

NHERI SimCenter Computational Framework for Simulating Impacts of Natural Hazards

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Advisory Committee for Earthquake Hazard Reduction

Online (August 23-24, 2022)

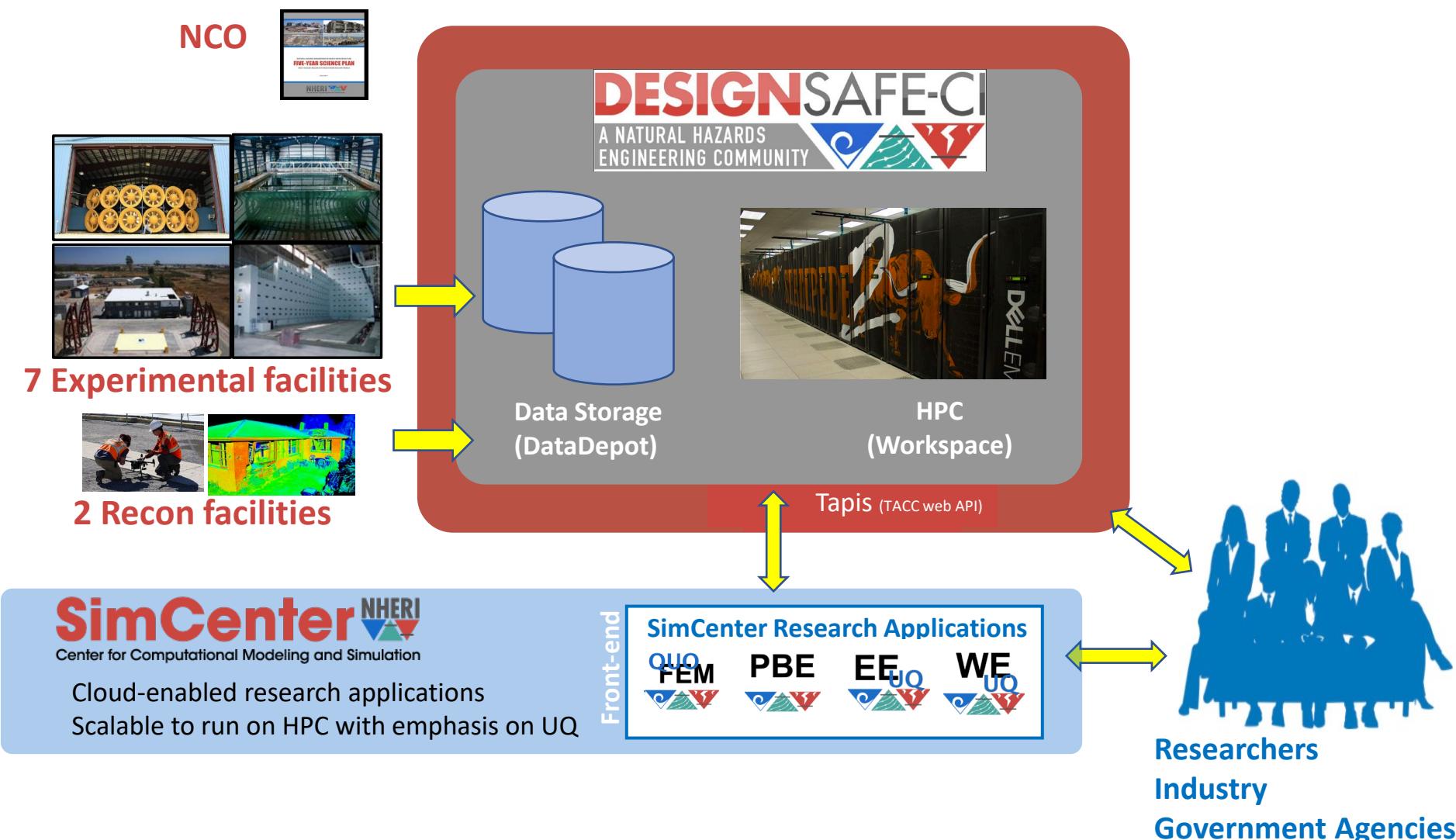


Center for Computational Modeling and Simulation

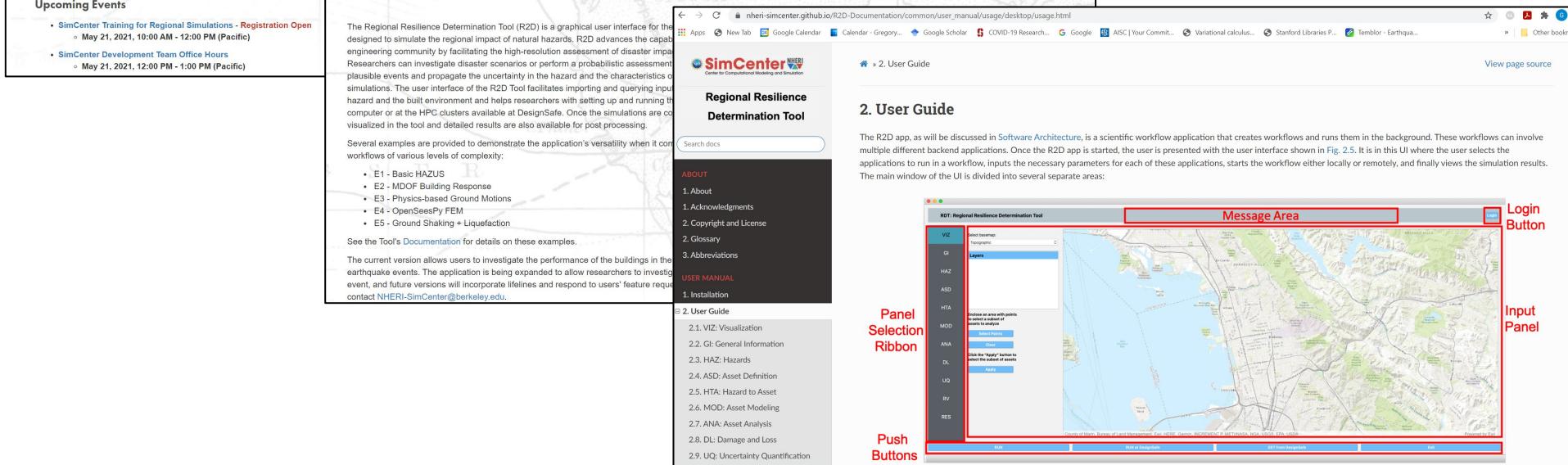
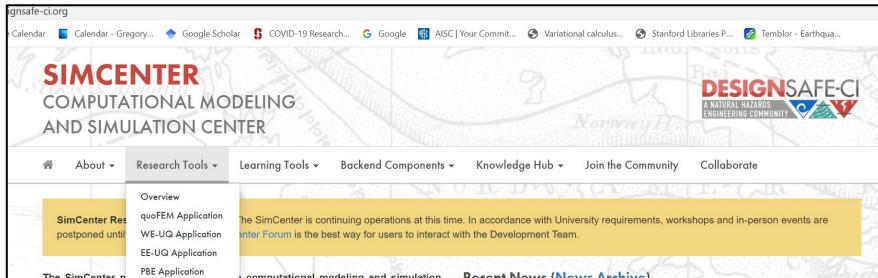


NSF award: CMMI 1612843

NSF NHERI Natural Hazards Engineering Research Infrastructure



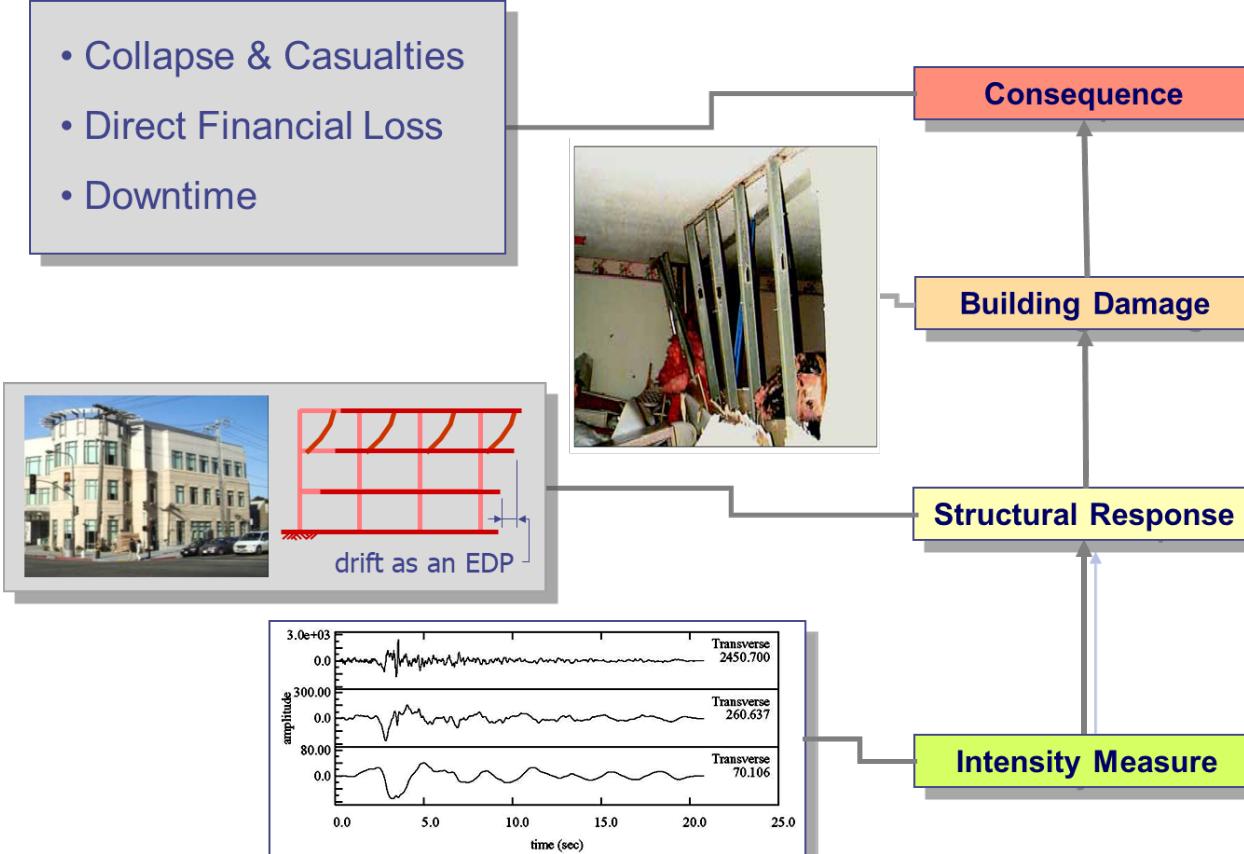
SimCenter Portal



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

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

Performance-Based Engineering Framework



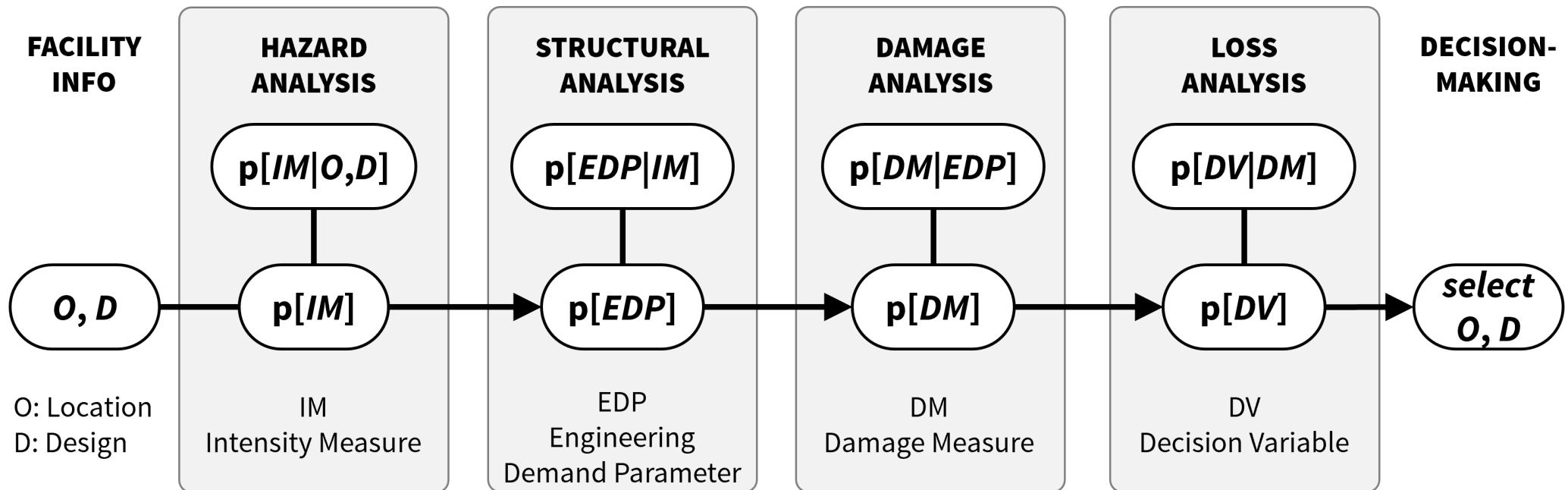
Seismic Performance Assessment of Buildings

