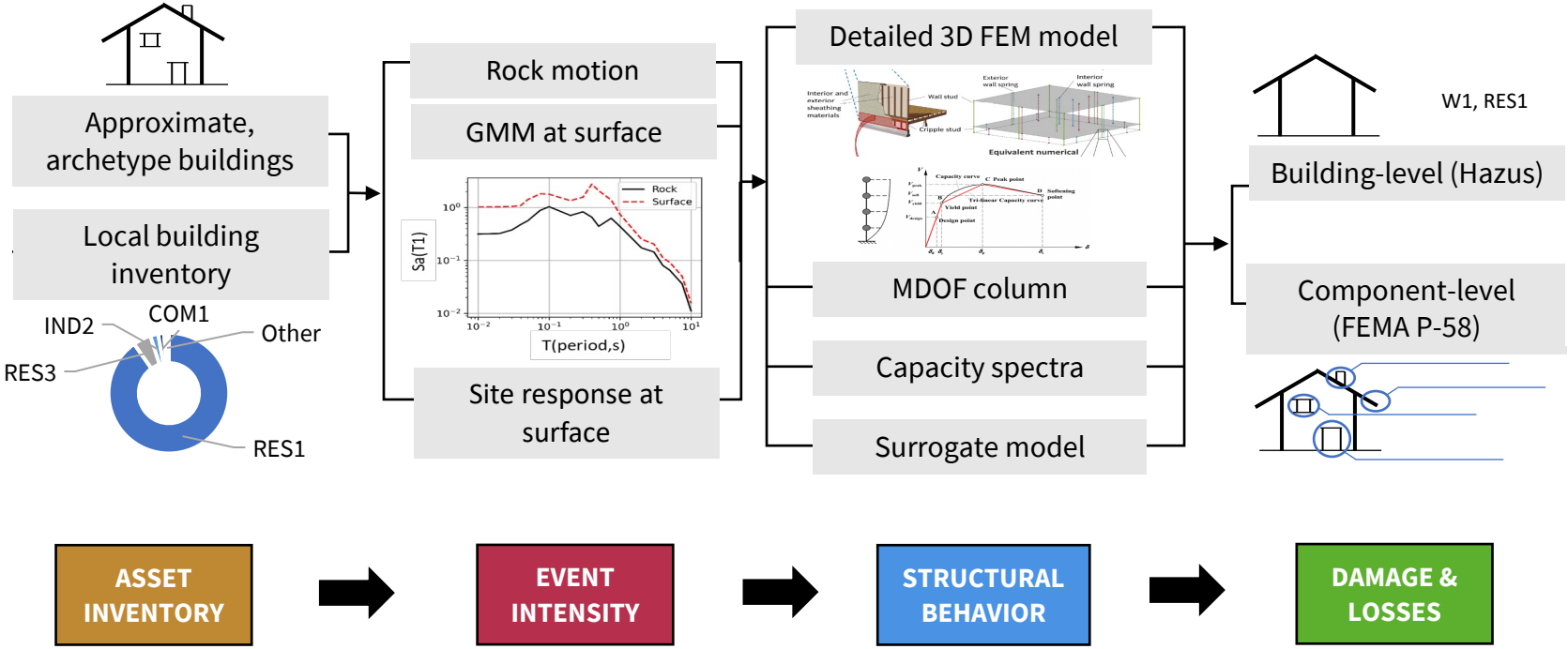
Ertugrul Taciroglu
Stella Yu

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

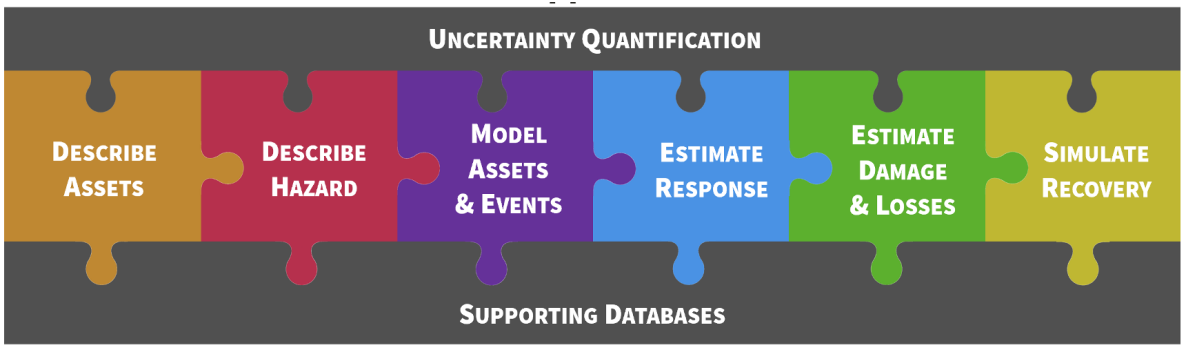
Foster large-scale collaboration in the Disaster Science community

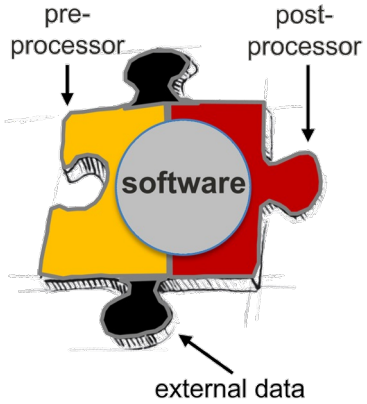
Facilitate transition from local to regional scale, multi-hazard studies

Open Source

Multi-Fidelity

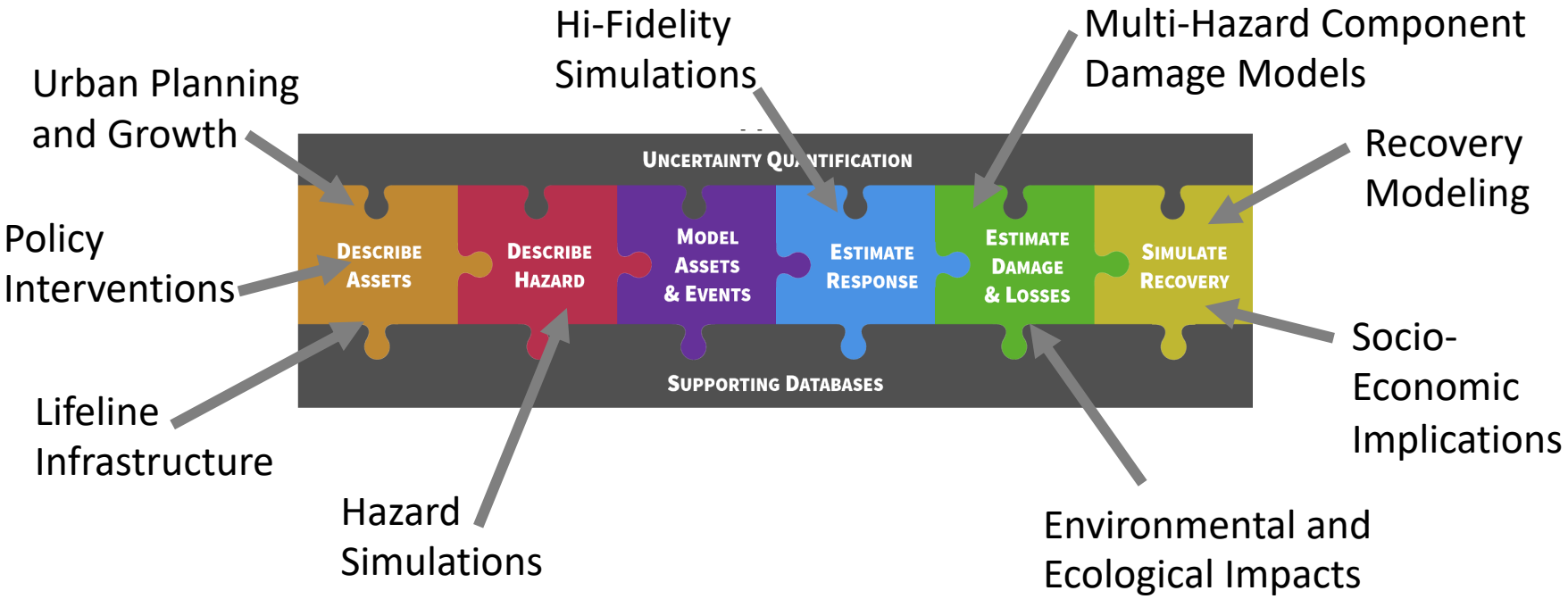
Multi-Hazard



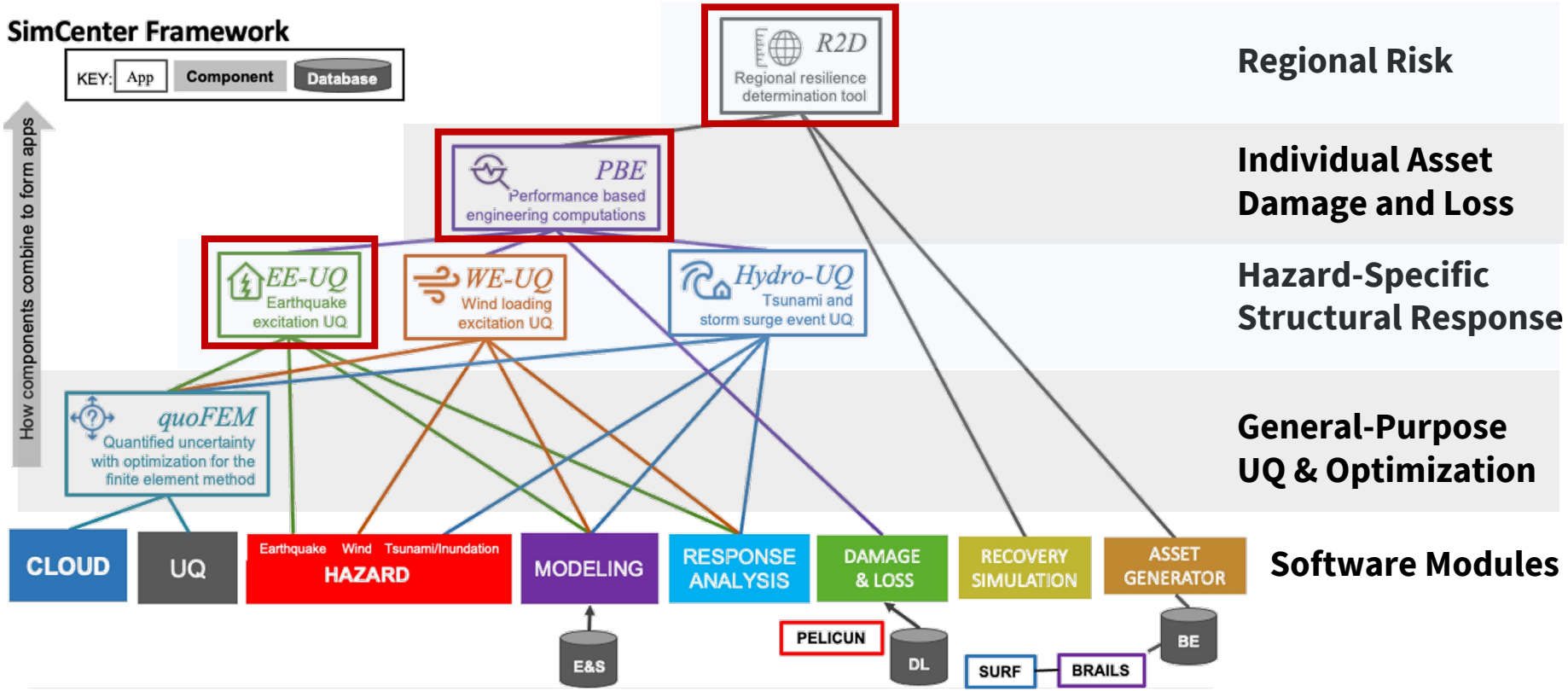


ASSET INVENTORY → EVENT INTENSITY → STRUCTURAL BEHAVIOR → DAMAGE & LOSSES → RECOVERY

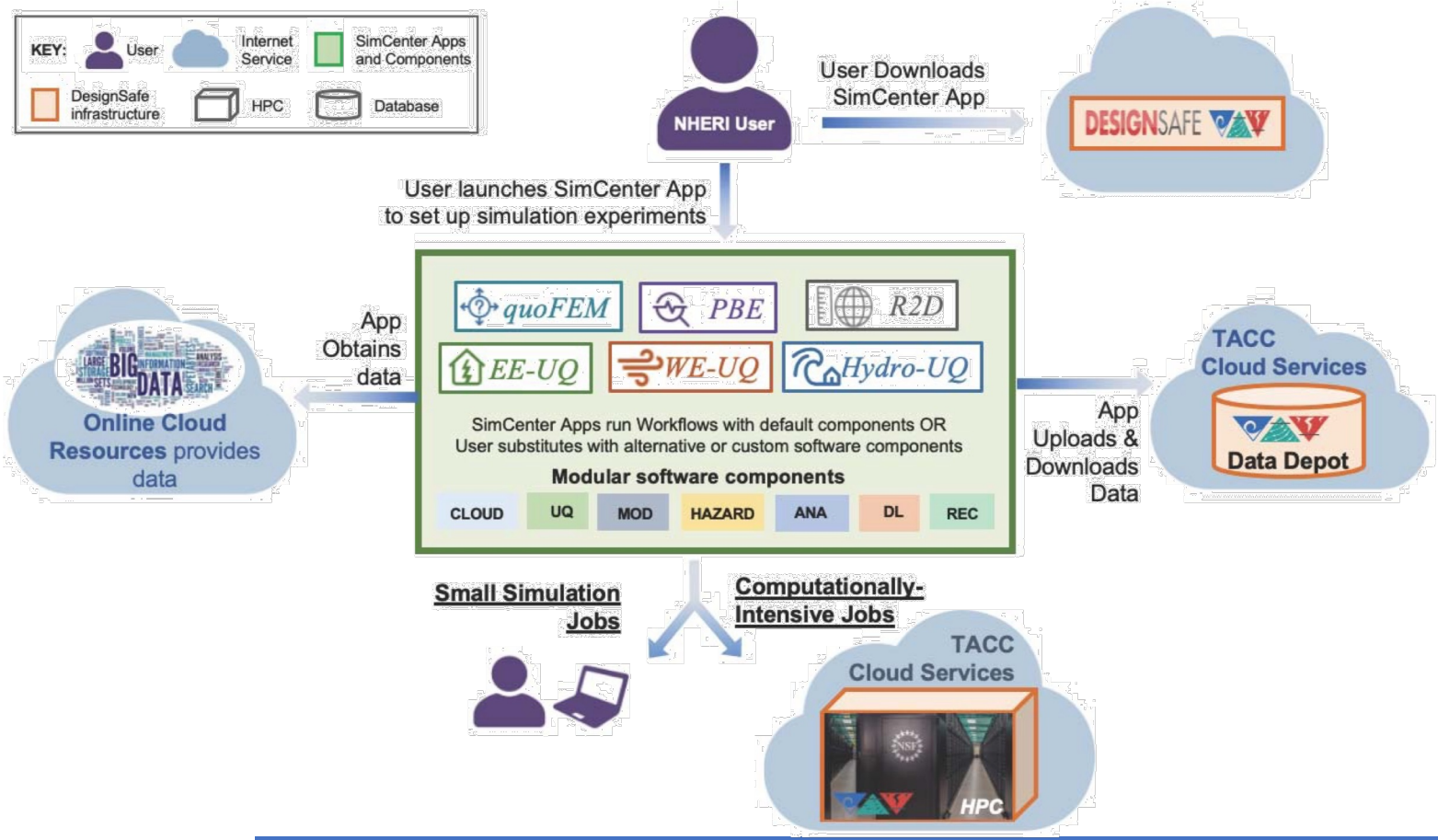
Framework for Multi-Disciplinary Collaboration