Volume 1 – Methodology

FEMA P-58-1 / September 2012



Performance-Based Framework



Porter/PEER (2005)



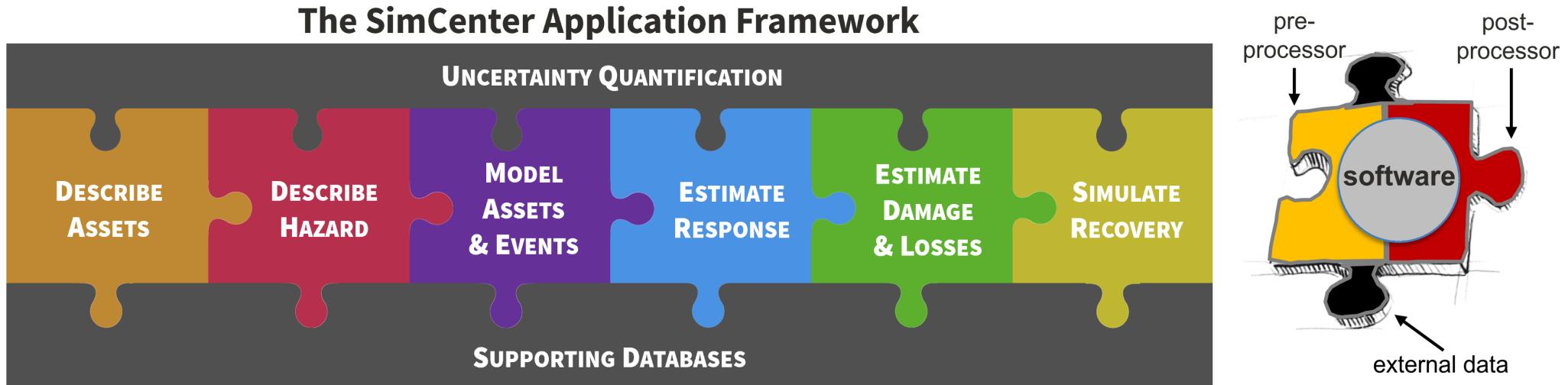
$$v(DV) = \iiint G\langle DV | DM \rangle | dG\langle DM | EDP \rangle | dG\langle EDP | IM \rangle | d\lambda(IM)$$

Impact

Performance (Loss) Models and Simulation

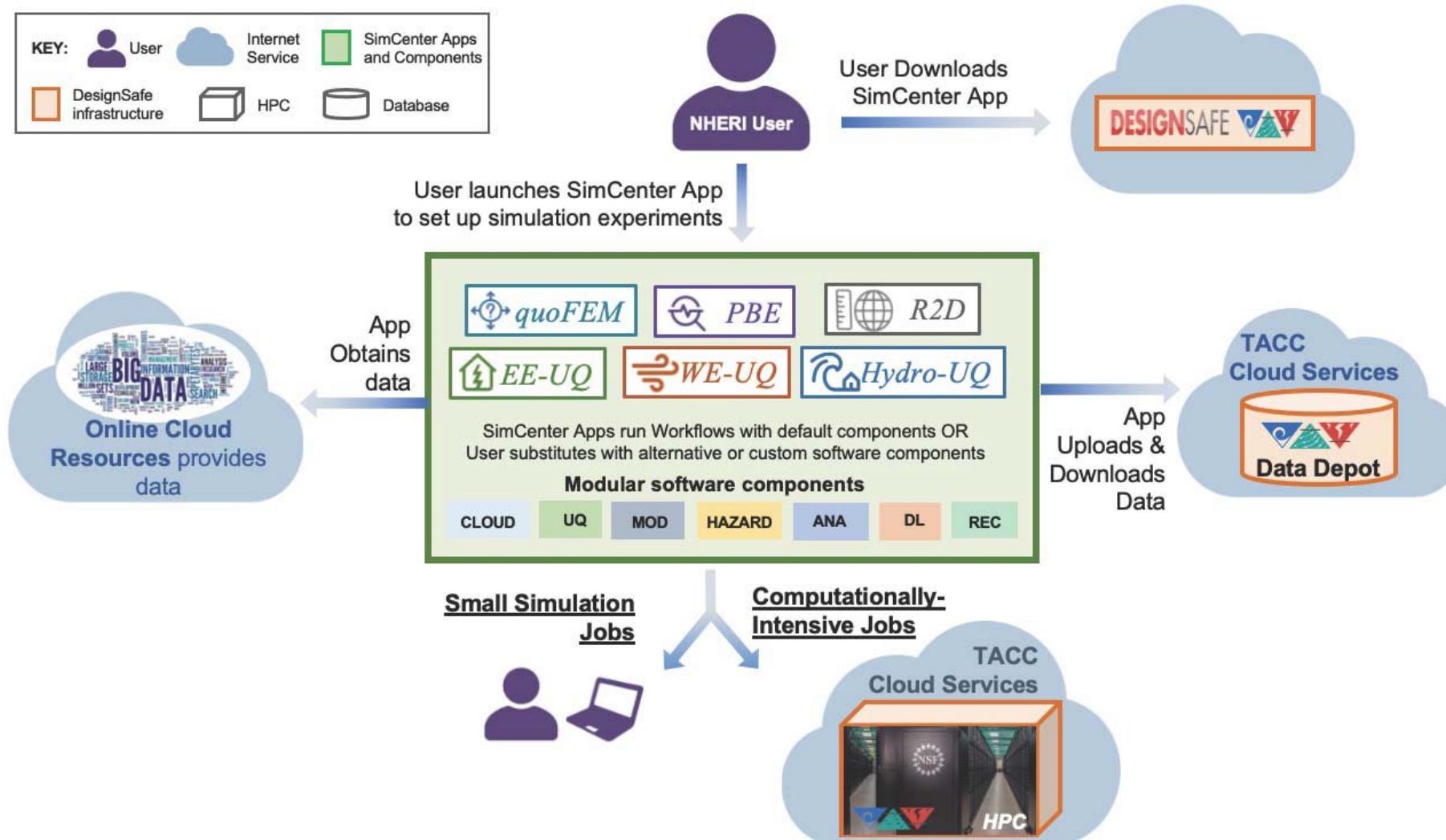
Hazard

Performance-Based Application Framework

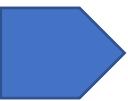


OpenSource :: Multi-Fidelity :: Multi-Hazard

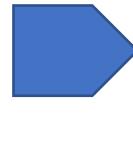
Performance-Based Applications



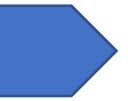
Desktop Applications



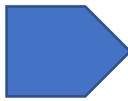
Coupling: Quantification of Uncertainties
& Optimization with FEM



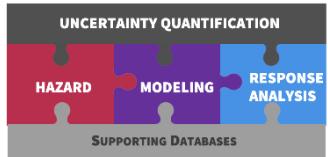
Response of structure to natural
hazard effects: ground shaking, wind
effects, and surge/tsunami flows



Performance-based computations of
individual facilities to natural hazards



Regional assessment of facilities and
systems to natural hazards to support
resilience decision making



EE-UQ V3.0

- Earthquake Simulation of Buildings and Site Effects
- Development of Surrogate Models (Machine Learning Tools)

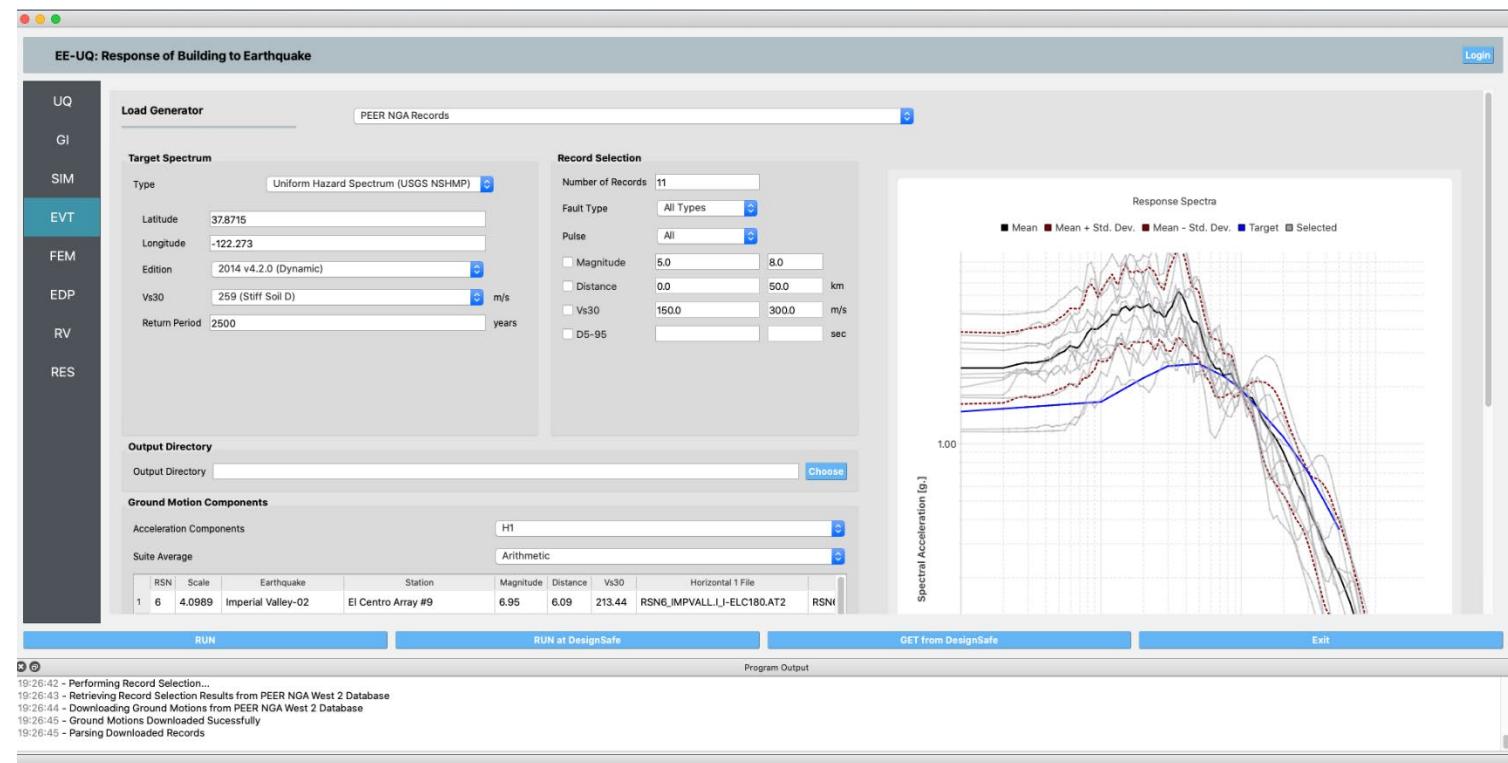
Hazard (Earthquake):

Stochastic Motions

Target Spectrum (OpenSHA, OpenQuake)

Ground Motion Selection/Scaling (PEER NGA, Simulated Motions)

Site Response with Random Fields

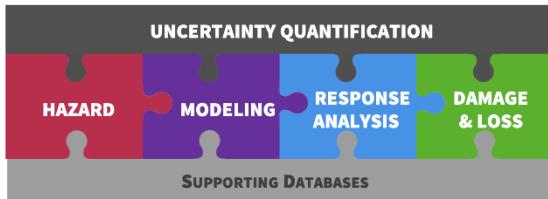


Structural Modeling:

Detailed FE Models (OpenSees)

Simplified Nonlinear Model

Auto Steel and RC Building Design

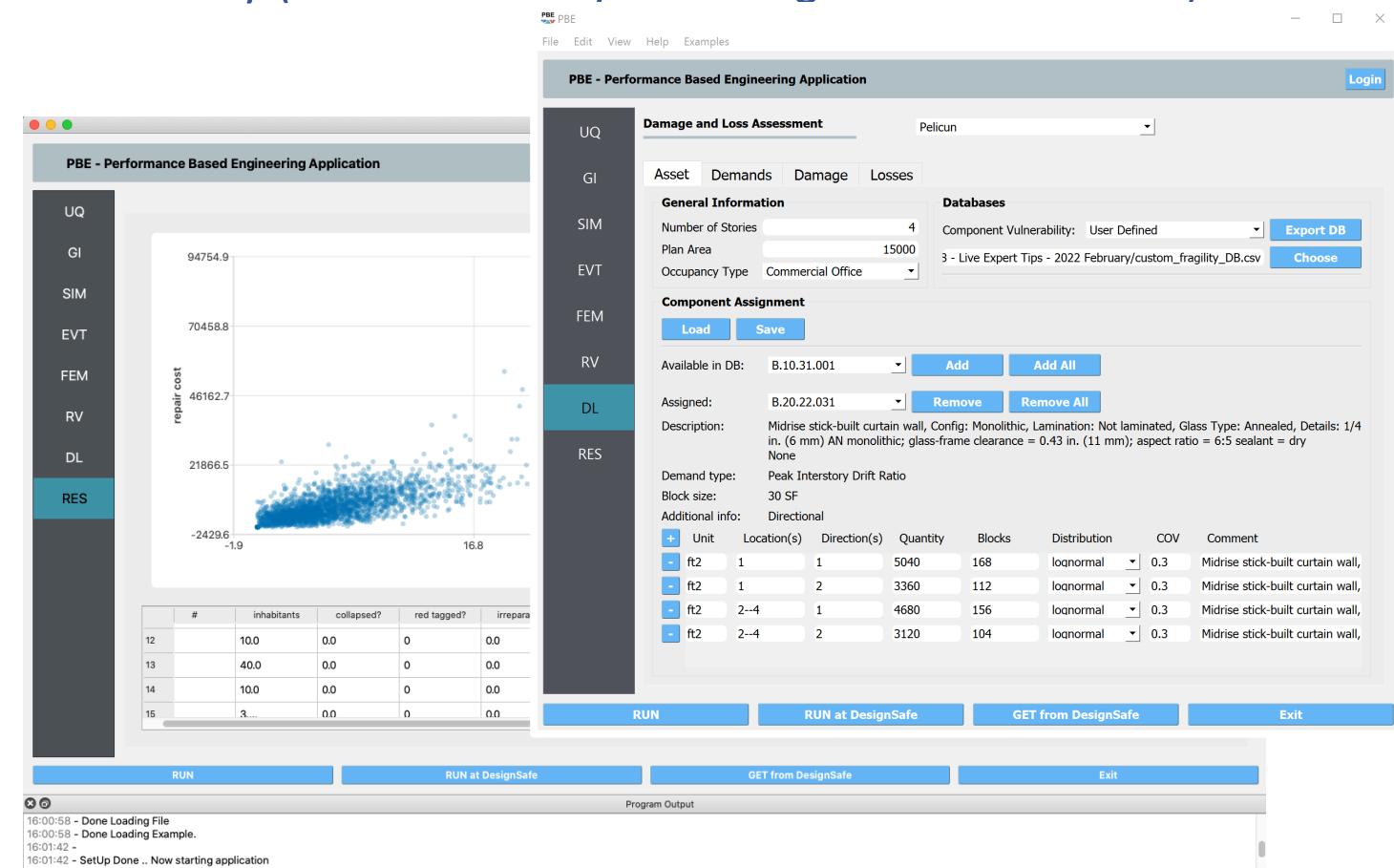
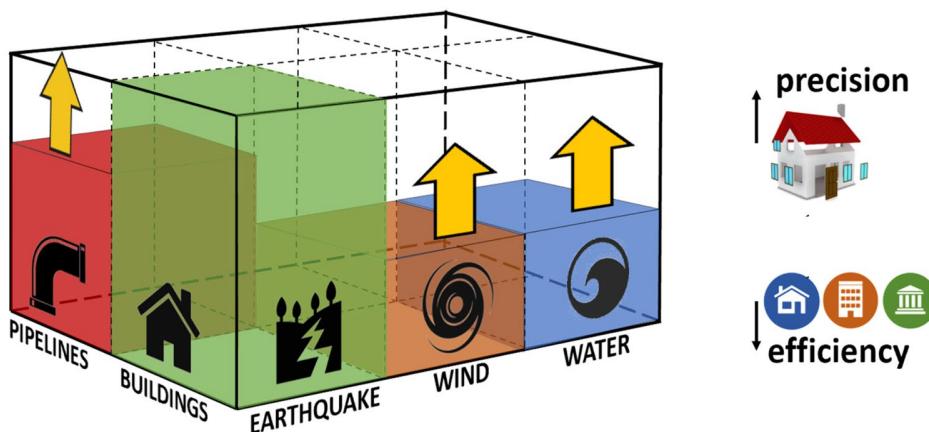


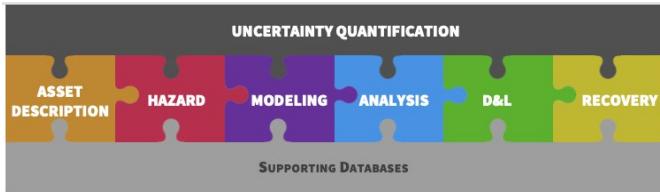
PBE v3.0

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 fragility & consequence functions





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

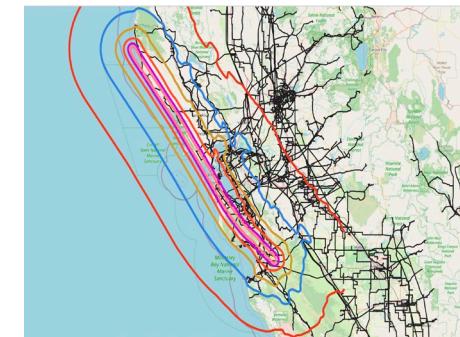
HAZUS and other fragility models

User-provided fragility functions

R2D V2.1

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

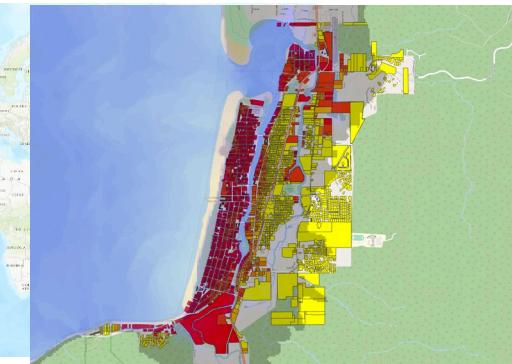
Multiple Hazards



Earthquakes

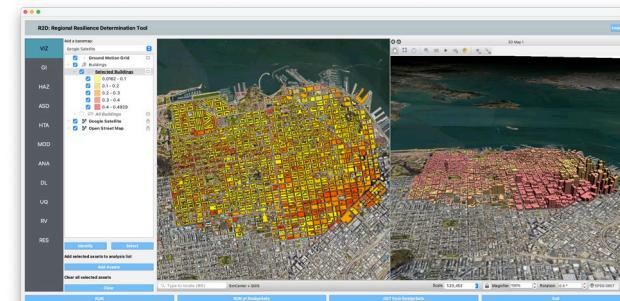


Hurricanes

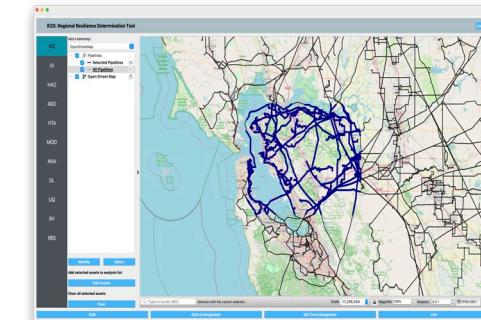


Tsunamis

Multiple Assets



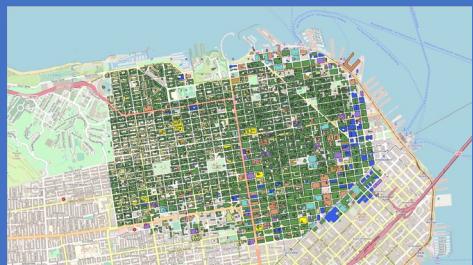
Buildings



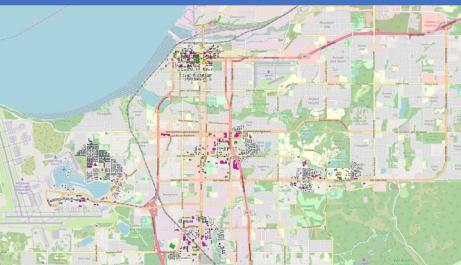
Lifelines

Earthquake

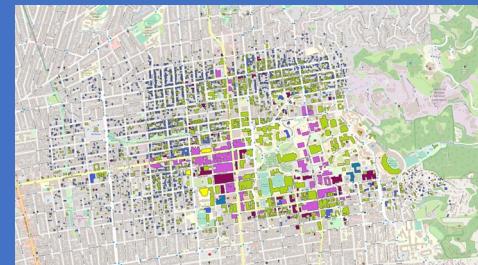
IM PGA



Recorded GMs



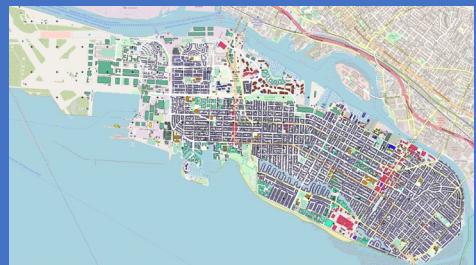
Physics-based GMs



NGAWII GMs



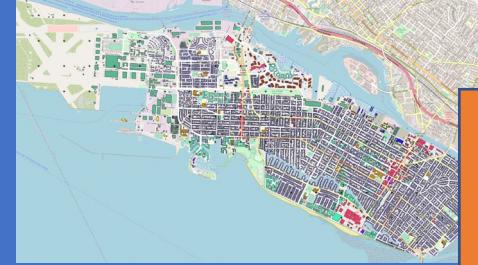
Liquefaction



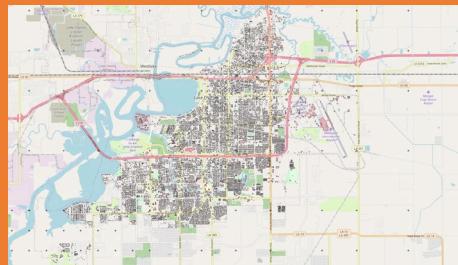
USGS ShakeMap



Site-response



Wind



Wind/Water

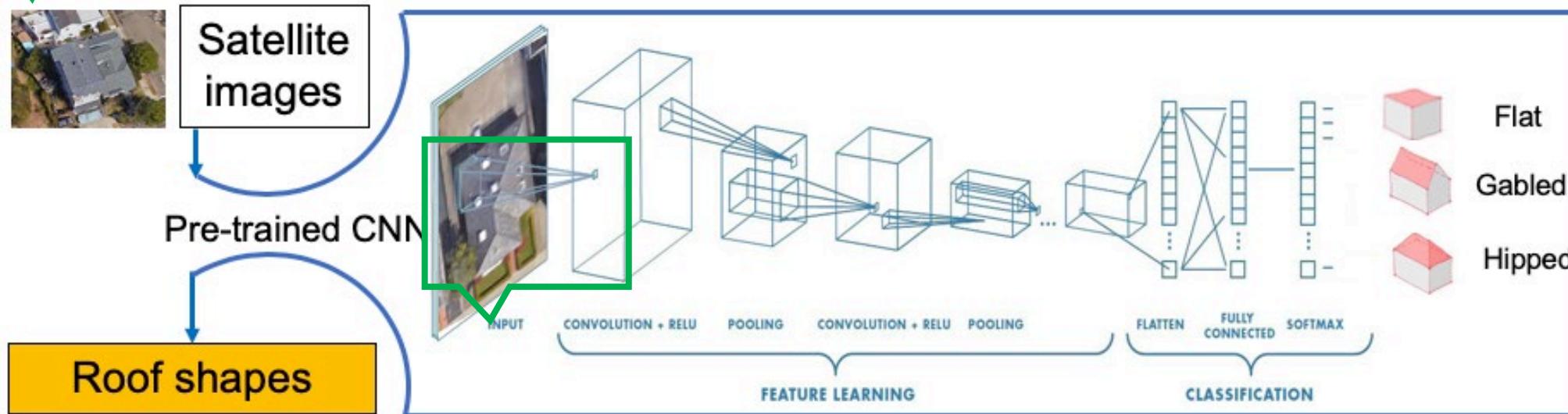


Hurricane

Building Inventory Development Tool



BRAILS (Building Recognition using AI at Large-Scale)



BRAILS creates regional-scale building inventories at building-level resolution using deep learning and computer vision techniques. Prediction models:

Roof shape

Occupancy type

Roof eave height

Roof cover type

Era of construction

Roof pitch angle

Number of floors

Building height

Window area

First floor height

Existence of chimneys

Existence of garages

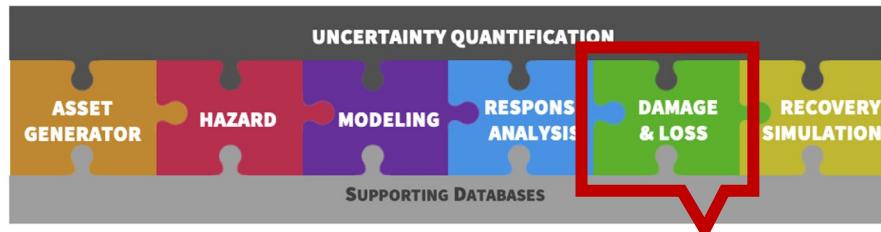
BRAILS Example: Elevations & Window Area