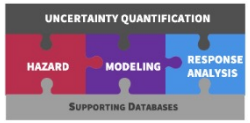
SimCenter – Desktop Applications



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):

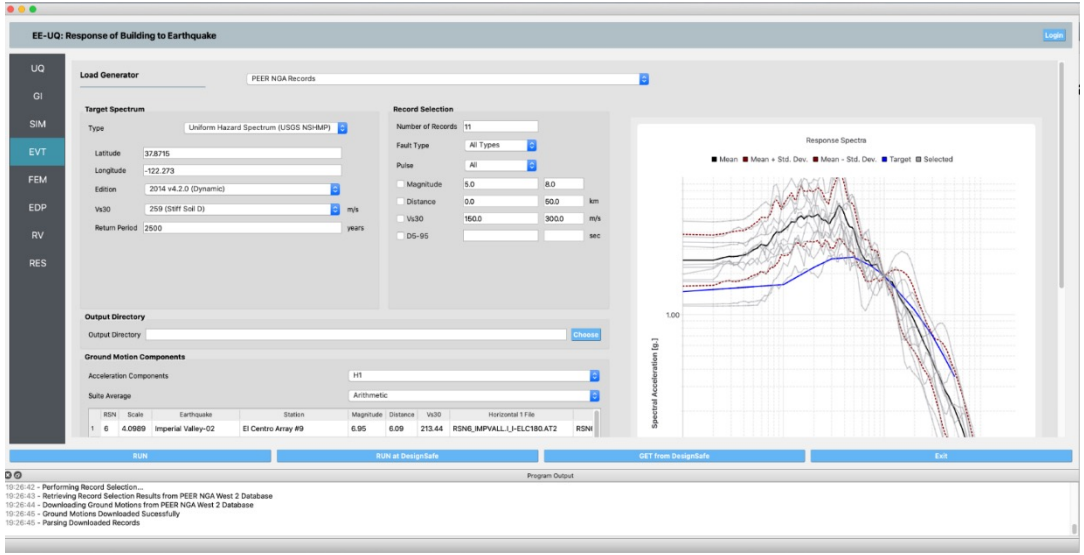
Stochastic Motions
PEER NGA Search with target spectrum
Site Response with Random Fields

Modeling (Building):

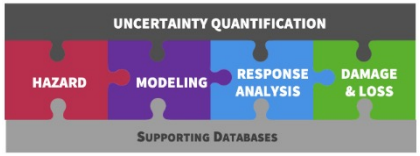
OpenSees
Nonlinear Shear Spring (MDOF)
Steel Building Design & Build (AutoSDA)
Concrete Building Design & Build
Multi-Model Surrogate

Response:

OpenSees
Multi-Model



Desktop Application for Performance Assessment



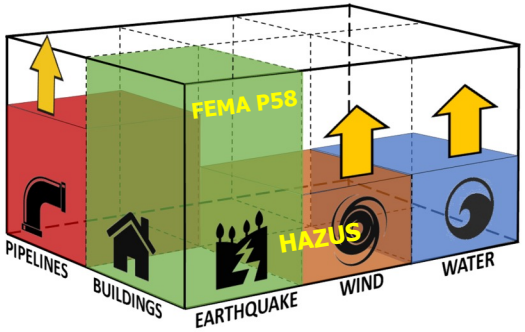
PBE v3.0

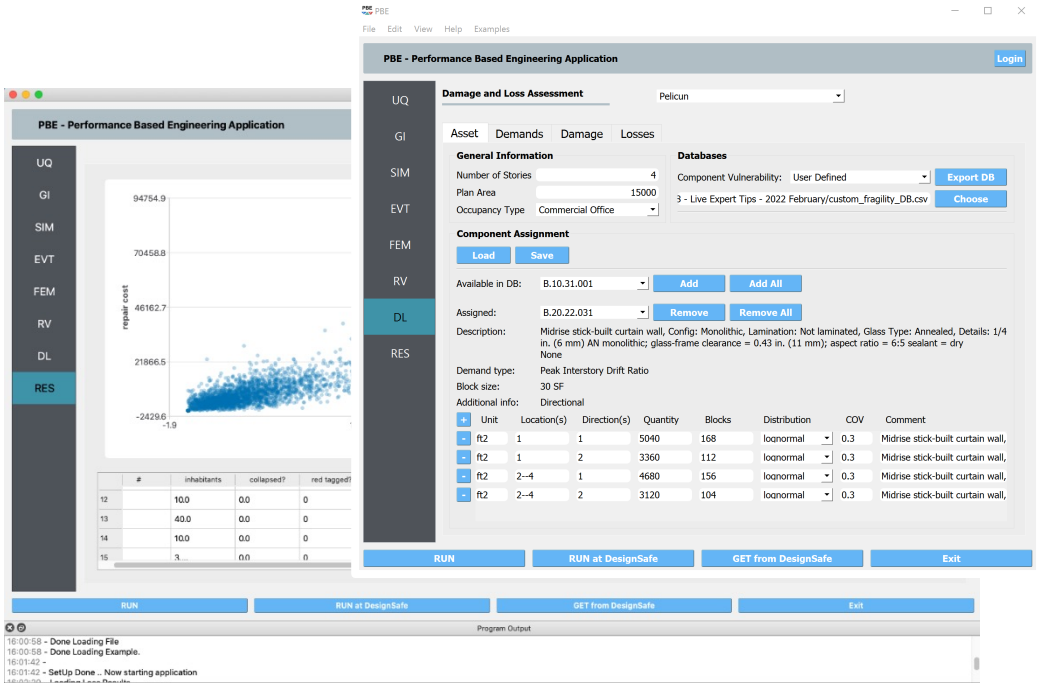
Performance-Assessment of Buildings and Infrastructure Components

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

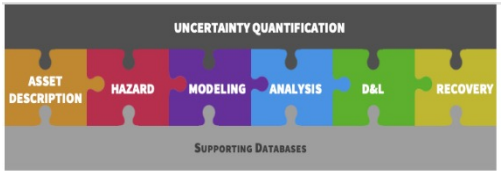
Damage & Loss (using PELICUN):

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





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

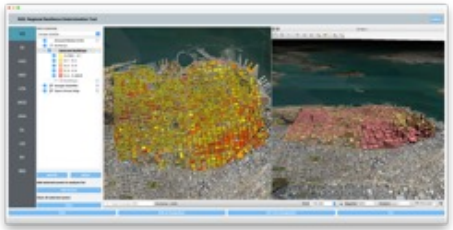
Multiple Hazards

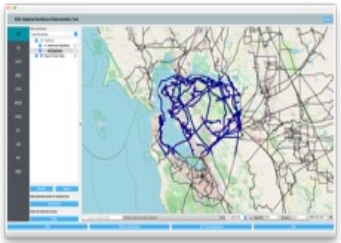

Earthquakes


Hurricanes

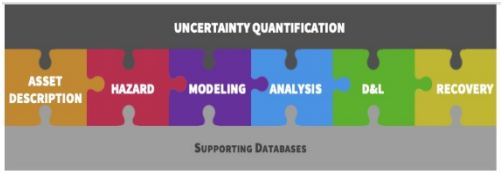

Tsunamis

Multiple Assets


Buildings


Lifelines

Desktop Application for Regional Simulation



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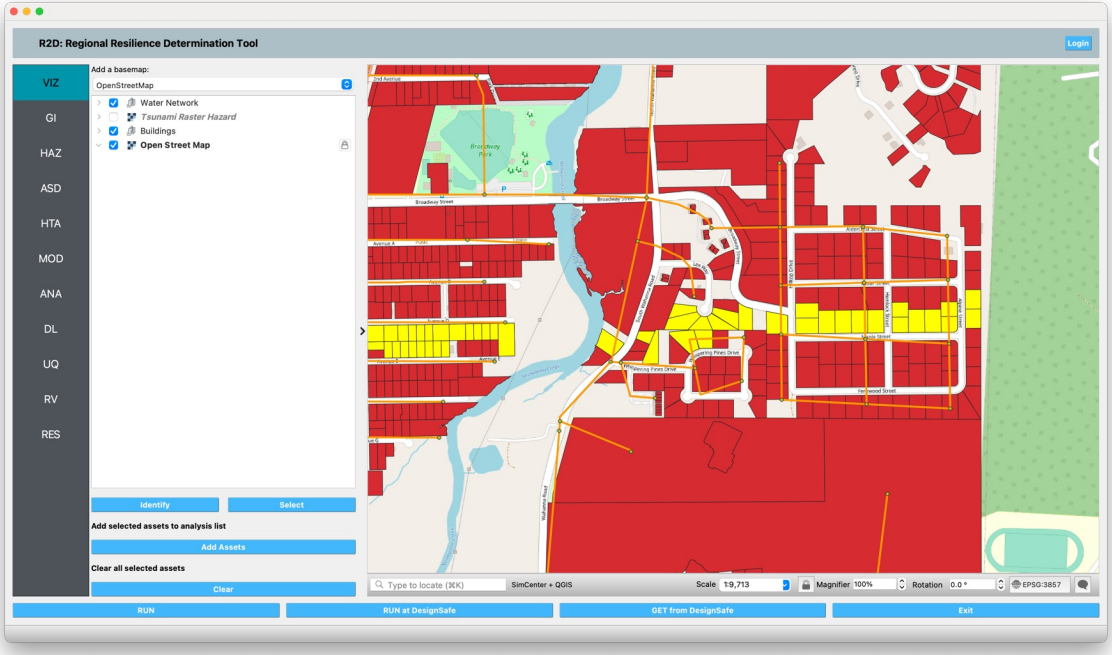
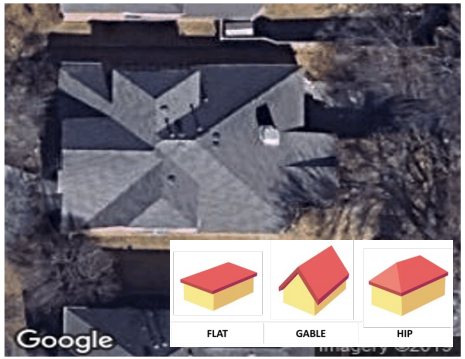


High-Res Inventories – Computer Vision – BRAILS

Elevations & Window Area

Number of Floors

Occupancy Class

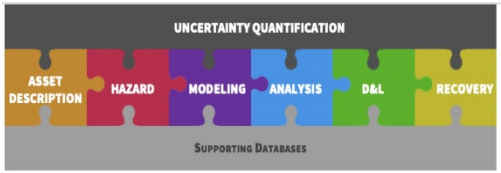


Roof Shape

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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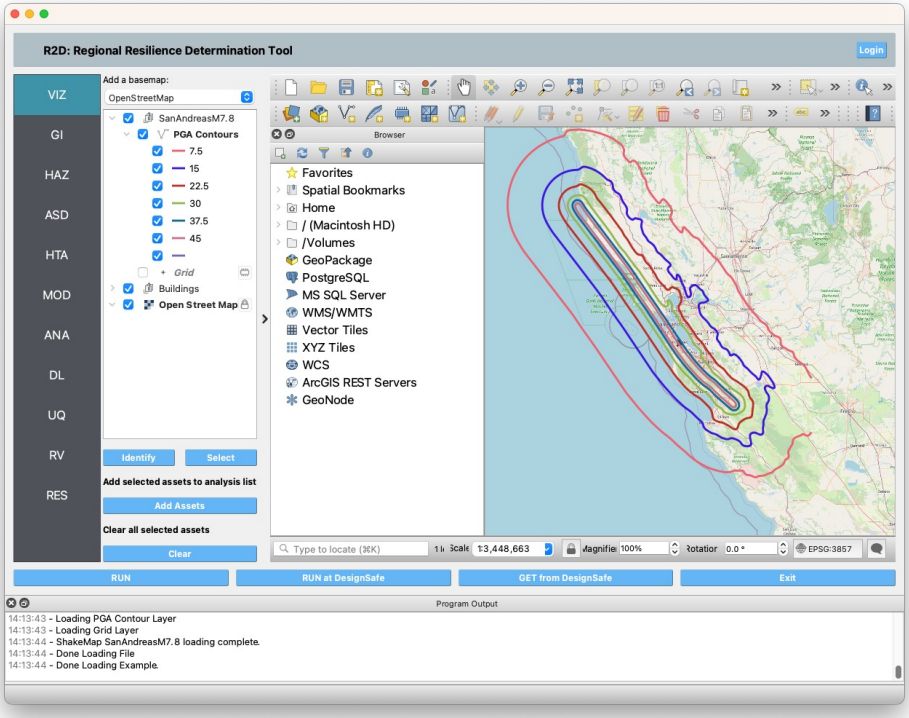

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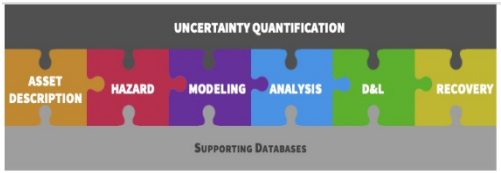