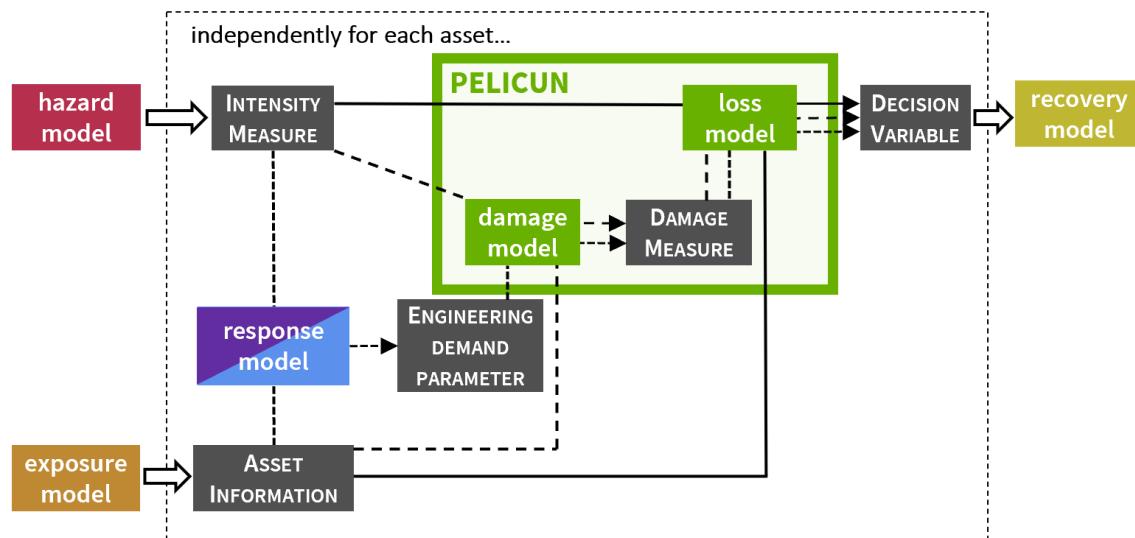
- Semantic segmentation model coupled with an image rectifier and scale determination algorithm
- Automatically detects the pixels that belong to various parts of the structure and all metric quantities can be extracted
- Trained on dataset of 5,000 images (80% training, 15% validation, 5% testing)
- **Outputs:**
 - First floor elevation,
 - building height,
 - roof eave height,
 - roof pitch,
 - window area

Performance Assessment Tool

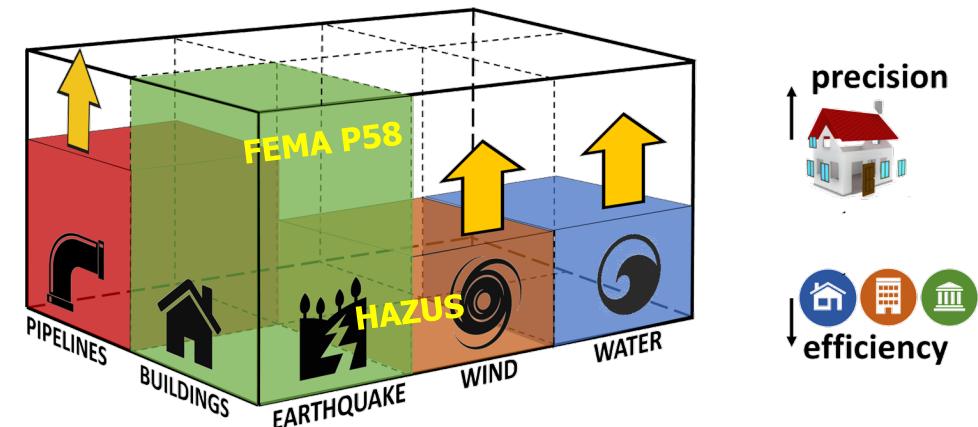
pelicun: PROBABILISTIC ESTIMATION OF LOSSES, INJURIES,
& COMMUNITY RESILIENCE UNDER NATURAL HAZARD EVENTS



- Standardized data schema that unifies performance model data across hazards, assets, and resolutions
- Library of damage functions (P58, HAZUS, In-Core)
- Customizable damage – consequence mapping

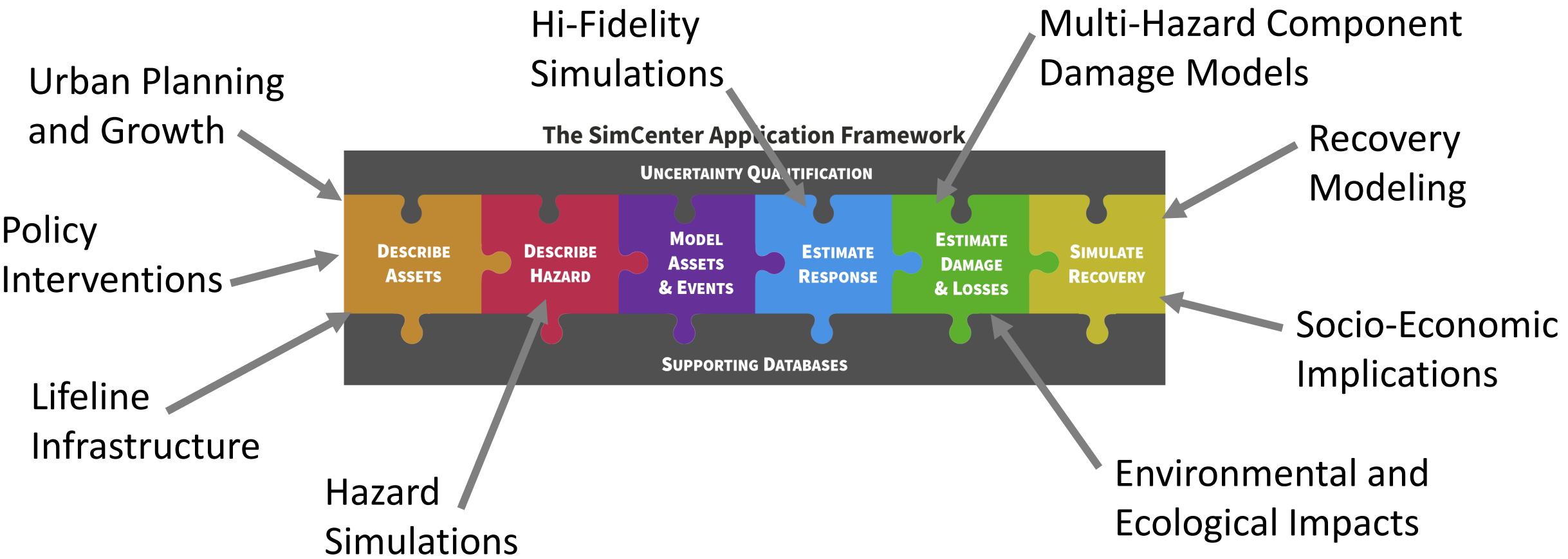


Multi-Fidelity Approach



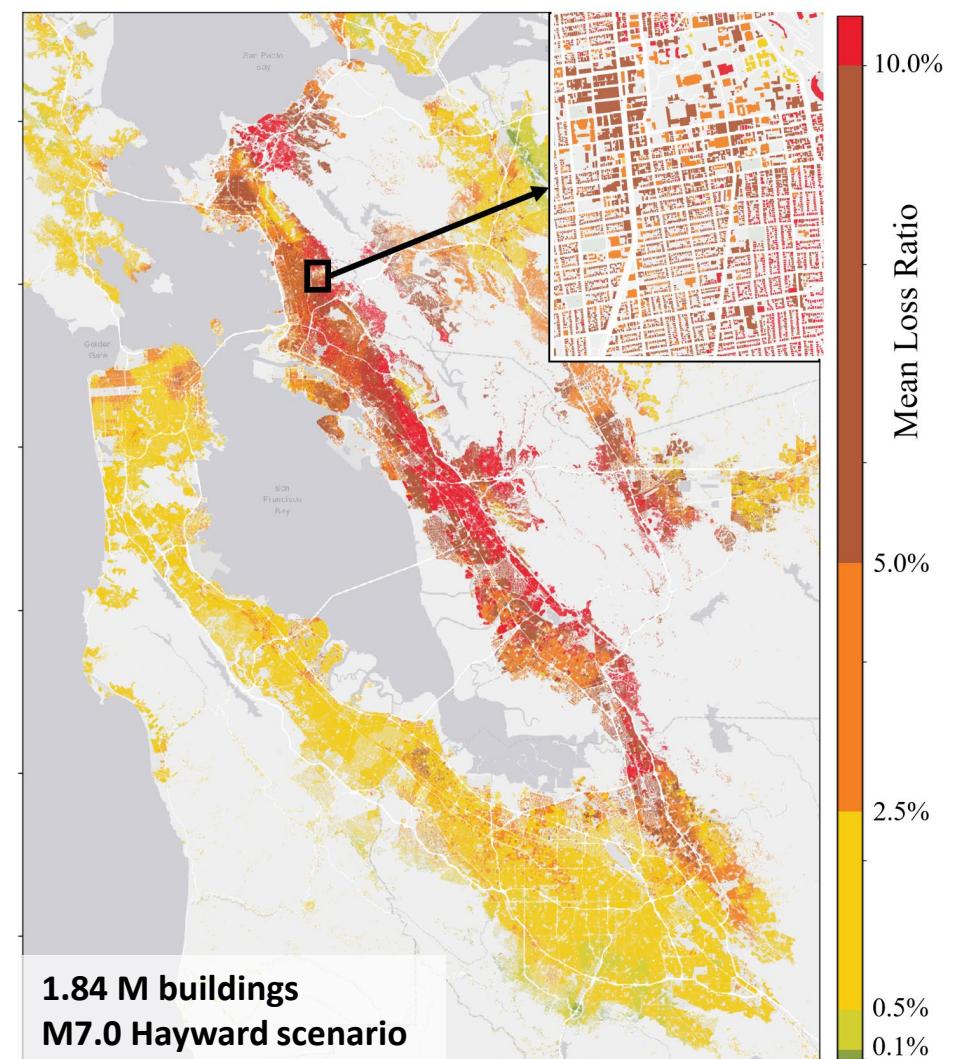
Community-Driven Development
of New Models & Data

Vignettes to Inspire Future Opportunities



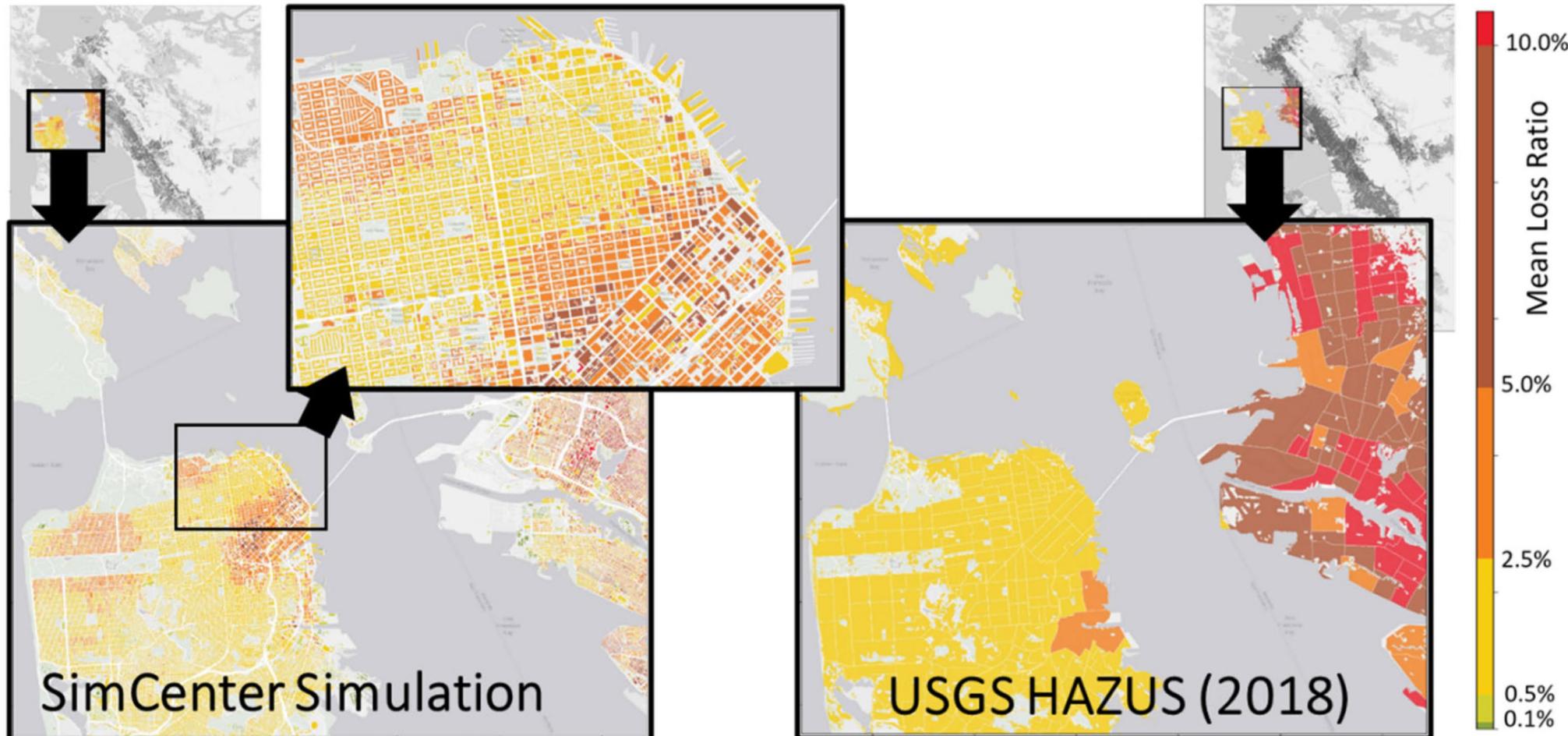
San Francisco Bay Area M7.0 Earthquake Testbed

- **M7.0 Hayward simulation (LLNL-SW4)**
- **1.84 M individual buildings**
- **Parcel-level inventory enhanced by AI tools**
- **Building Evaluations**
 - *HAZUS building configurations*
 - *OpenSees MDOF (story shear) models*
 - *25 pairs of ground motions*
 - *HAZUS story-level damage functions*
 - *modeling uncertainty*
- **DesignSafe HPC (Stampede2)**
 - *16 hr runtime on 12,800 cores*



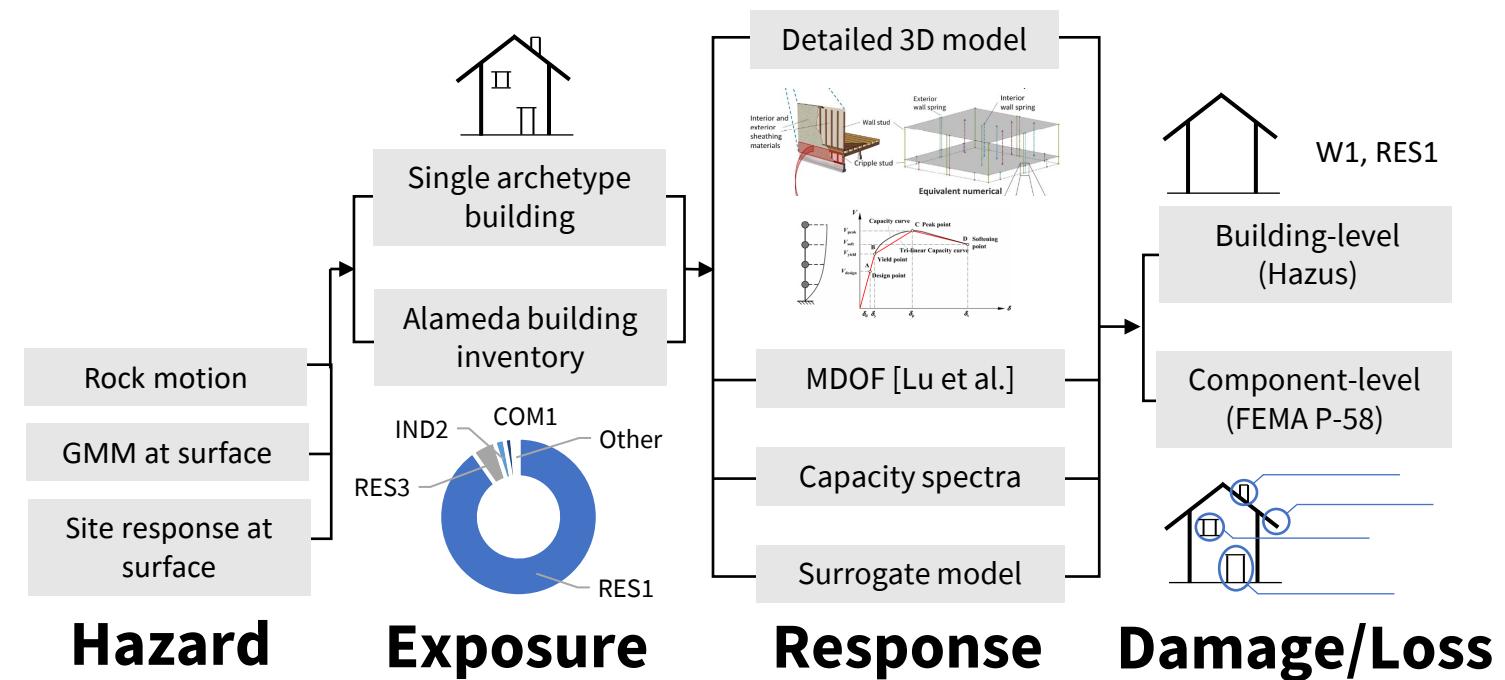
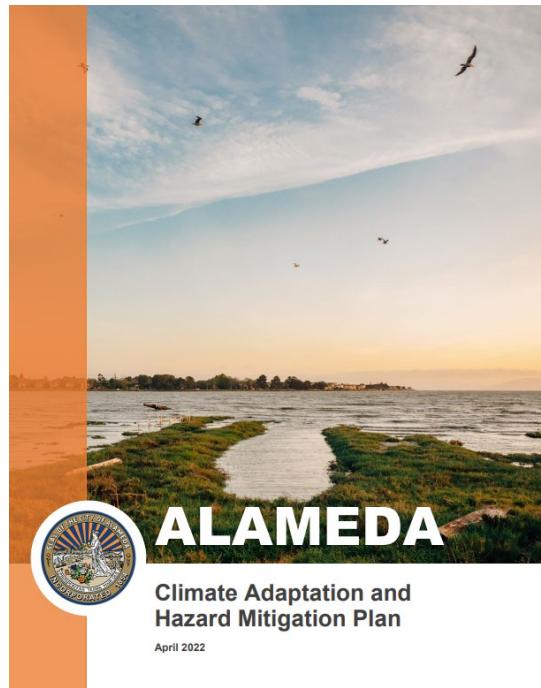
San Francisco Bay Area M7.0 Earthquake Testbed

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



Alameda Testbed

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



Alameda Testbed

Publicly available datasets

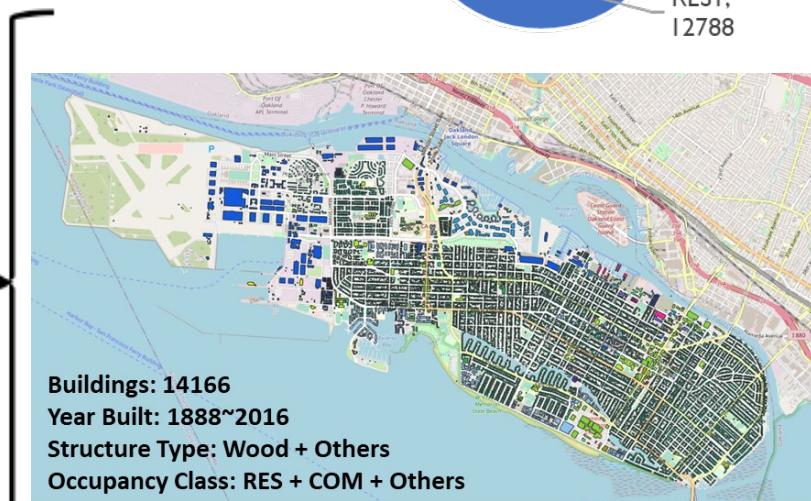
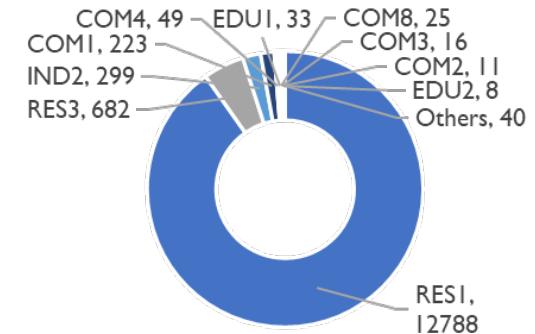
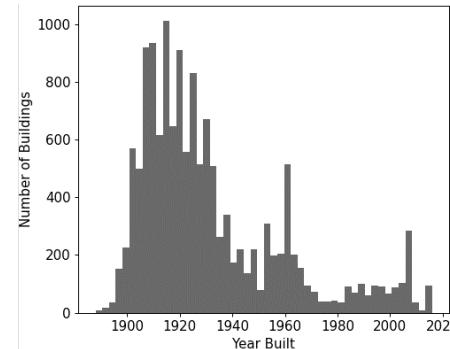
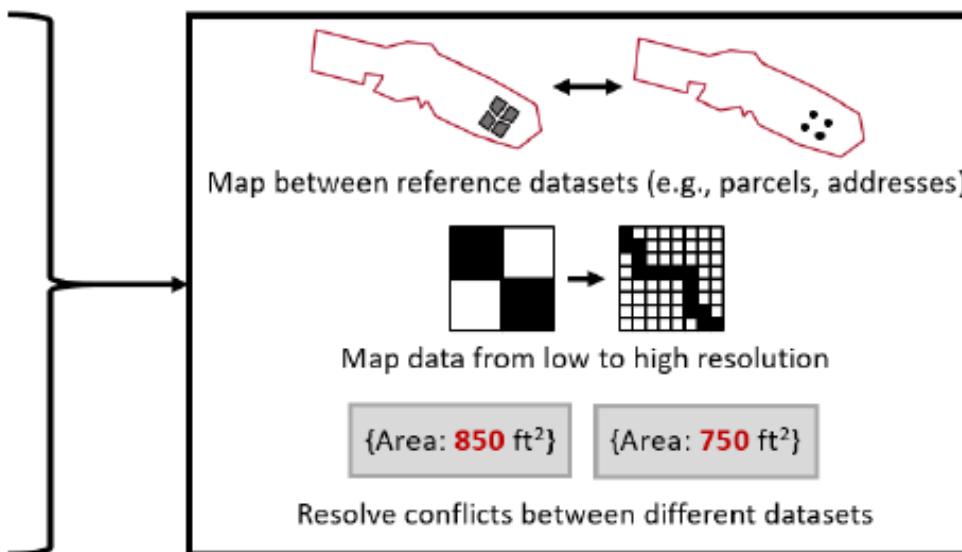


United States
Census
Bureau

BRAILS



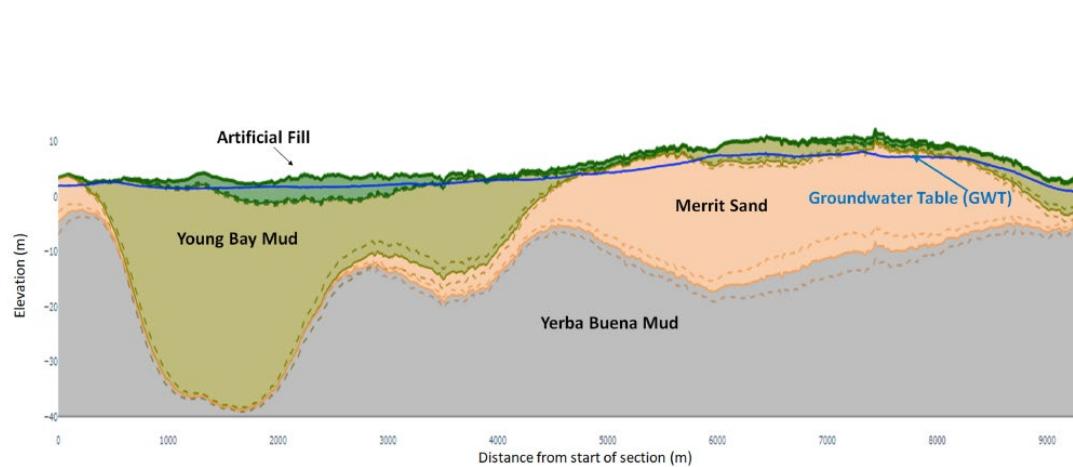
OpenStreetMap



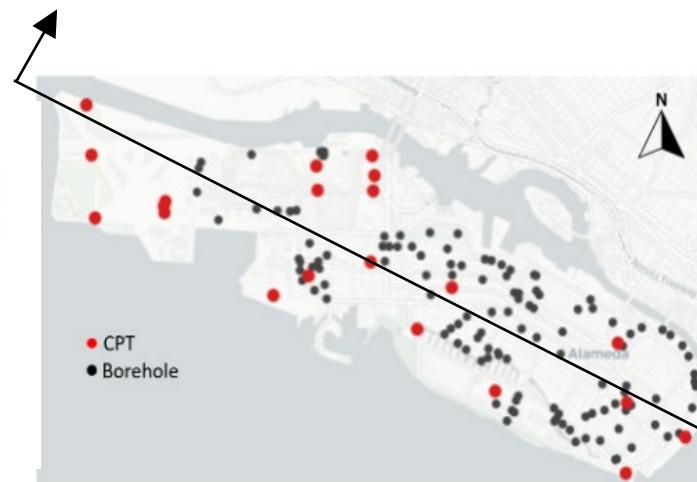
High-Fidelity Building Inventory for Performance Assessment

Bassman T.J., Zsarnóczay A., Saw J., Wang S., Deierlein G.G., "High-Fidelity Testbed Development for Regional Risk Assessment in Alameda, California", 12th National Conference on Earthquake Engineering, Salt Lake City, Utah, 2022