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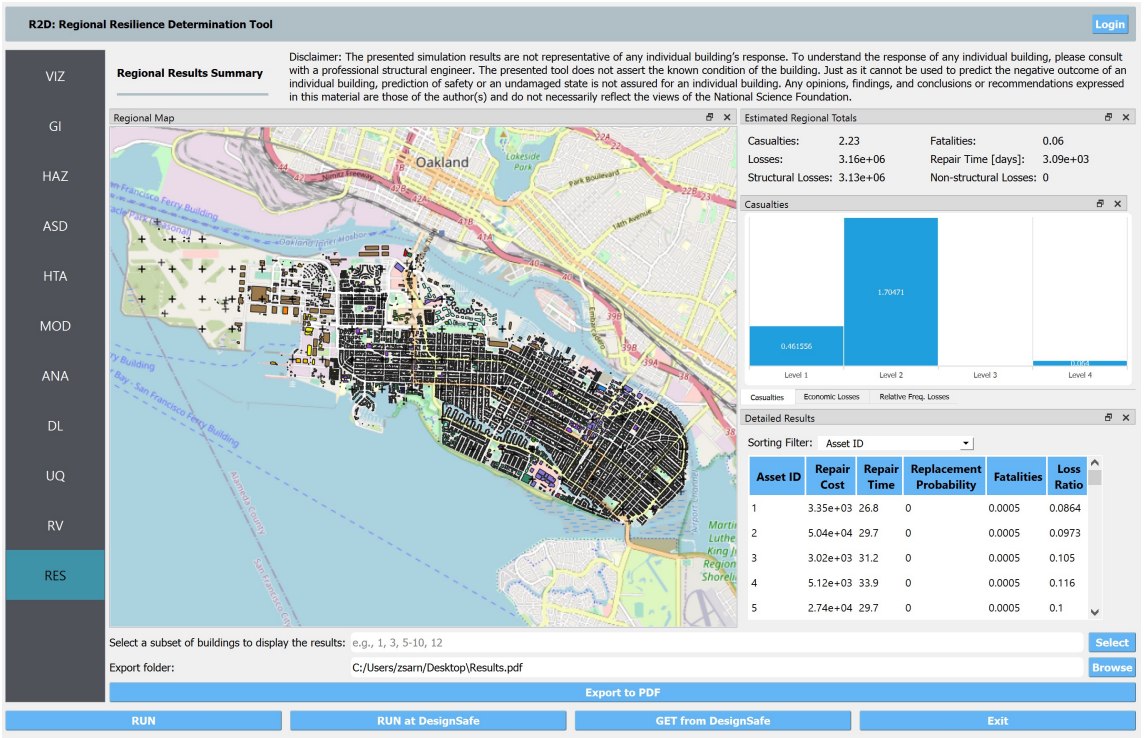
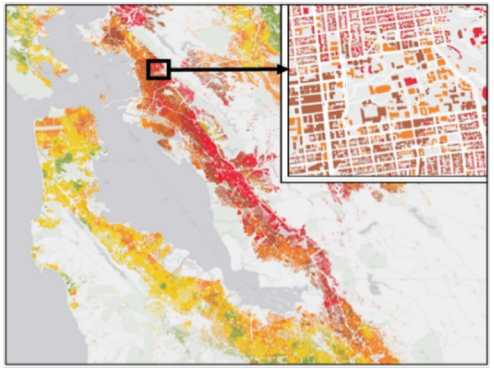
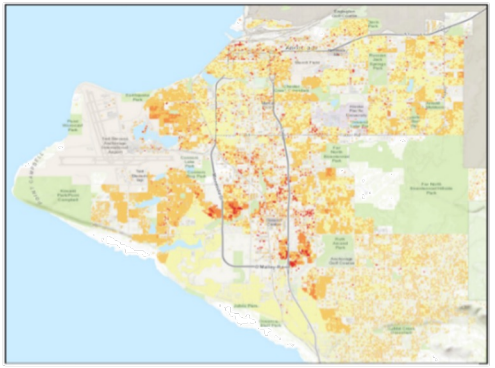


SimCenter – Regional Testbeds

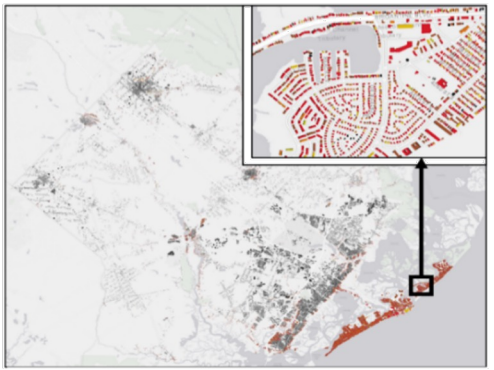
- Proof of concept
- Benchmark & verify methods
- Engage researchers and users
- Identify gaps & opportunities
- Establish data standards



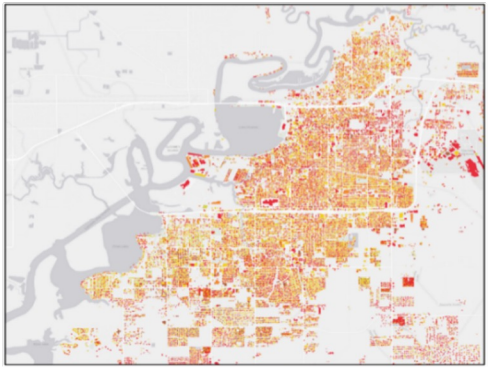
SF Bay Area – EQ Scenario



Anchorage – EQ Hindcast



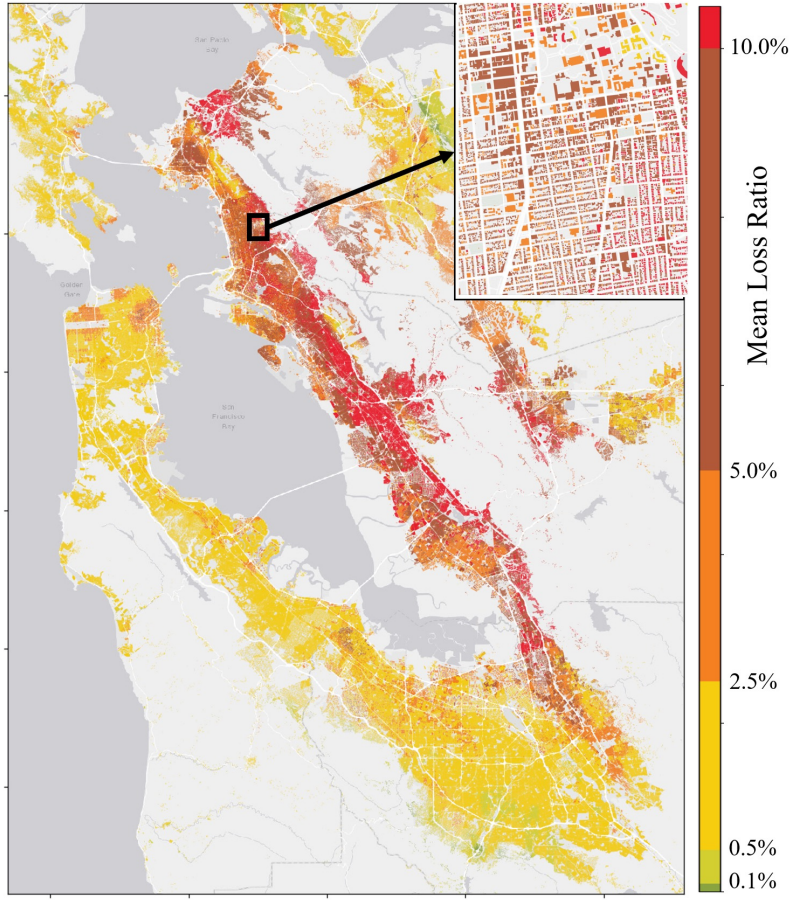
Atlantic City – Hurricane Scenario



Lake Charles – Hurricane Hindcast

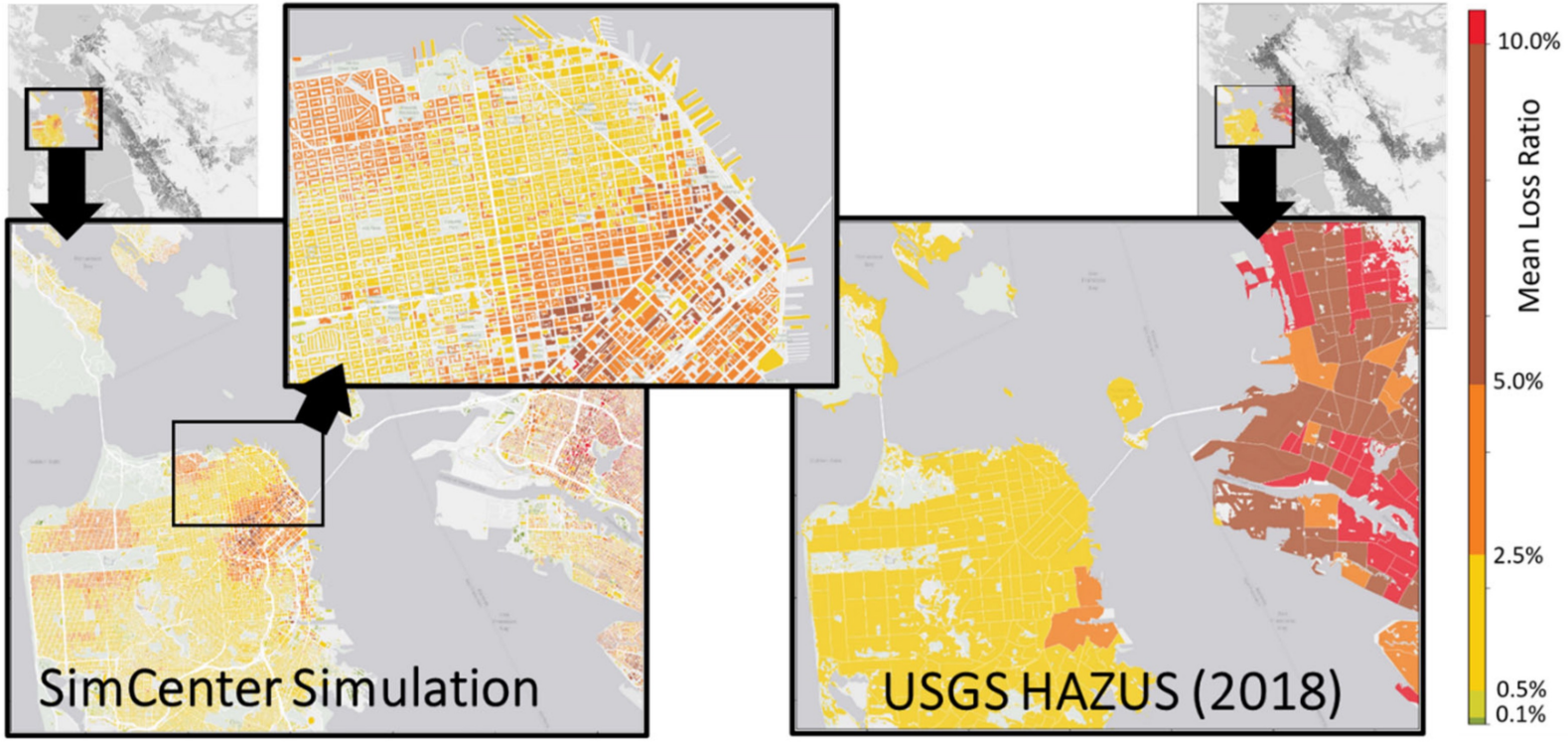
San Francisco Bay Area M7.0 Earthquake Testbed

- **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

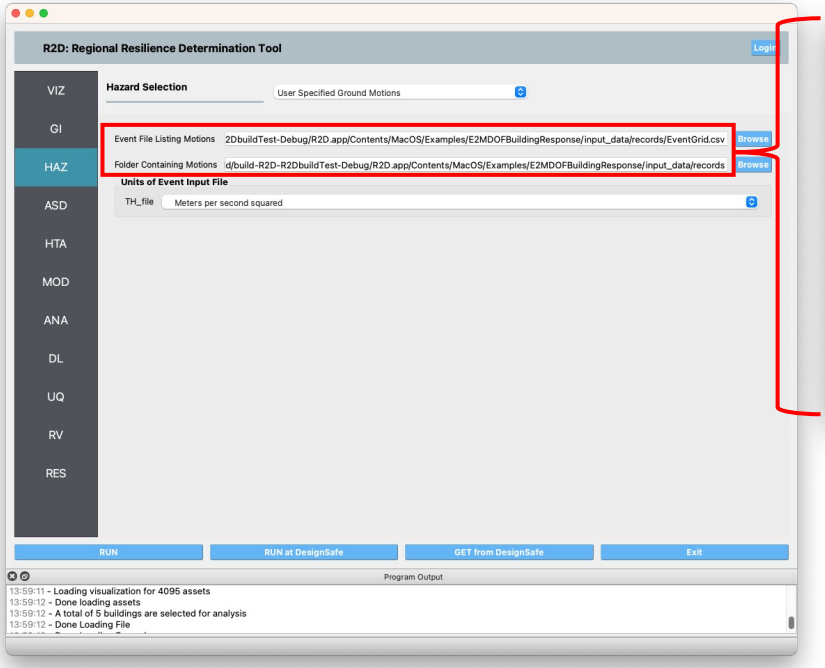
High Resolution Modeling: Parcel-level resolution enables unprecedented quantification of *engineered interventions for policy level decisions*

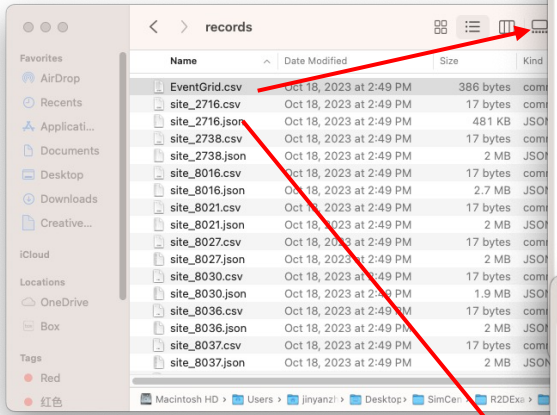


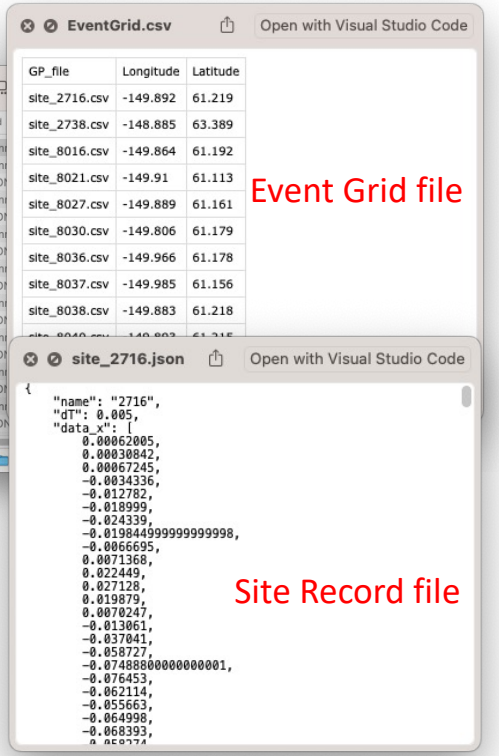
Earthquake hazard definition options in R2D

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.



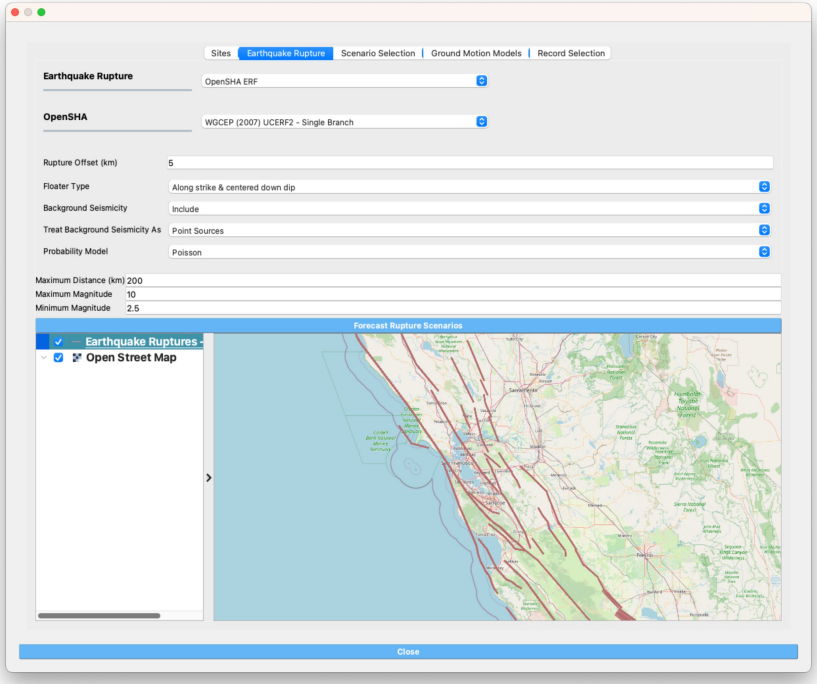


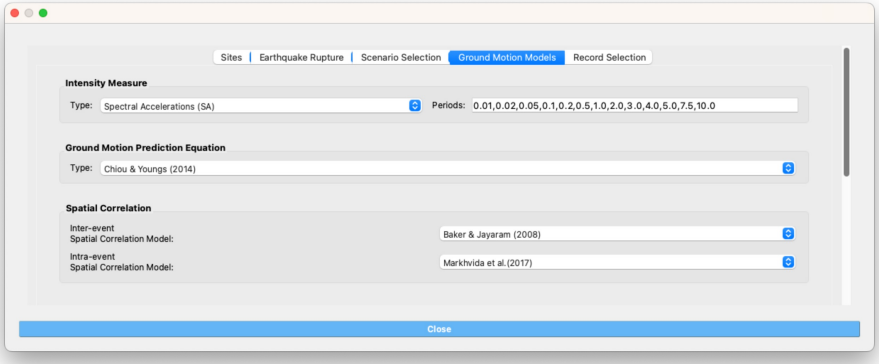


Earthquake hazard definition options in R2D

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.

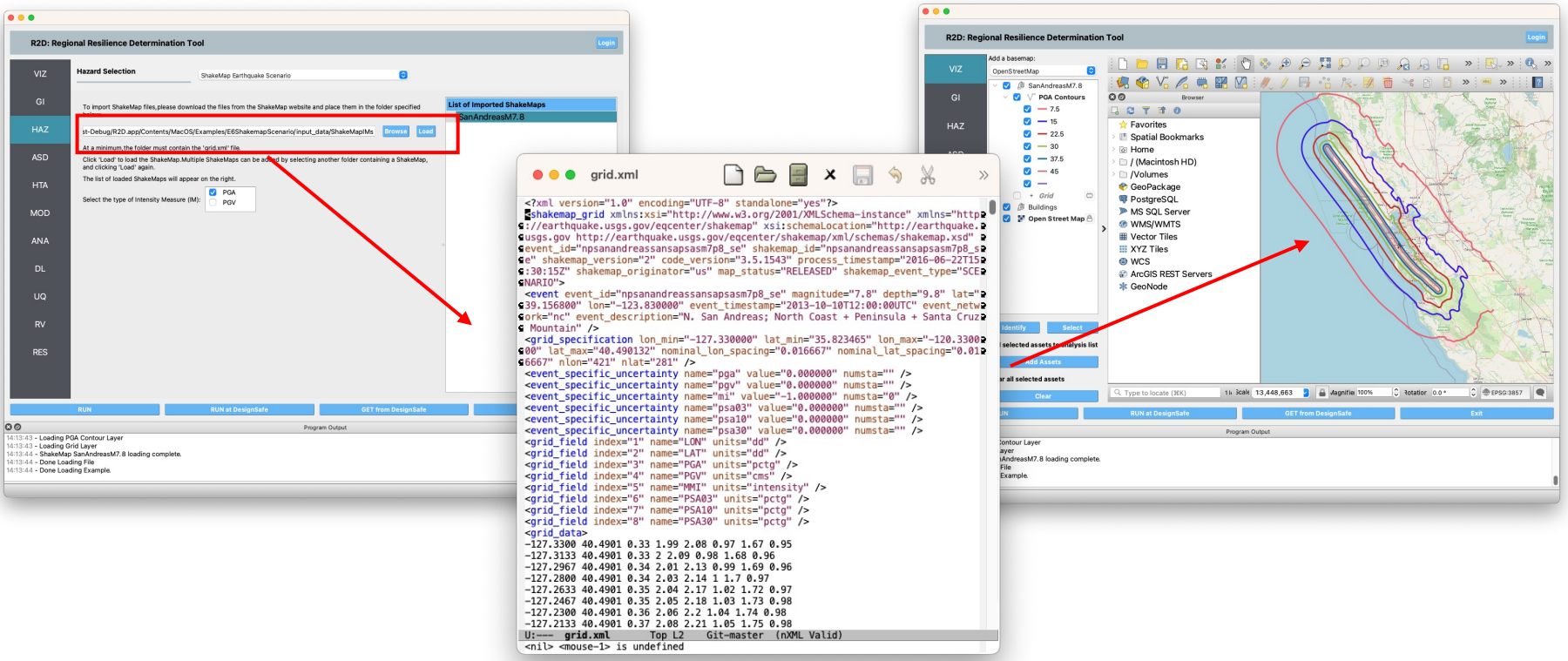




Earthquake hazard definition options in R2D

Option 2: Import from ShakeMap Scenario

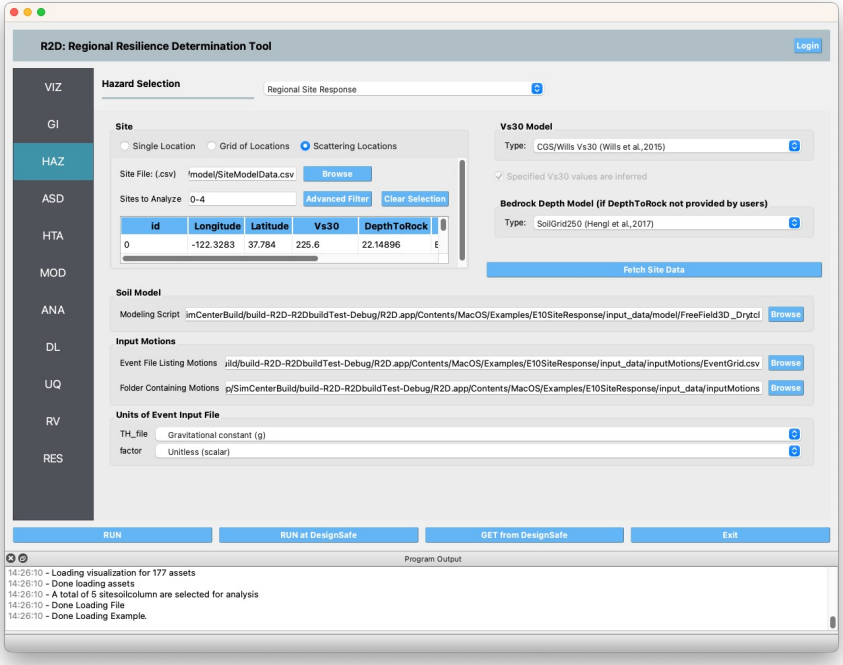
Users prepare a ShakeMap Grid (.xml) file that defines a grid and the intensity measures at each grid point.

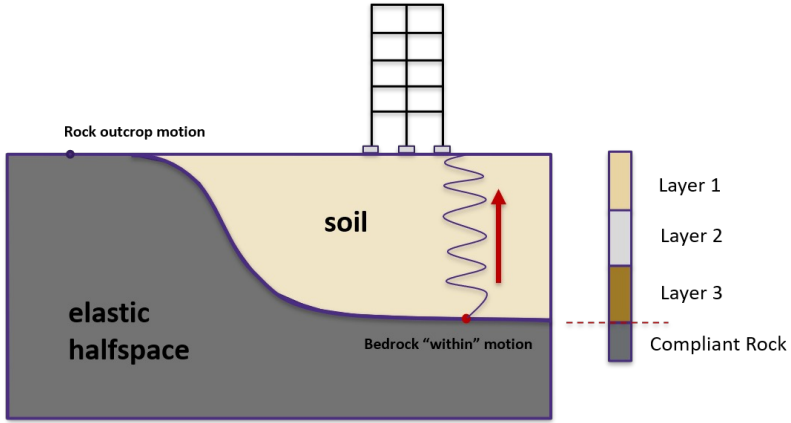


Earthquake hazard definition options in R2D

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.



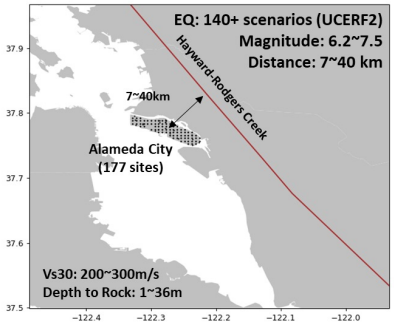


Current R2D Worflow to include Site Response effects

- 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

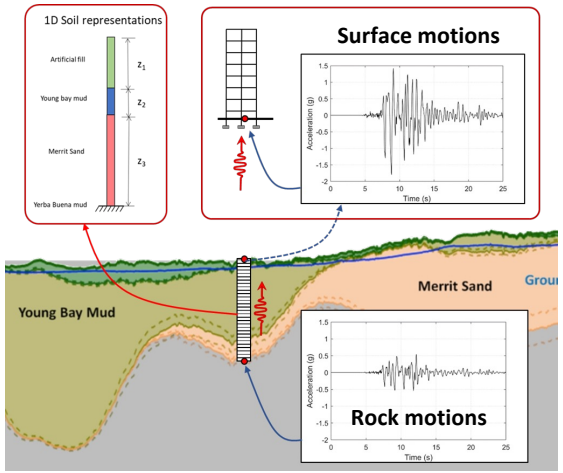
Earthquake ground motions



- **Rock motions:**

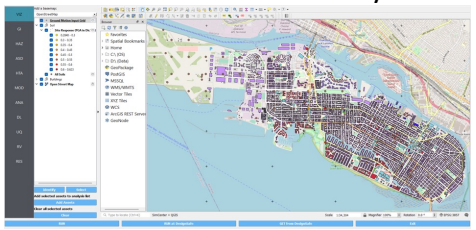
1. **GMPE w/ rock Vs30 + record selection**
2. **Physics-based earthquake records**

1D Soil layer simplification and building analysis

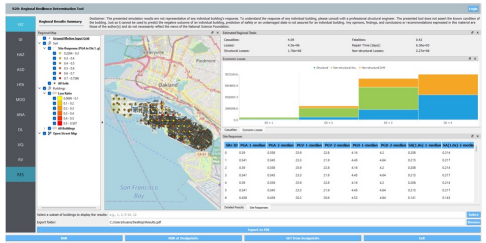


Risk Assessment(R2D)

Surface motion intensity



Building damage and loss

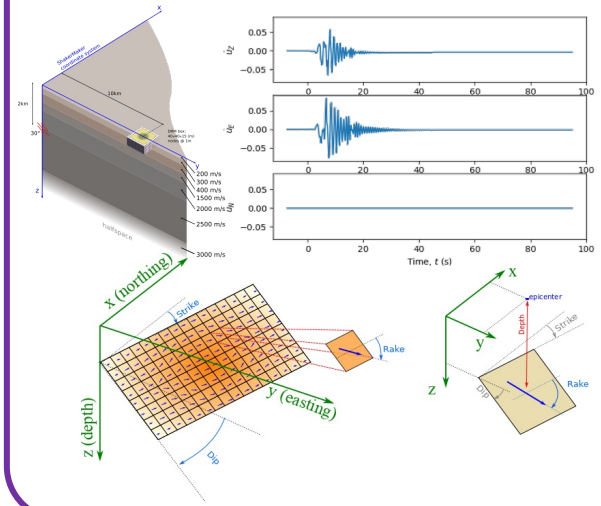


Proposed R2D Workflow to include SiteResponse effects

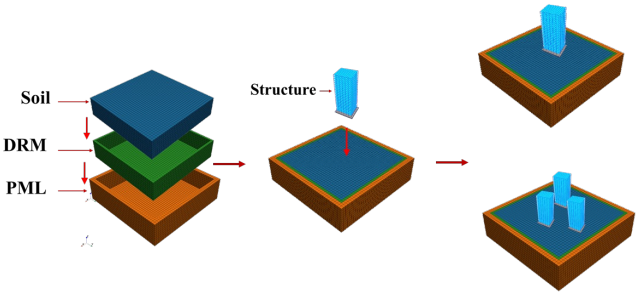
- Transition to Cutting-Edge Simulations that includes DRM and PML
- Exploring Source Rupture Modeling and Uncertainty
- Conducting Risk Assessment in Research Area

Workflow using DRM and PML

Source Modeling



State-of-the-Art Finite Element Model

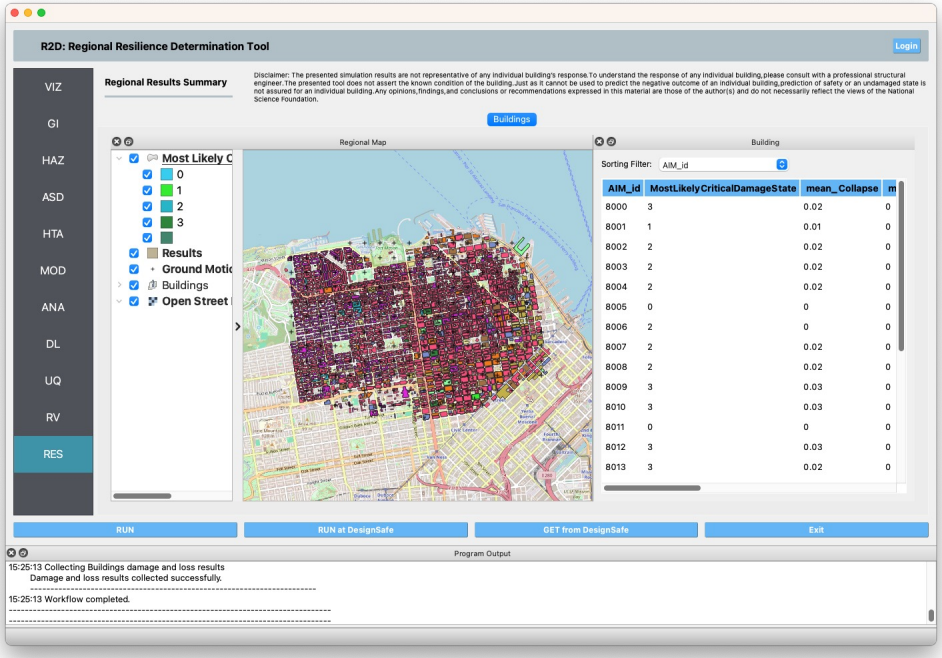


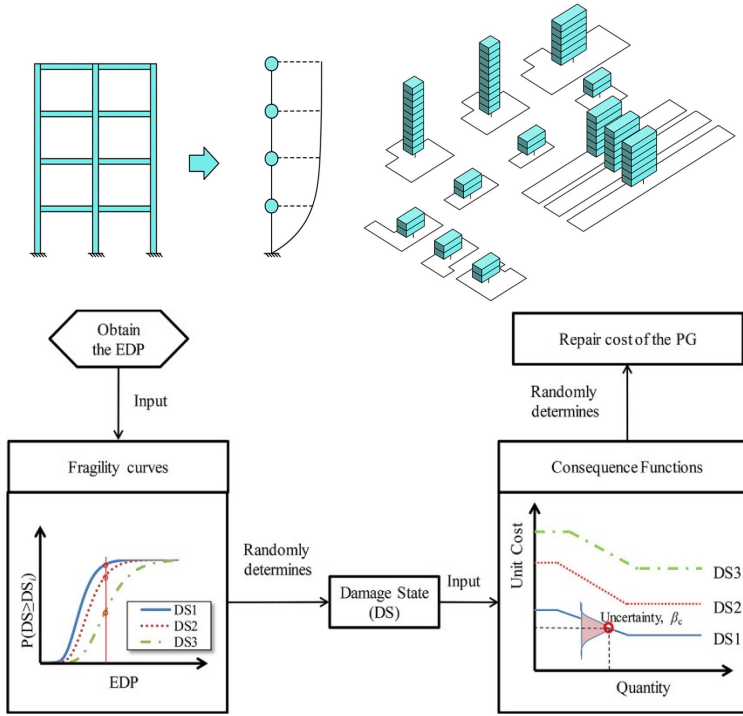
Risk Assessment(R2D)

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.