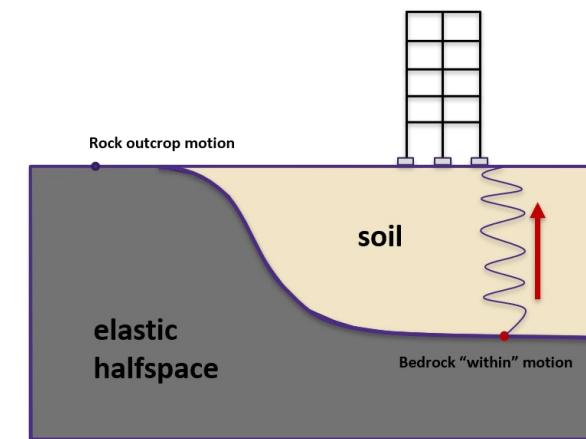
Alameda Testbed



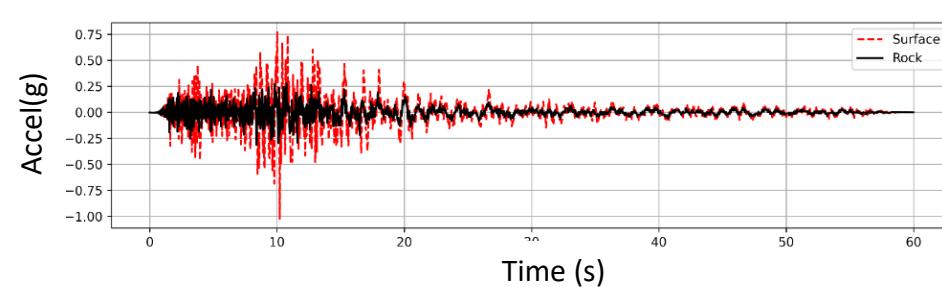
Geotechnical Cross-Section Through Alameda



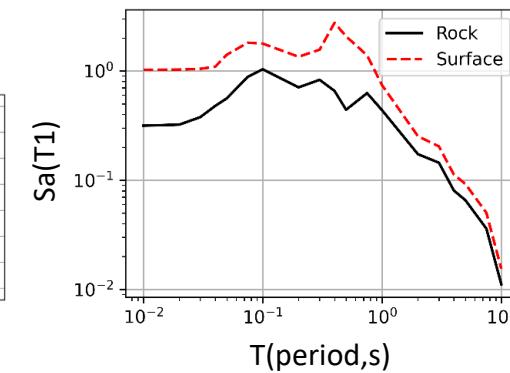
CPT sites and borehole locations



EE-UQ Simulation



Rock versus Ground Surface Motions

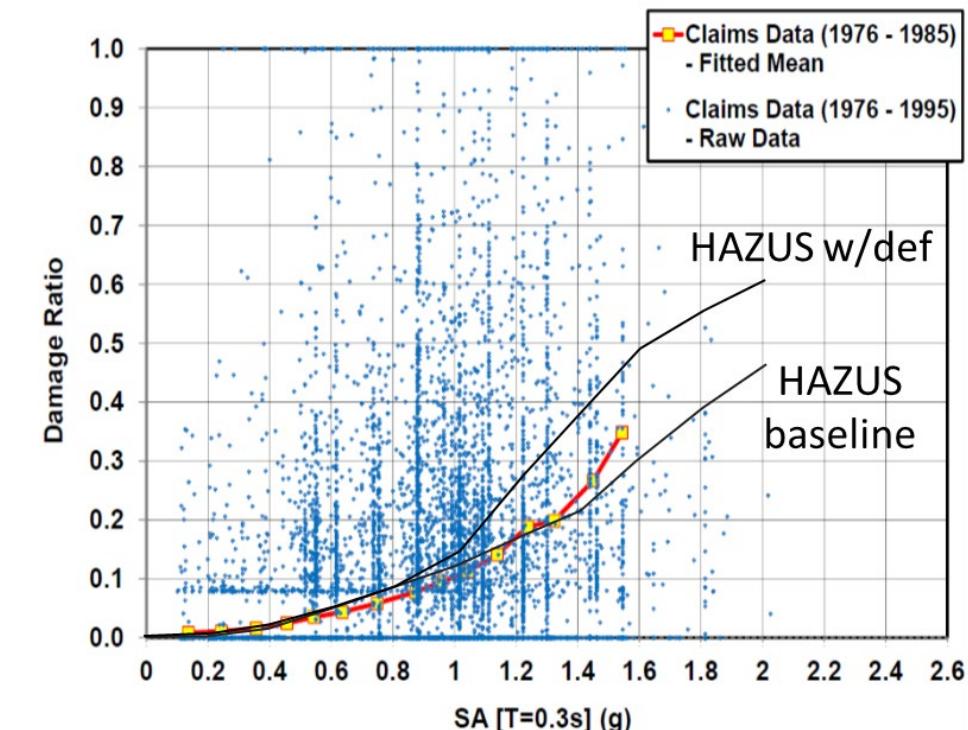


City-scale Simulation of Ground Shaking Amplification

Wood-Frame House Risk Mitigation



Economic Benefits/Incentives of Foundation Wall Retrofit

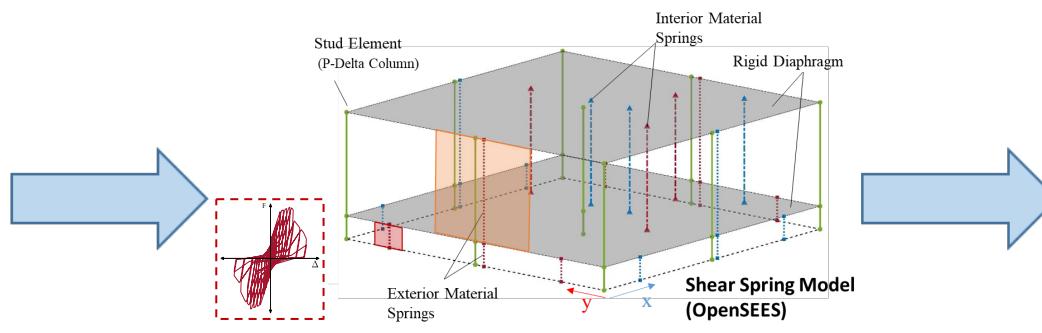
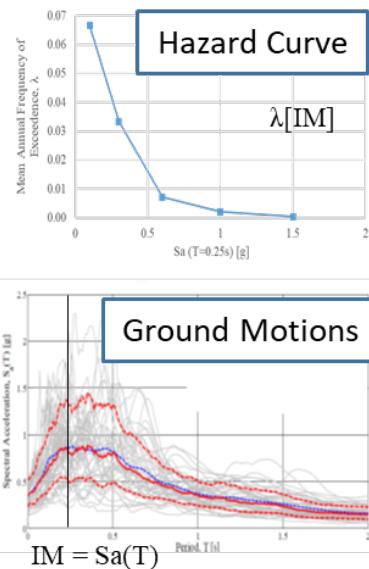
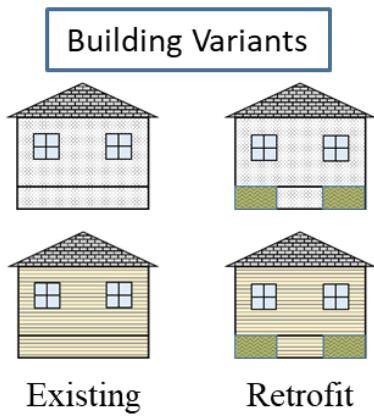


Limitations to “The Law of Averages”

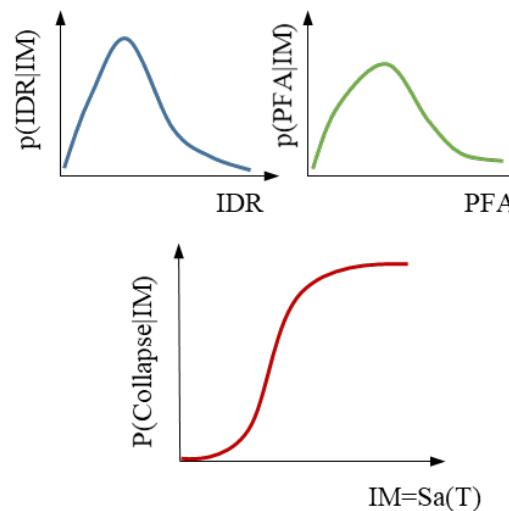


Welch and Deierlein

Wood-Frame House Risk Mitigation



EDP Response and Collapse Fragility



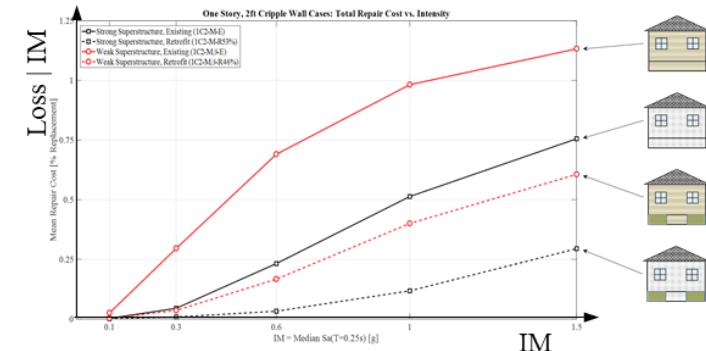
Define Damageable Inventory

- Exterior wall material
- Interior wall material
- Number of interior walls

Assign Damage Fragilities and Consequence Functions



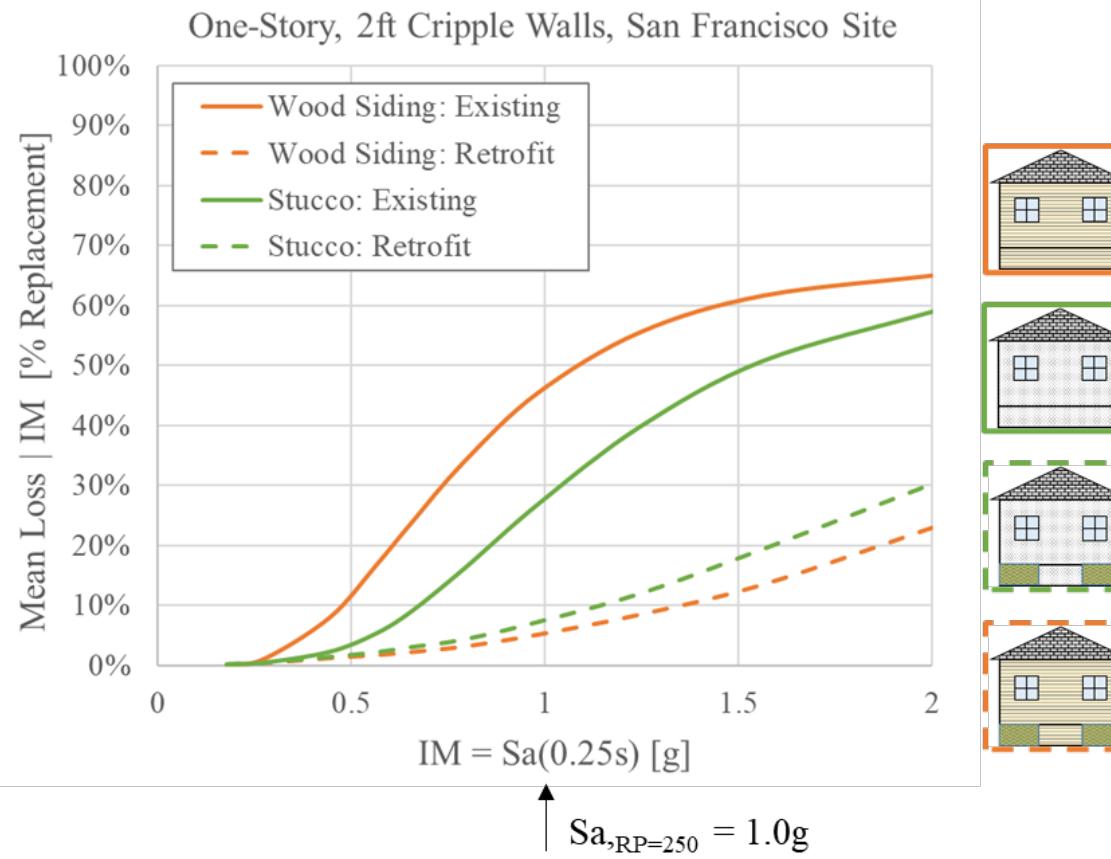
Estimate Seismic Performance



FEMA P-58 Loss Assessment

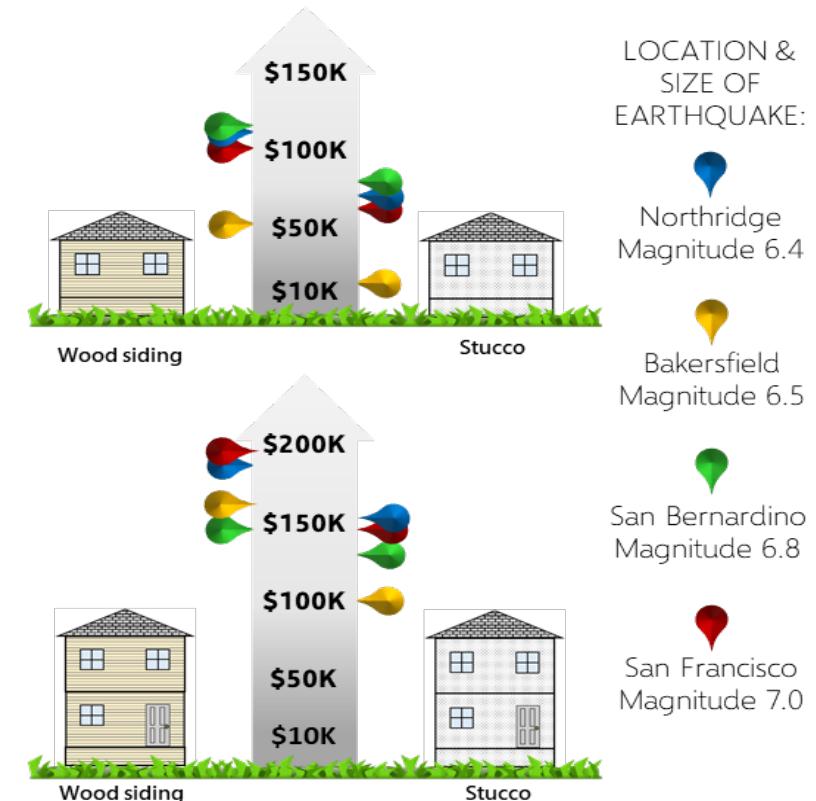
Welch, D.P., Deierlein, G.G. (2020), Structural Analysis and Performance Assessment (PEER-CEA Project), PEER 2020-22

Wood-Frame House Risk Mitigation



Loss versus Earthquake Intensity

How Much Could I Save In "The Big One" If I Retrofit My House?