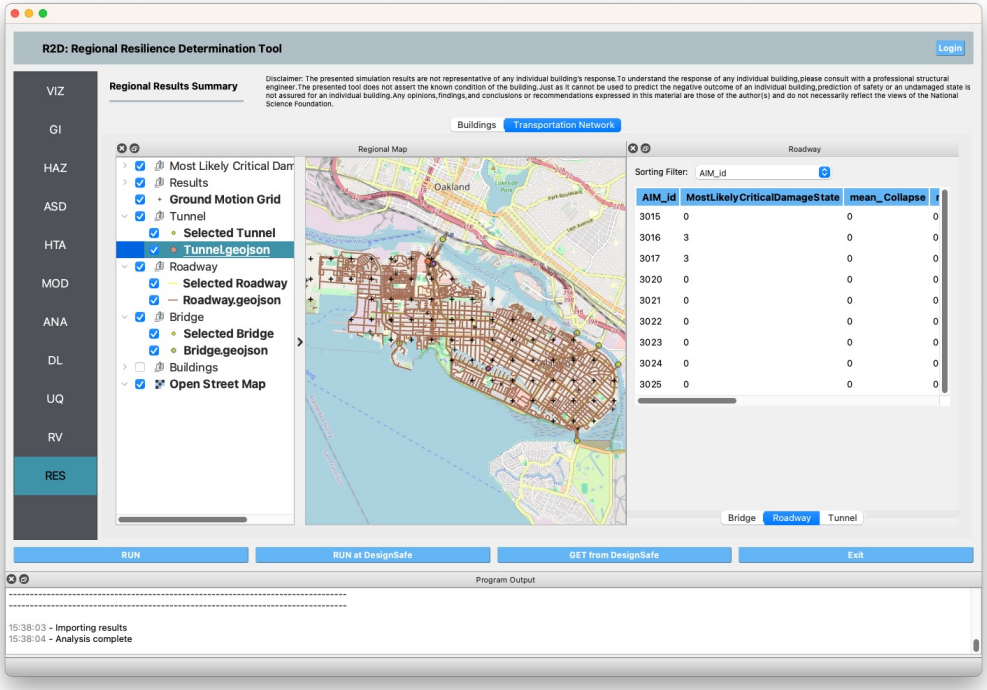


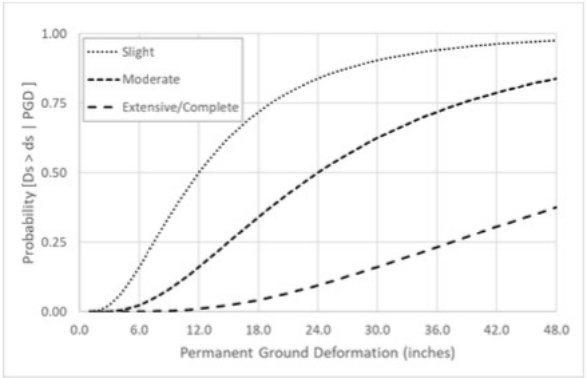


Application of the ground motions

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.

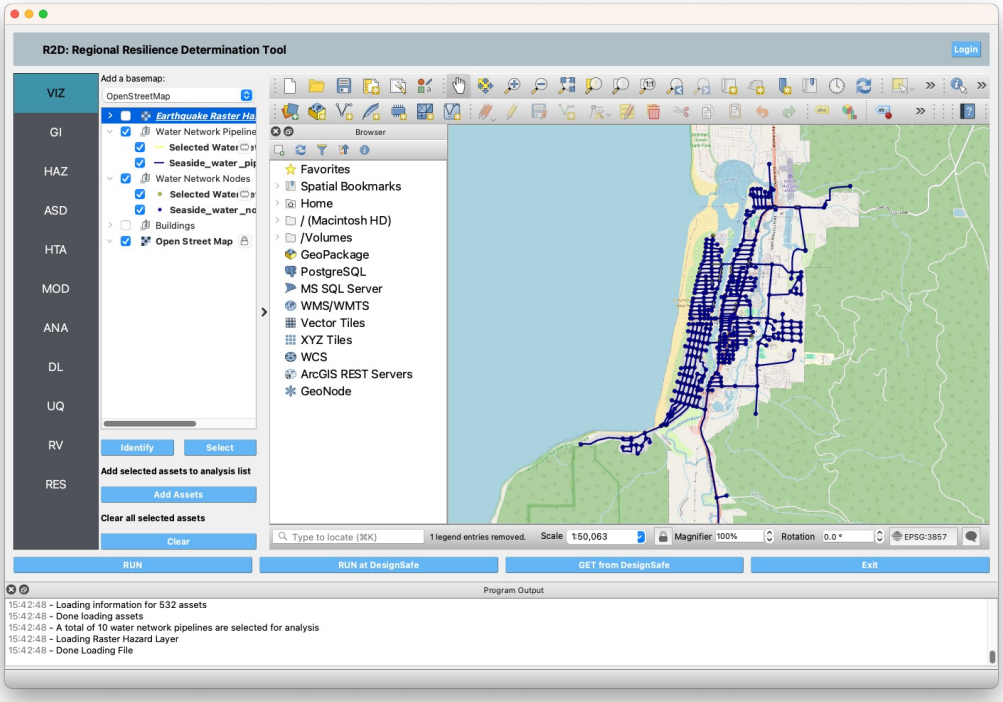


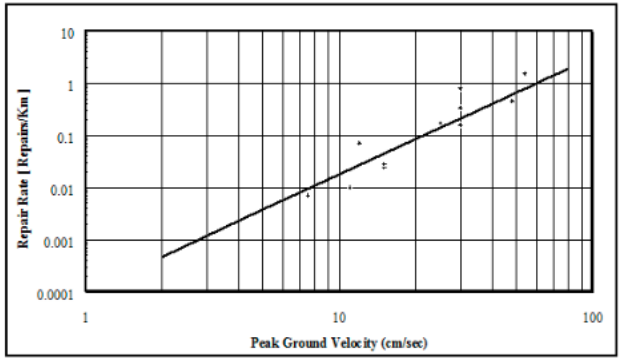


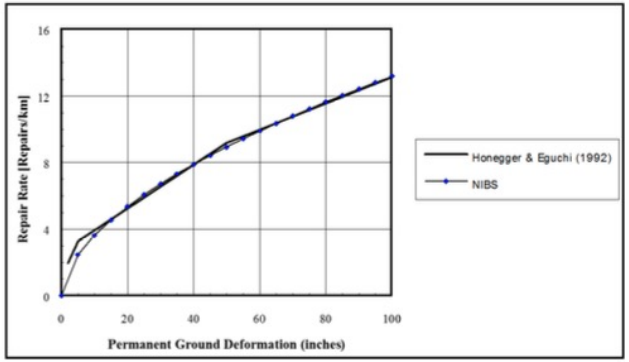
Application of the ground motions

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.

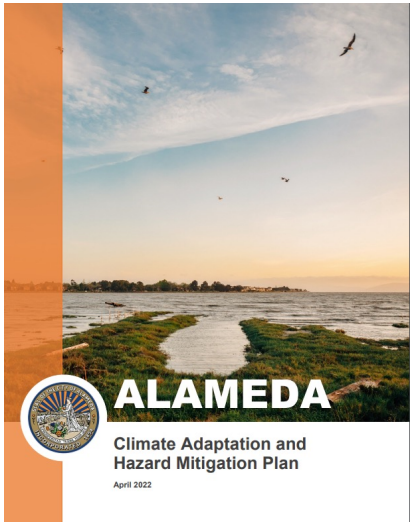


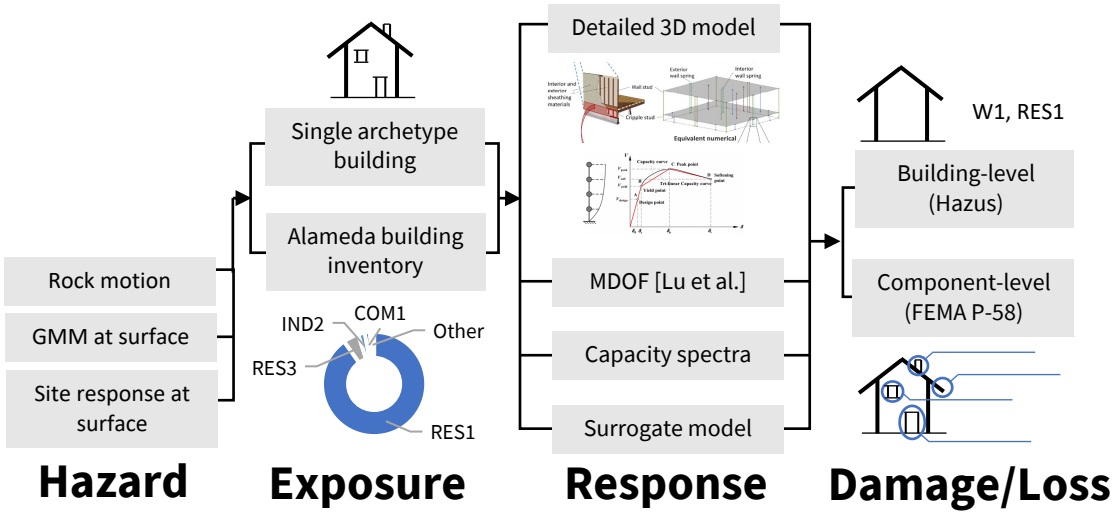




Alameda Case Study

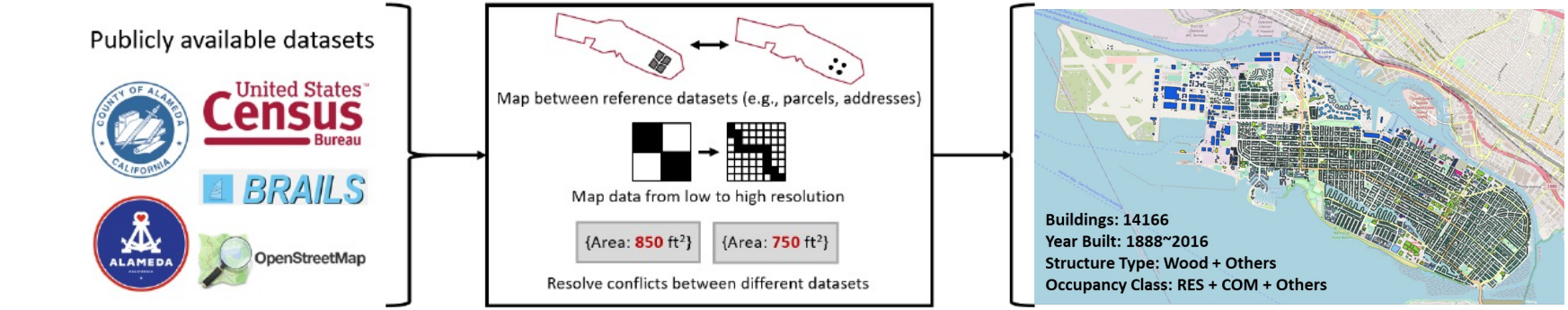
- Inform the Local Hazard Mitigation Plan
- Support research in geotechnical engineering and recovery modeling
- Initiate assessment of multiple subsystems (building, bridge/transportation, pipelines)





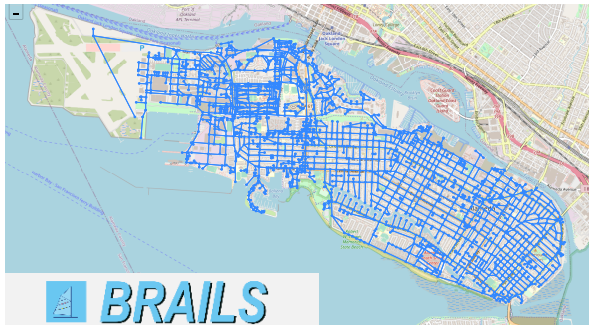
Alameda Case Study – Buildings, Transportation & Water

High-Fidelity Building Inventory

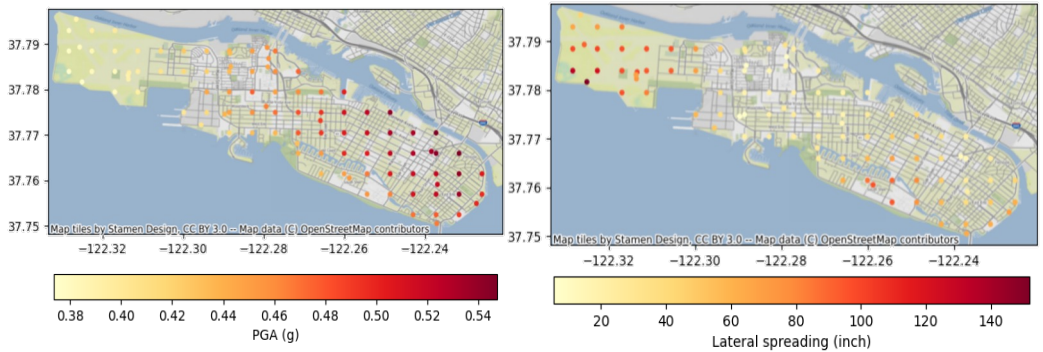


Bassman T.J., Zsarnóczay A., Saw J., Wang S., Deierlein G.G., *"High-Fidelity Testbed Development for Regional Risk Assessment in Alameda, California", 12th NCEE, 2022*

Transportation & Water Infrastructure

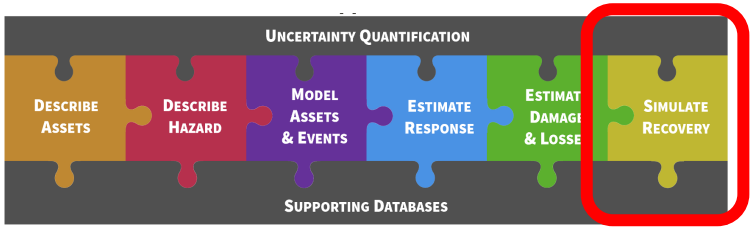


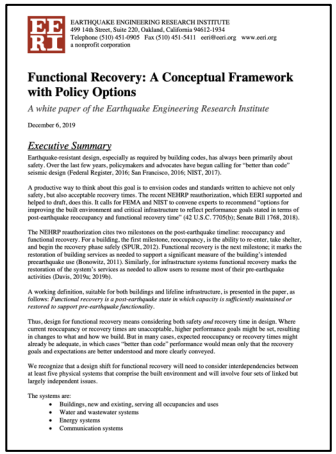
Inventory Generation Tools



Ground Shaking and Permanent Deformation

Modeling Functional Recovery





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a nonprofit corporation

Functional Recovery: A Conceptual Framework with Policy Options

A white paper of the Earthquake Engineering Research Institute

December 6, 2019

Executive Summary

Earthquake-resistant design, especially as required by building codes, has always been primarily about safety. Over the last few years, policymakers and advocates have begun calling for "better than code" seismic design (Federal Register. 2016; San Francisco, 2016; NIST, 2017).

A productive way to think about this goal is to envision codes and standards written to achieve not only safety, but also acceptable recovery times. The recent NEHRP reauthorization, which EERI supported and helped to draft, does this. It calls for FEMA and NIST to convene experts to recommend "options for improving the built environment and critical infrastructure to reflect performance goals stated in terms of post-earthquake reoccupancy and functional recovery time" (42 U.S.C. 7705(b); Senate Bill 1768, 2018).

The NEHRP reauthorization cites two milestones on the post-earthquake timeline: reoccupancy and functional recovery. For a building, the first milestone, reoccupancy, is the ability to re-enter, take shelter, and begin the recovery phase safely (SPUR, 2012). Functional recovery is the next milestone; it marks the restoration of building services as needed to support a significant measure of the building's intended preearthquake use (Bonowitz, 2011). Similarly, for infrastructure systems functional recovery marks the restoration of the system's services as needed to allow users to resume most of their pre-earthquake activities (Davis, 2019a; 2019b).

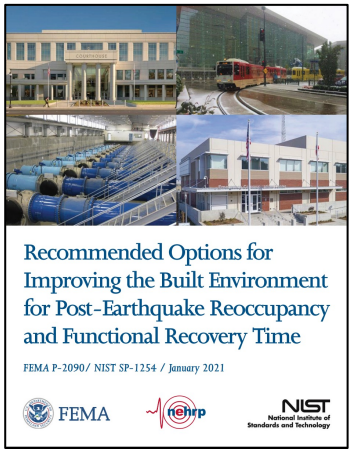
A working definition, suitable for both buildings and lifeline infrastructure, is presented in the paper, as follows: *Functional recovery is a post-earthquake state in which capacity is sufficiently maintained or restored to support pre-earthquake functionality.*

Thus, design for functional recovery means considering both safety *and* recovery time in design. Where current reoccupancy or recovery times are unacceptable, higher performance goals might be set, resulting in changes to what and how we build. But in many cases, expected reoccupancy or recovery times might already be adequate, in which cases "better than code" performance would mean only that the recovery goals and expectations are better understood and more clearly conveyed.

We recognize that a design shift for functional recovery will need to consider interdependencies between at least five physical systems that comprise the built environment and will involve four sets of linked but largely independent issues.

The systems are:

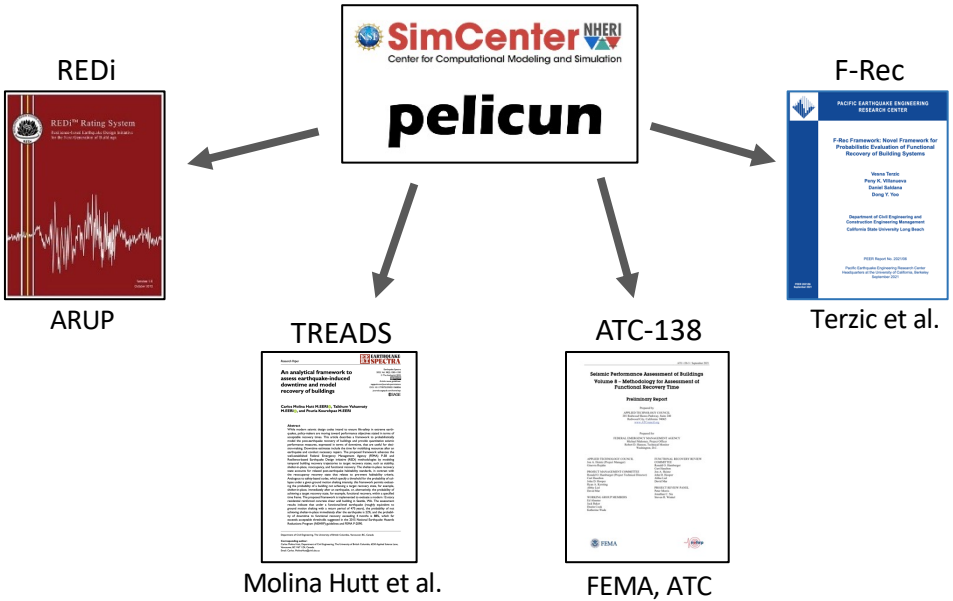
- Buildings, new and existing, serving all occupancies and uses
- Water and wastewater systems
- Energy systems
- Communication systems



Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time

FEMA P-2090/ NIST SP-1254 / January 2021

FEMA NEHRP NIST National Institute of Standards and Technology



- 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

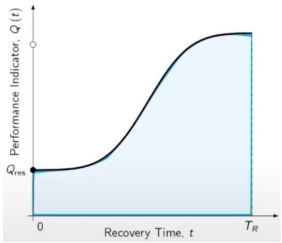
- Tool to allocate resources post-event based on both certain and uncertain data and uncertainty in other parameters (i.e. known pipe/valve break) **+ OTHER INFRASTRUCTURE DAMAGE DATA**

Building damage
Road closures

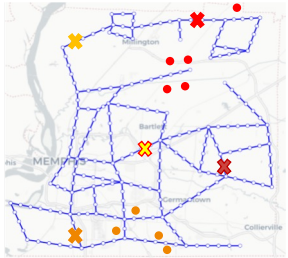
R2D ☑

Damage & Loss

pelicun ☑

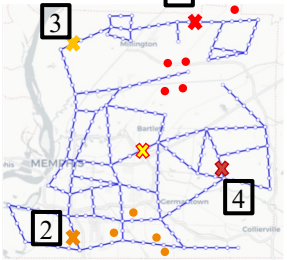


Recovery (based on simple recovery curves)



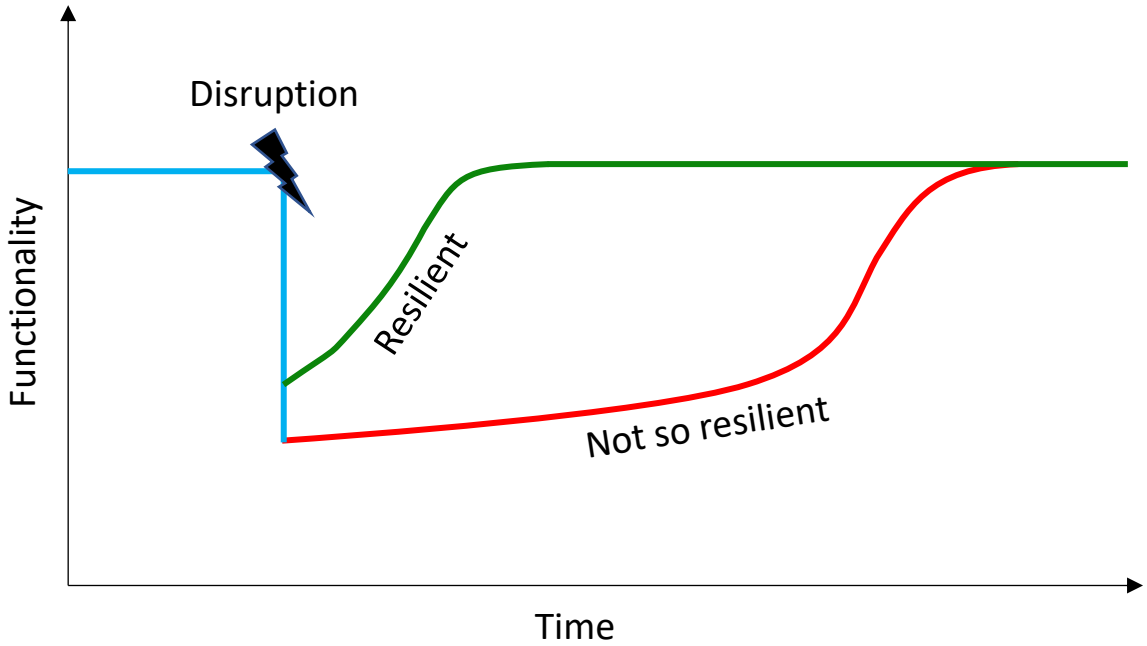
Uncertain & Certain Data

Bayesian Updating (update model based on UQ simulations)

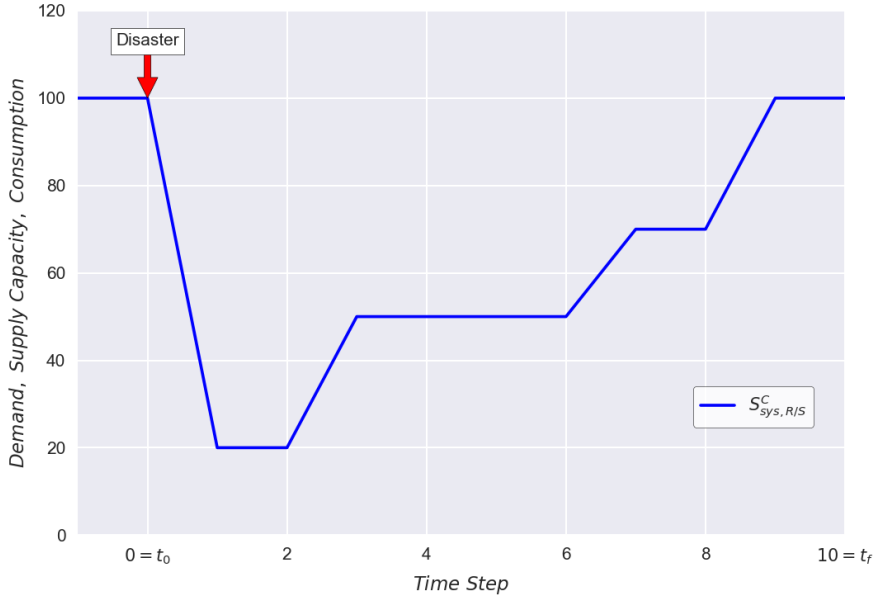


Resilience using Resource Allocation (with interdependencies)

What is resilience?



Resilience assessment using supply/demand/consumption



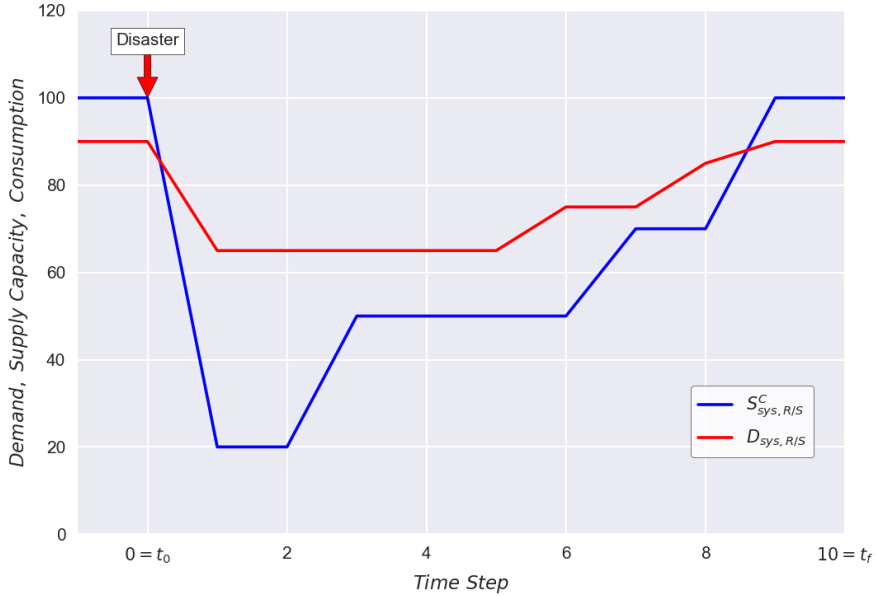
Post-disaster demand, supply and consumption of a system during recovery.

Disaster Resilience Quantification:

- System Supply: $S^C_{sys,R/S}(t) = \sum_{i \in \{1,\ldots,I\}} S^C_{i,R/S}(t)$

Didier, Broccardo, Esposito, Stojadinović (2018) *A compositional demand/supply framework to quantify the resilience of civil infrastructure systems (Re-CoDeS).* Sustainable and Resilient Infrastructure.

Resilience assessment using supply/demand/consumption



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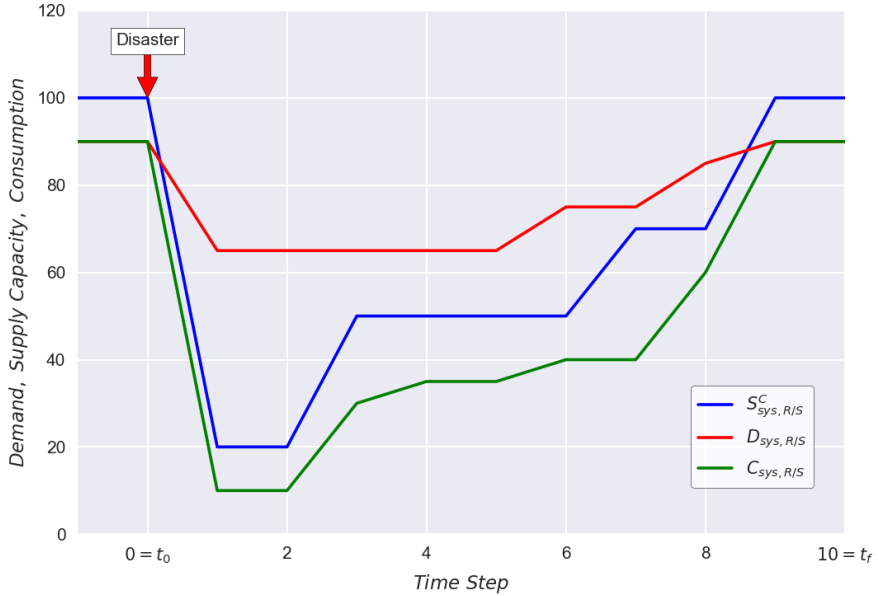
Resilience assessment using supply/demand/consumption



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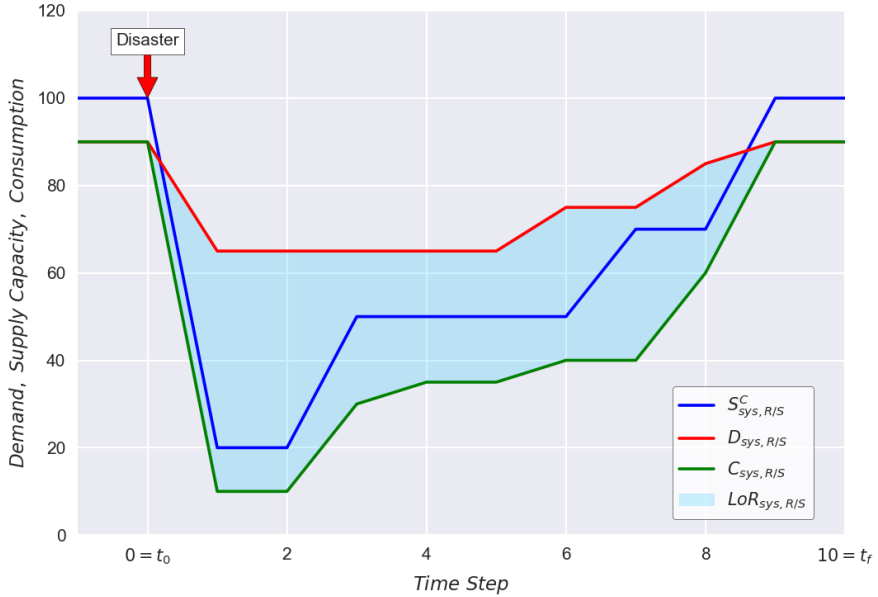

Post-disaster demand, supply and consumption of a system during recovery.