Welch, D.P., Deierlein, G.G. (2020), Structural Analysis and Performance Assessment (PEER-CEA Project), PEER 2020-22

SF Downtown Office Recovery



Structural System

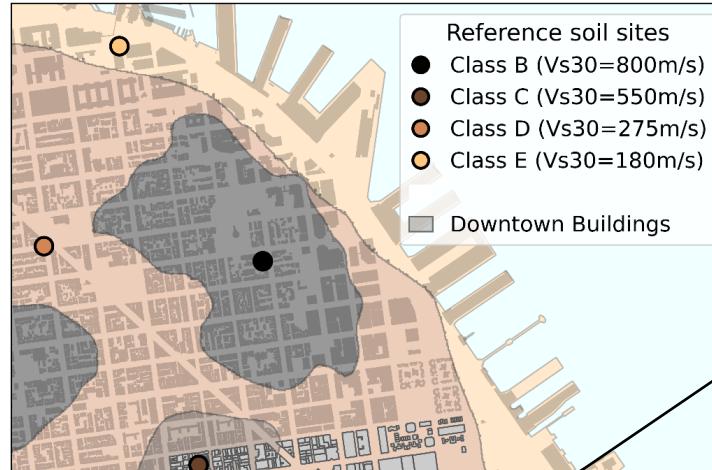
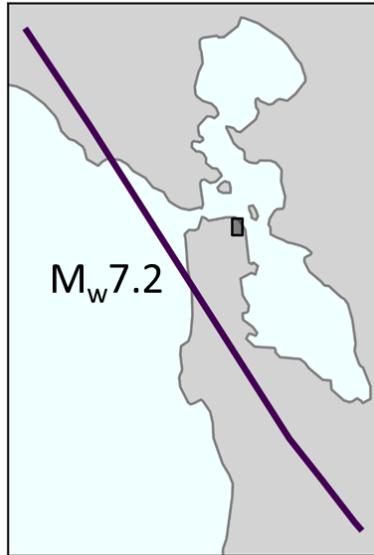
- Steel Moment Frame
- RC Shear Wall (with or without dual system)
- Steel Braced Frame

RECOVERY TARGETS FOR SAN FRANCISCO

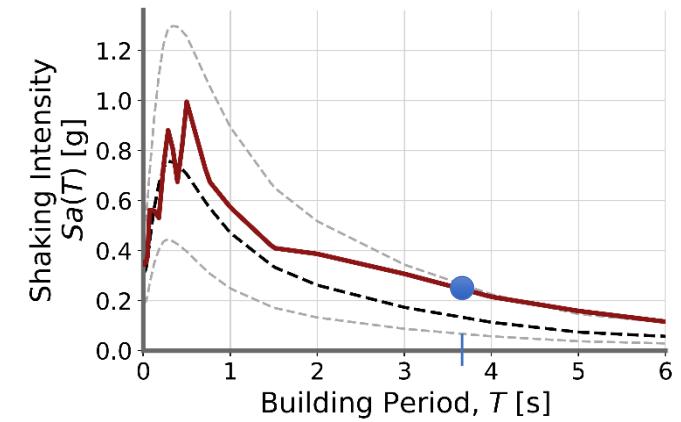
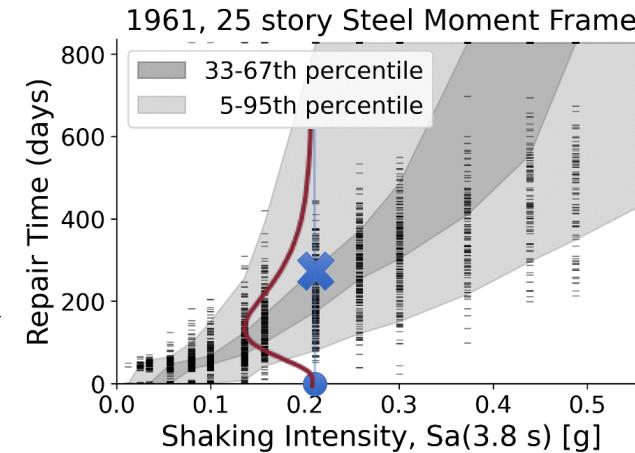
	Months		
	4	36	36+
COMMUNITY FUNCTIONS			
All residences repaired, replaced or relocated	◆		
95% neighborhood retail businesses open	◆		
50% offices and workspaces open	◆		
Non-emergency city services		◆	
All businesses open		◆	

Adapted from *The Resilient City*, SPUR 2009

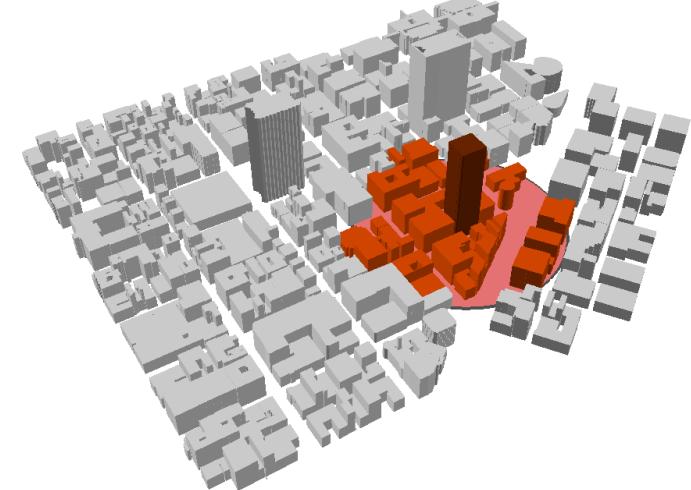
SF Downtown Office Recovery



San Andreas M7.2 Scenario



$$dv_i = \begin{cases} t_{functional} \\ Tr_{cordon} \\ t_{stable} \end{cases}$$

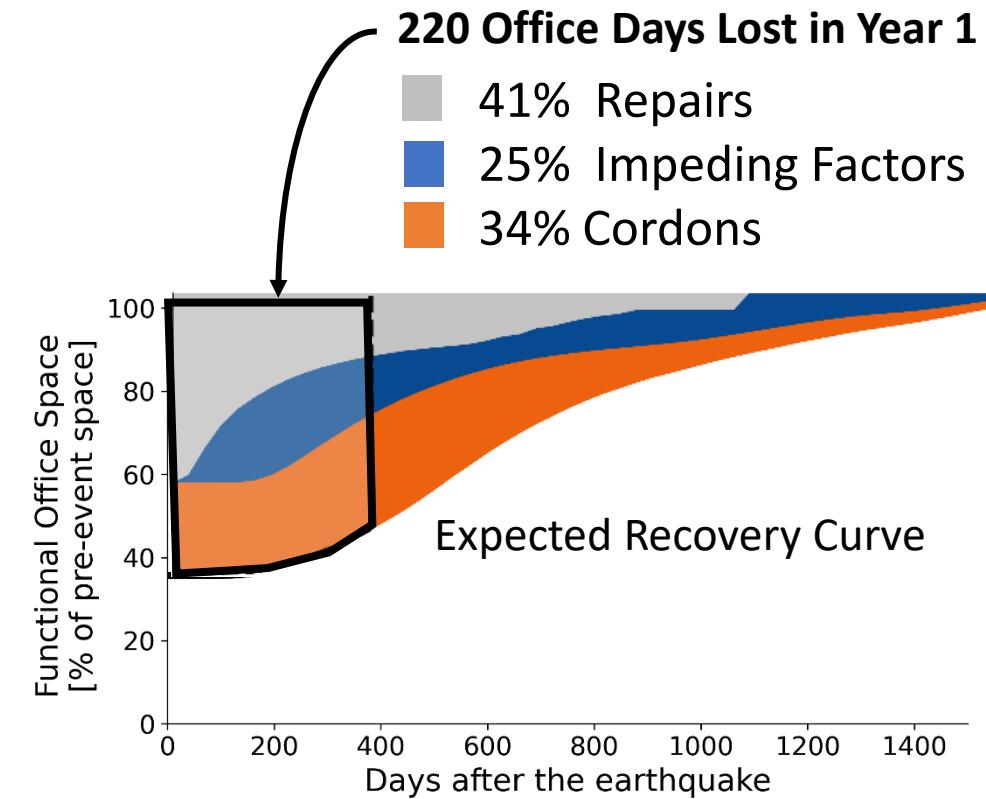
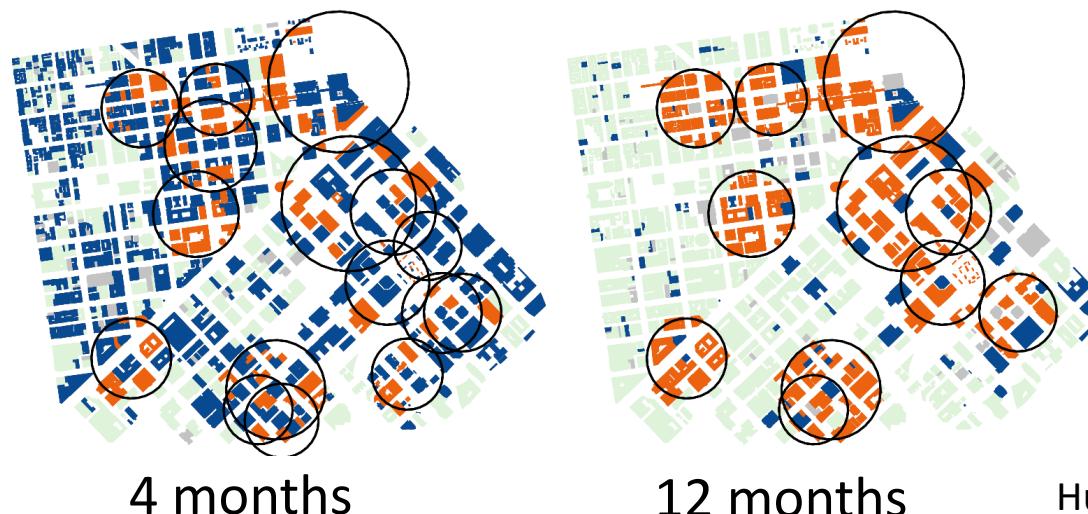
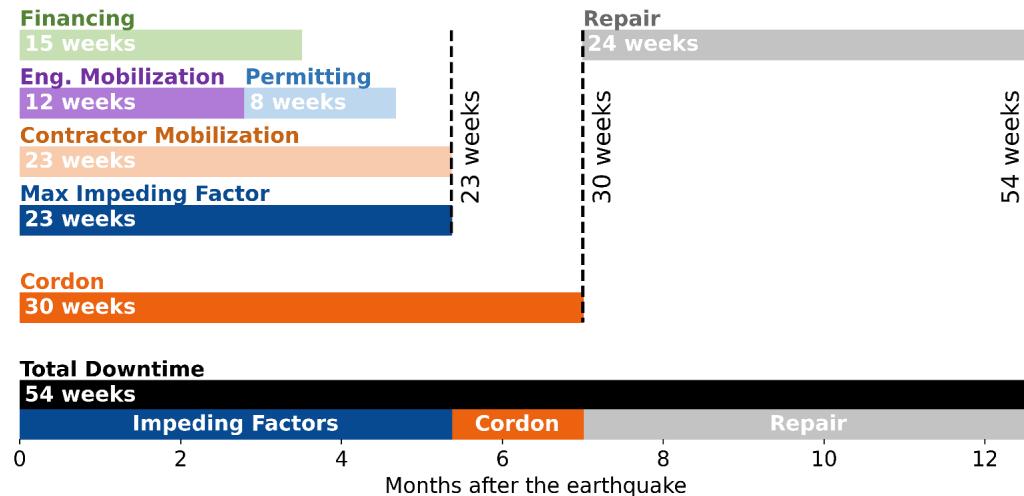


Impact of Building Safety Cordons

Hulsey, A., Baker, J.W., Deierlein, G.G. (2021), "High-Resolution Post-Earthquake Recovery Simulation: Impact of Safety Cordons," *Earthquake Spectra*