- Disaster Resilience Quantification:
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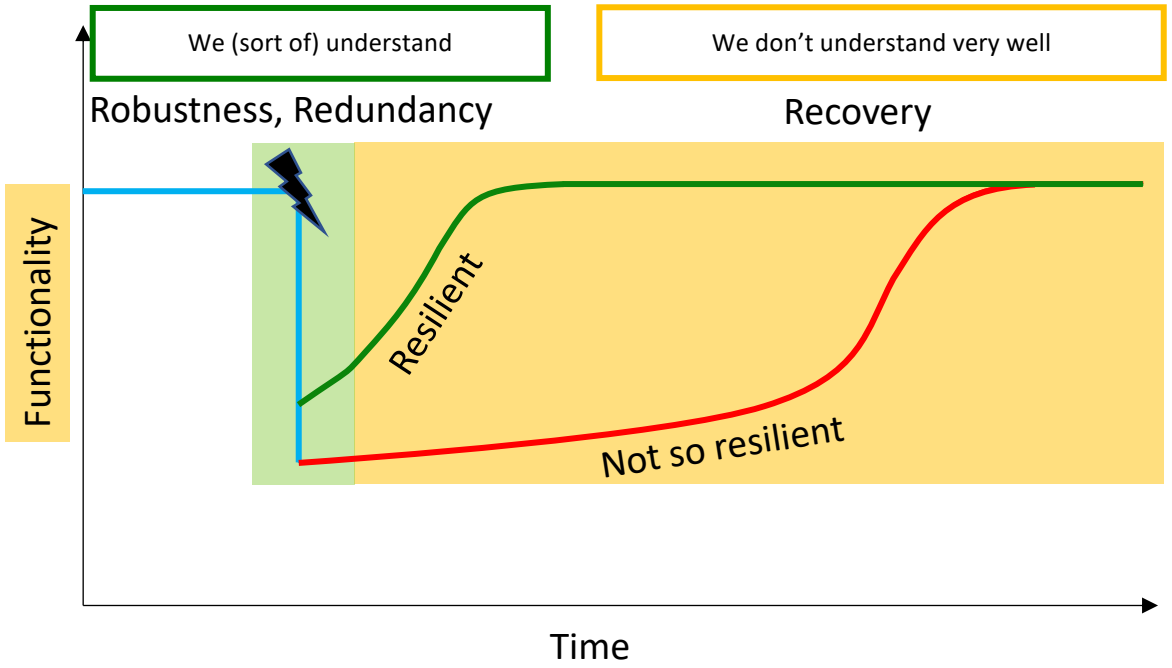
  - System Consumption: $C_{sys,R/S}(t) = \sum_{i\in\{1,..,I\}} C_{i,R/S}(t)$
  - Resilience Metric:

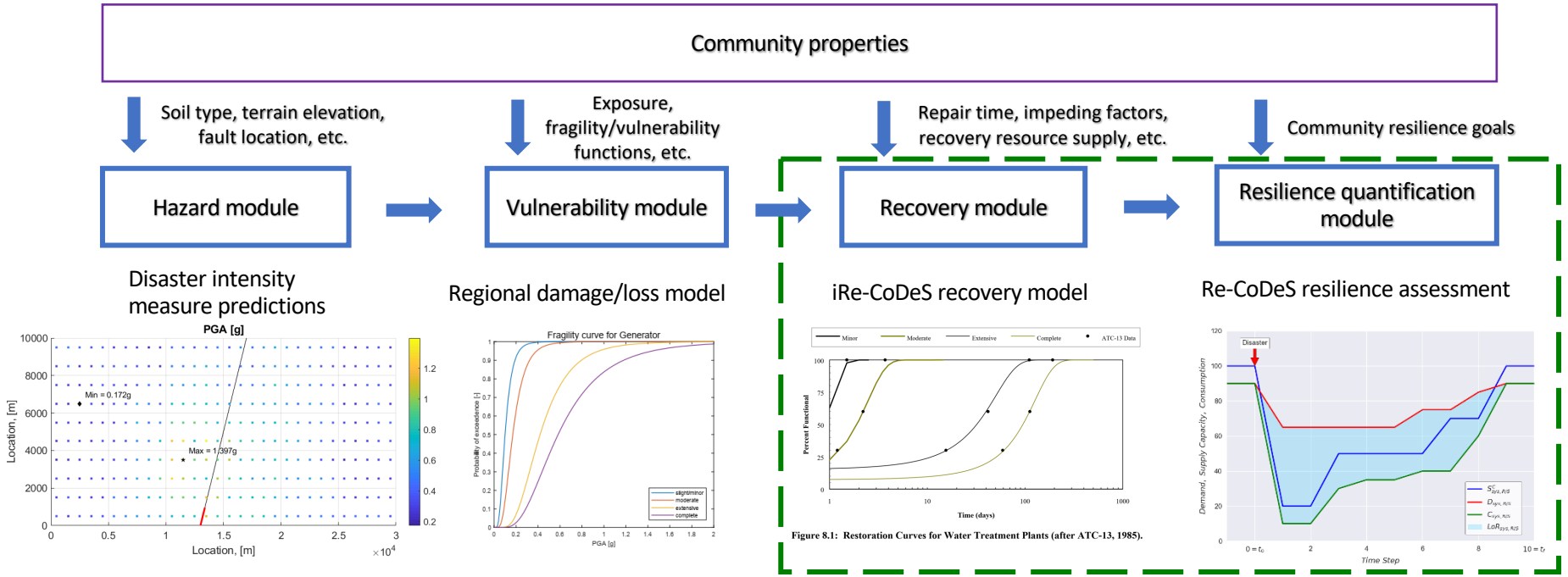
$$LoR_{sys,R/S} = \int_{t_0}^{t_f} \left(D_{sys,R/S}(t) - C_{sys,R/S}(t) \right) dt$$

Didier, Broccardo, Esposito, Stojadinović (2018) *A compositional demand/supply framework to quantify the resilience of civil infrastructure systems (Re-CoDeS).* Sustainable and Resilient Infrastructure.

How well do we understand our built environment?



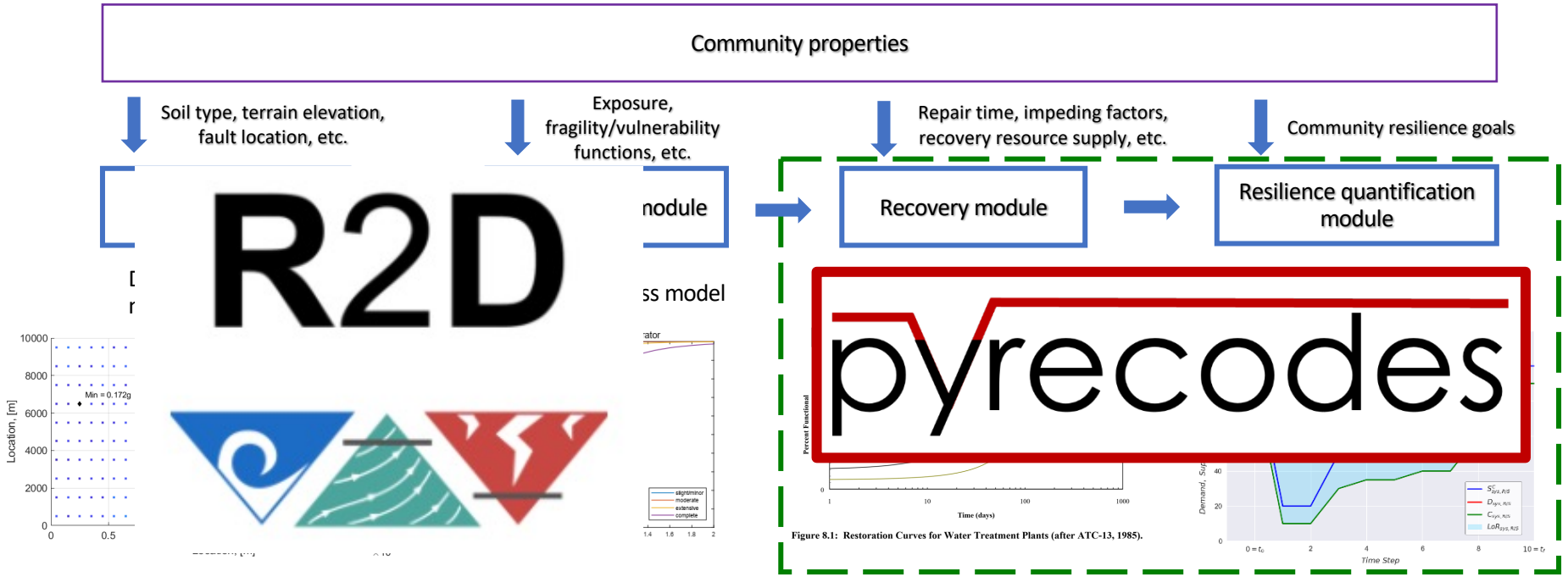
iRe-CoDeS computational workflow: physics-based and modular



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.

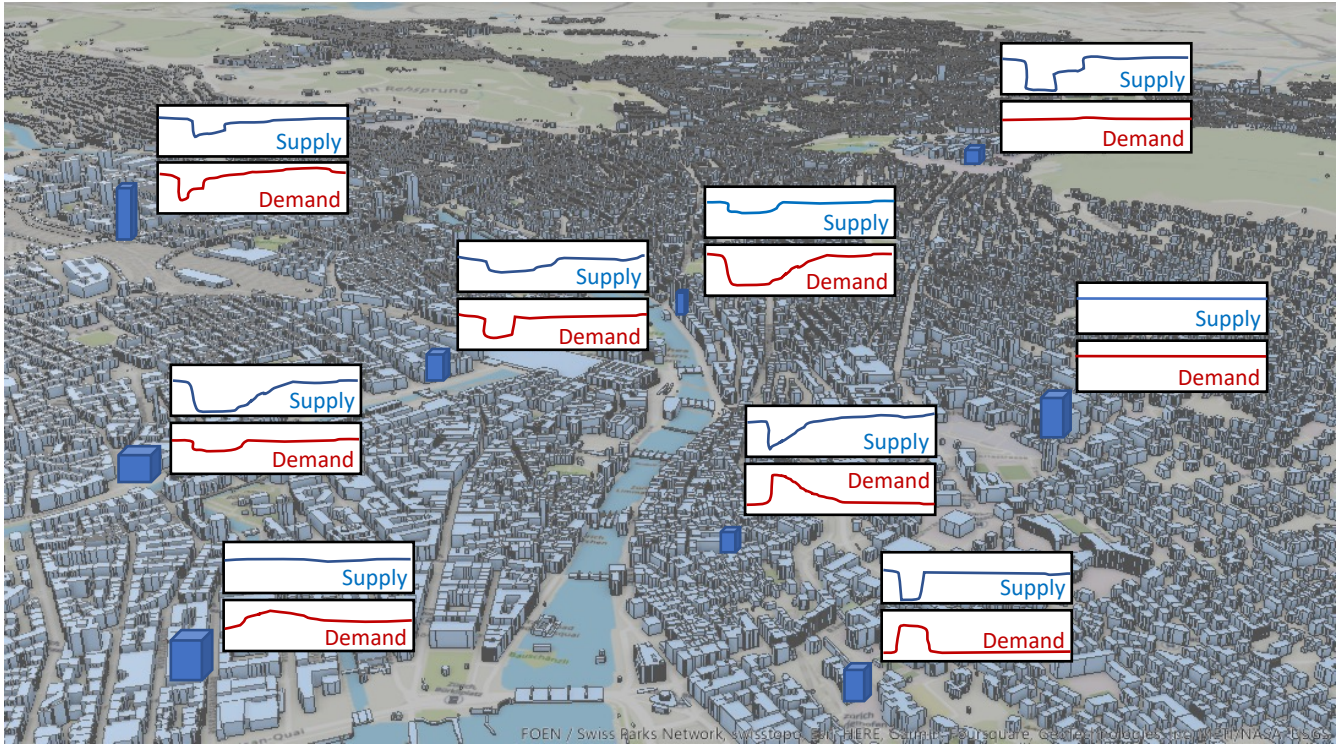
Blagojević, Kipfer, Didier, Stojadinović (2020) *Scenario-based Resilience Assessment of Communities with Interdependent Civil Infrastructure Systems.* Proceeding of the 17th World Conference on Earthquake Engineering. Sendai, Japan.

iRe-CoDeS computational workflow: physics-based and modular



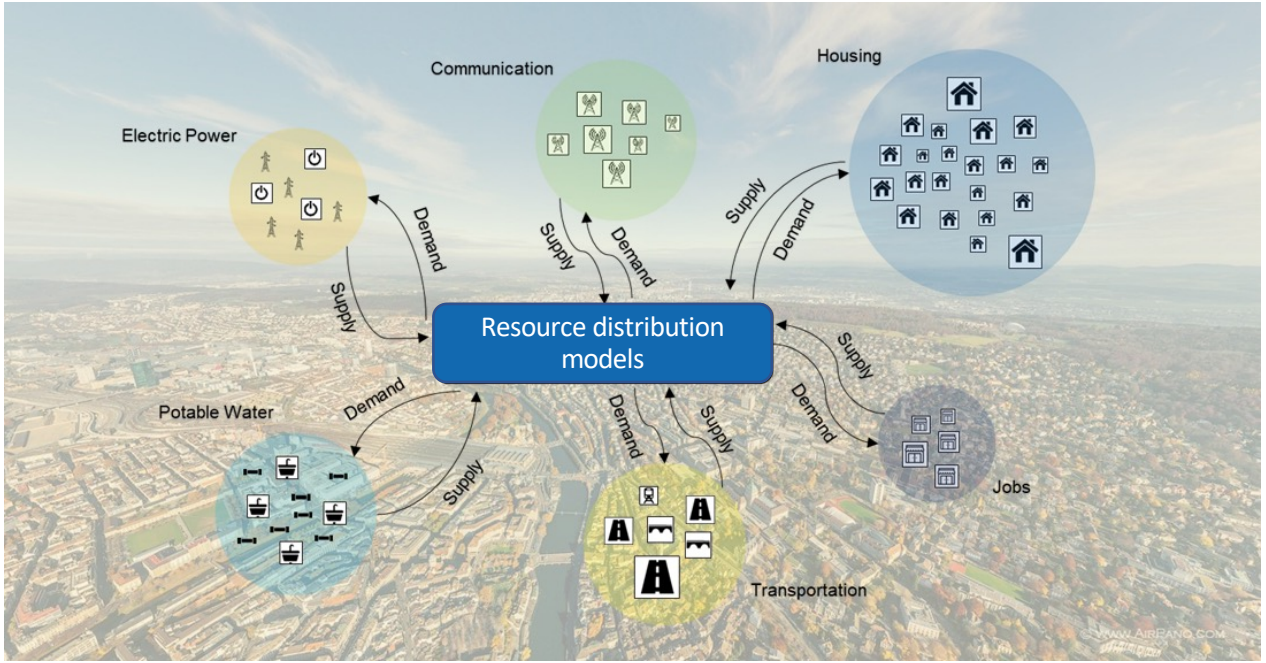
pyrecodes is an open-source framework for regional disaster recovery simulation and disaster resilience assessment of interdependent systems.

Monitor/simulate components‘ resource supply and demand during recovery



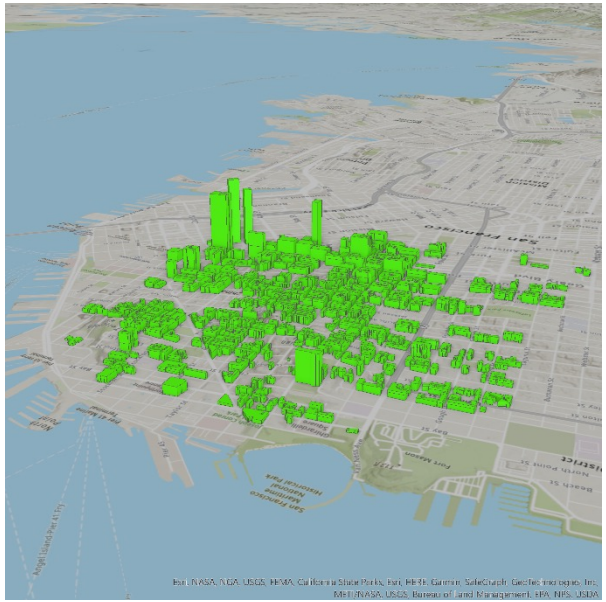
Blagojević, Hefti, Henken, Didier, Stojadinović (2022) *Quantifying Disaster Resilience of a Community with Interdependent Civil Infrastructure Systems.* Structure and Infrastructure Engineering.

Component interdependencies simulated as a flow of resources and services

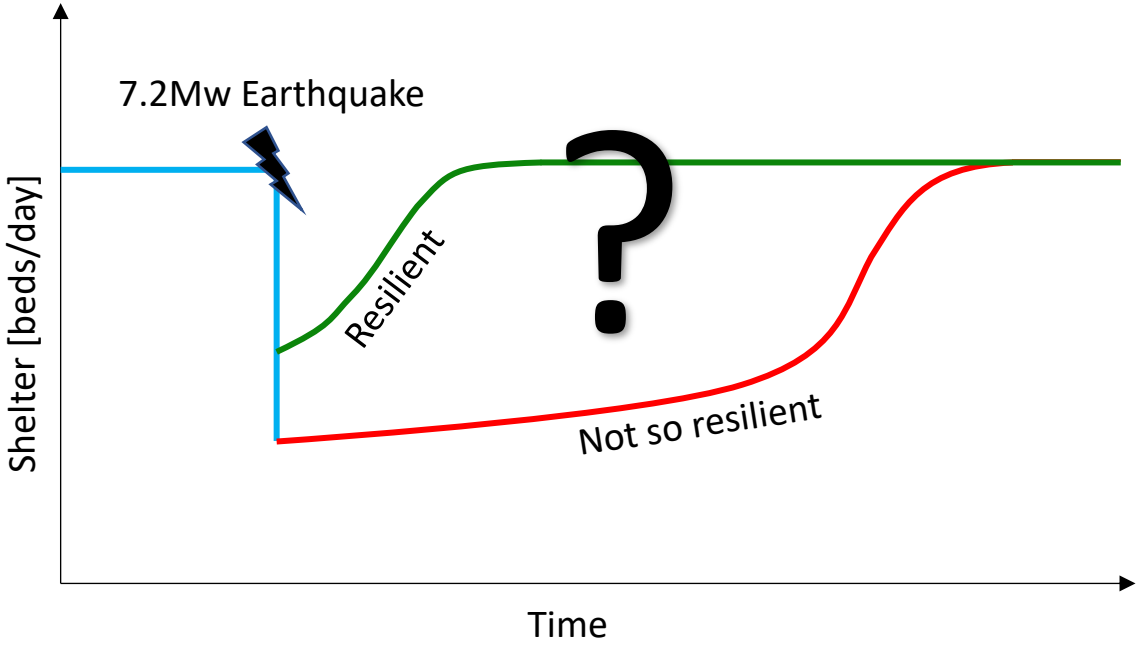


Blagojević, Hefti, Henken, Didier, Stojadinović (2022) *Quantifying Disaster Resilience of a Community with Interdependent Civil Infrastructure Systems.* Structure and Infrastructure Engineering.

Case Study: Housing Resilience of North-East San Francisco

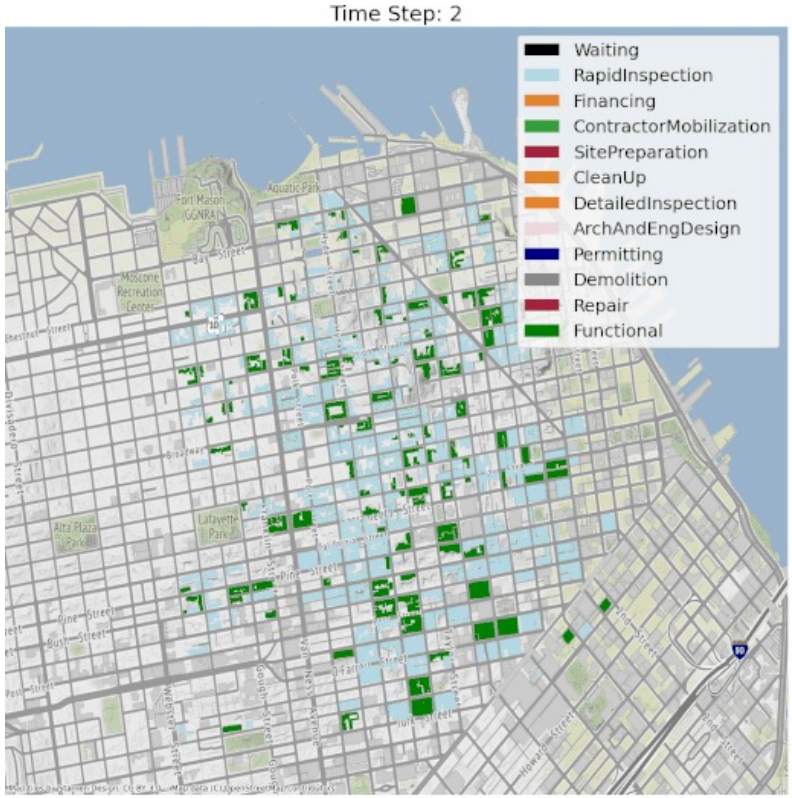


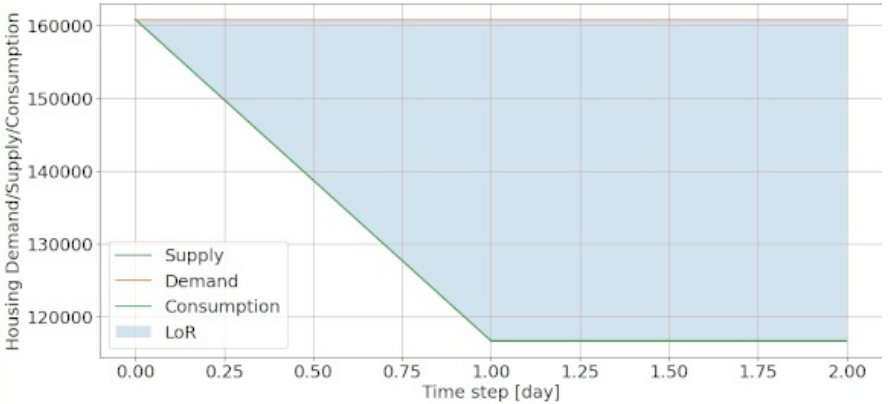
Residential buildings considered in the Case Study.

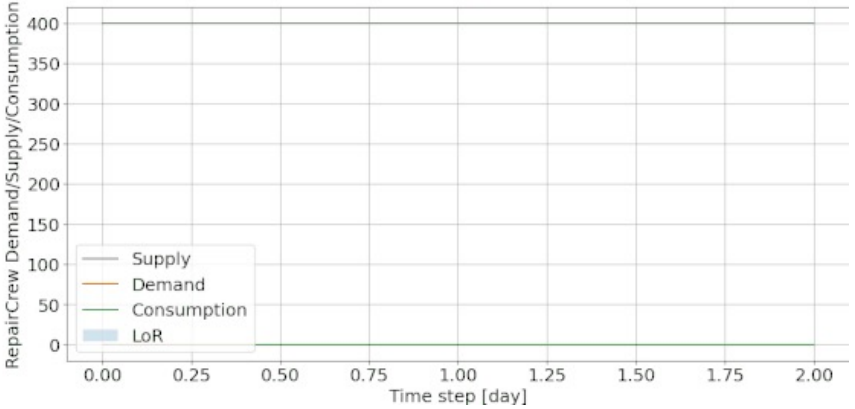


Blagojević and Stojadinović (2022) *A Demand-Supply Framework for Evaluating the Effect of Resource and Service Constraints on Community Disaster Resilience.* Resilient Cities and Structures.

Housing recovery of North-East San Francisco







Blagojević and Stojadinović (2022) *A Demand-Supply Framework for Evaluating the Effect of Resource and Service Constraints on Community Disaster Resilience.* Resilient Cities and Structures.

pyrecodes: integration and future development

Finite-element models

Water: **REWET**

Ground motion models

Fragility functions

Transportation: **spatial-queue model**

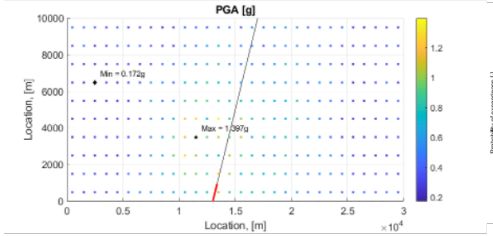
Horizontal integration

Regional risk models

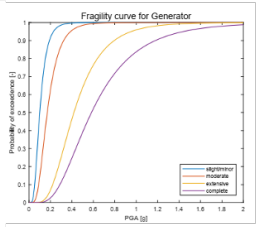
Hazard module → Vulnerability module → Recovery module → Resilience quantification module

pyrecodes

Disaster intensity measure assessment

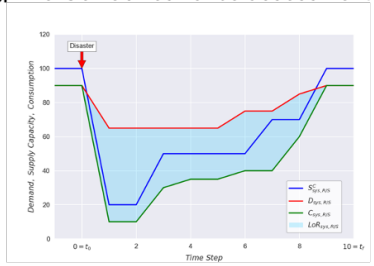


Regional damage/loss model

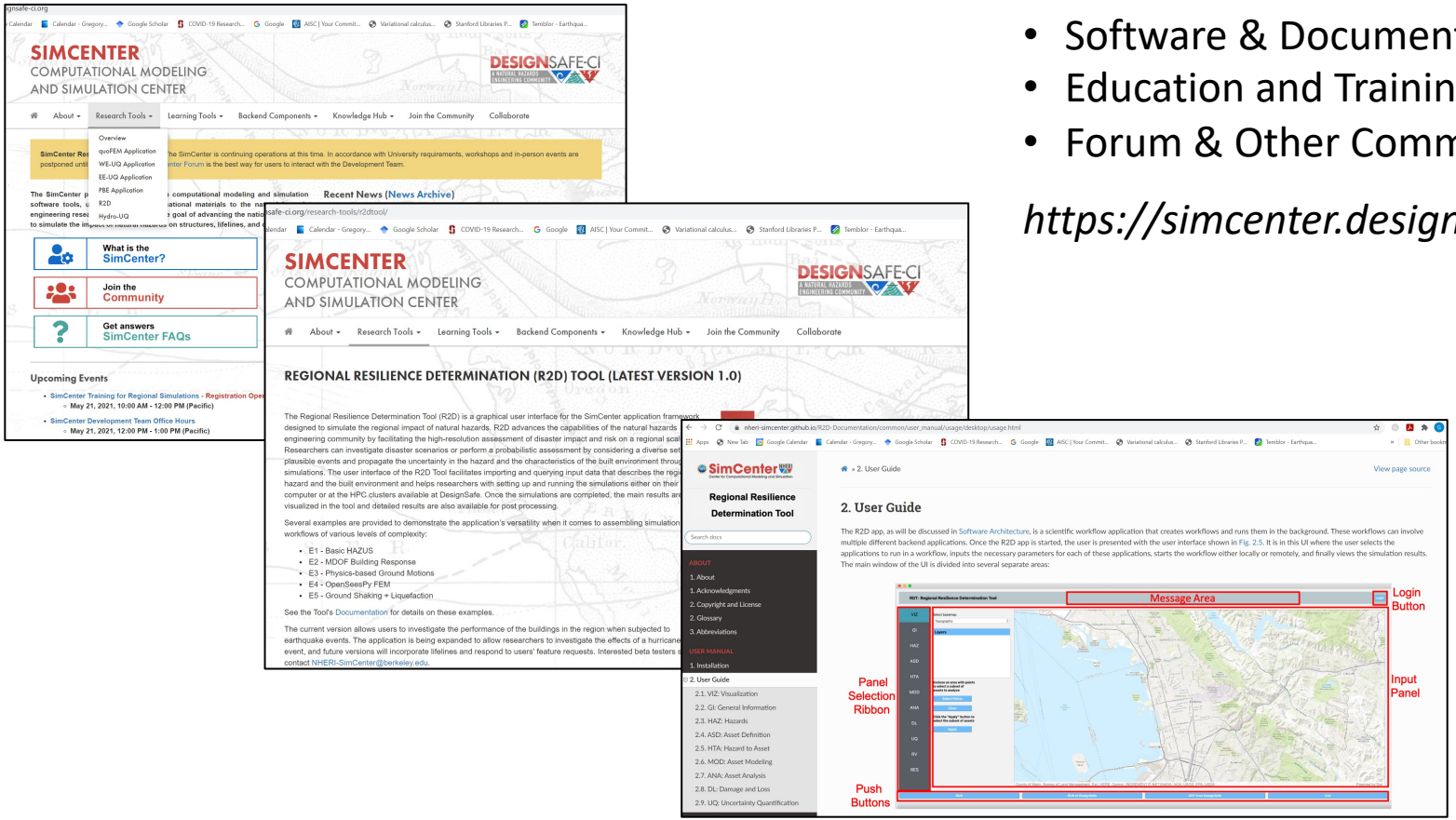


iRe-CoDeS regional recovery model

Re-CoDeS resilience assessment



SimCenter Portal



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

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