NIST Disaster Resilience Grant

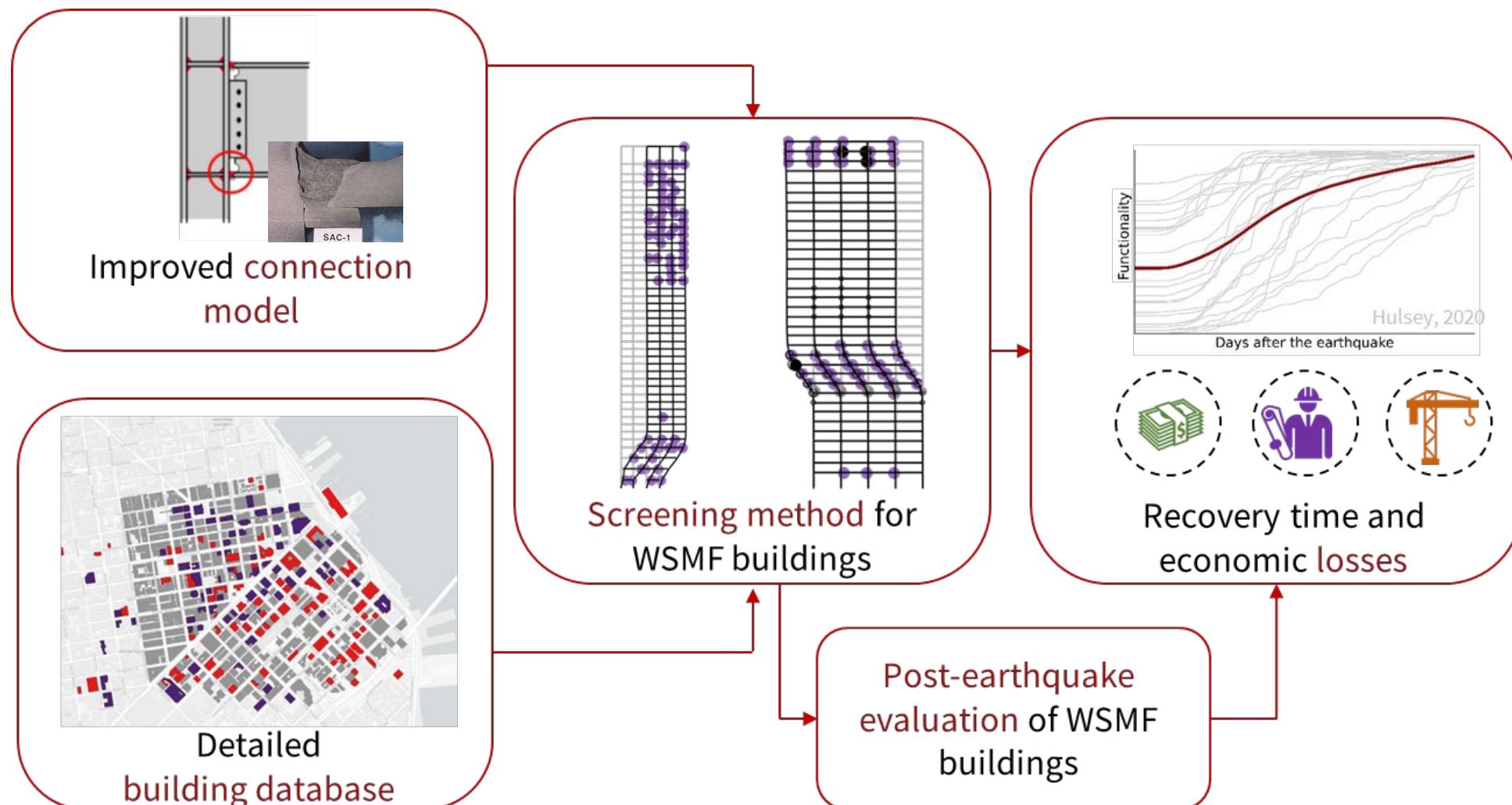
SF Downtown Office Recovery



Office Space Recovery

Hulsey, A., Baker, J.W., Deierlein, G.G. (2021), "High-Resolution Post-Earthquake Recovery Simulation: Impact of Safety Cordons," *Earthquake Spectra*

Pre-Northridge Tall Building Evaluation

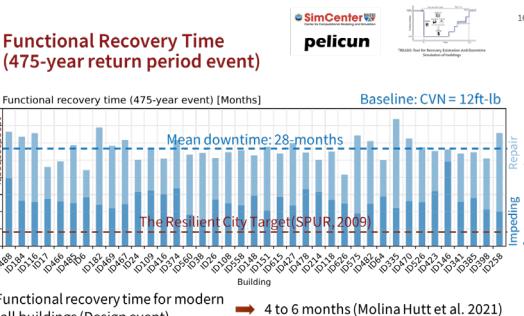
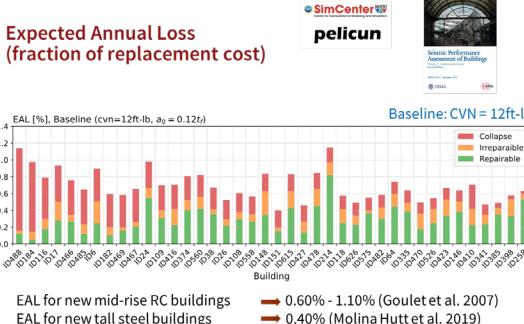
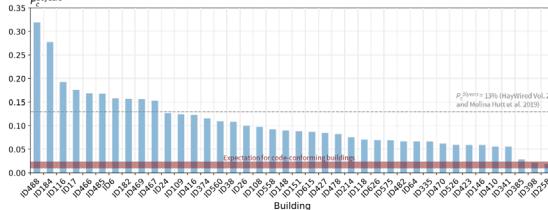


NIST Disaster Resilience Grant

Galvis, Molina-Hutt, Baker and Deierlein (2022)

Pre-Northridge Tall Building Evaluation

Portfolio risk assessment results: safety metrics
Baseline: CVN = 12ft-lb



Archetype Study of Pre-Northridge Frames:

Collapse Risk

- highly variable
- up to 20x higher than conforming buildings

Expected Annual Loss

- ~ 2 to 3 x higher than conforming buildings
- higher contribution from collapse risk

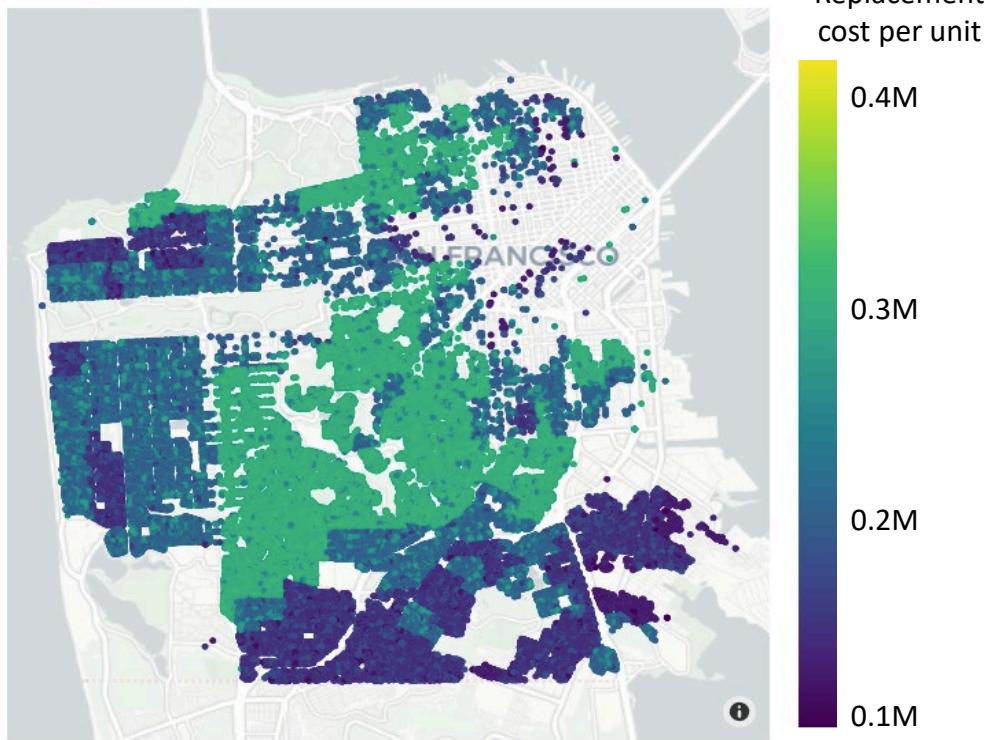
Functional Recovery Time

- ~ 4 to 7x higher than conforming buildings
- equal contributions of impeding factors and repairs

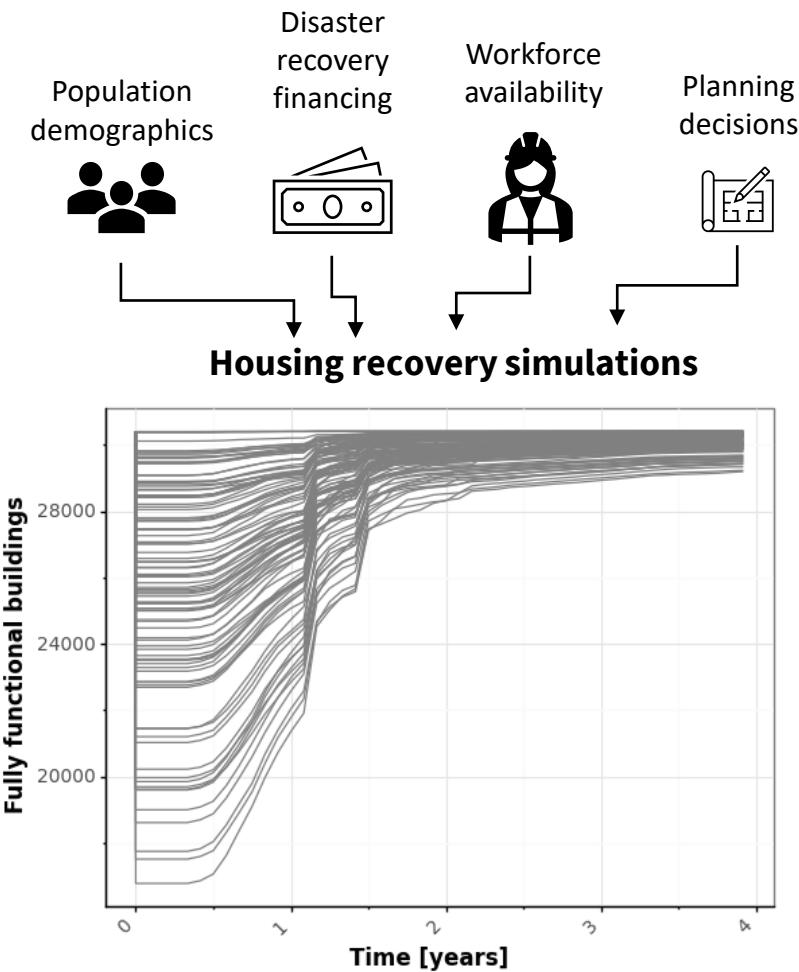
NIST Disaster Resilience Grant

Galvis, Molina-Hutt, Baker and Deierlein (2022)

Post-EQ Housing Recovery



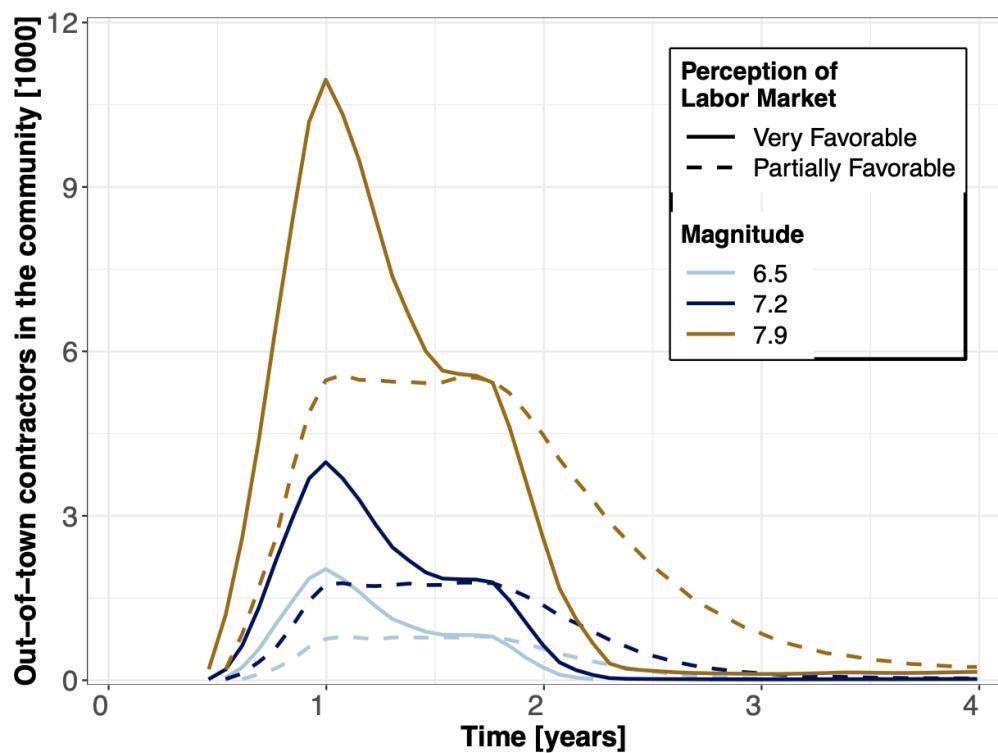
Parcel-Level Inventory of Buildings & Population Demographics



Simulation of Post-EQ Housing Recovery

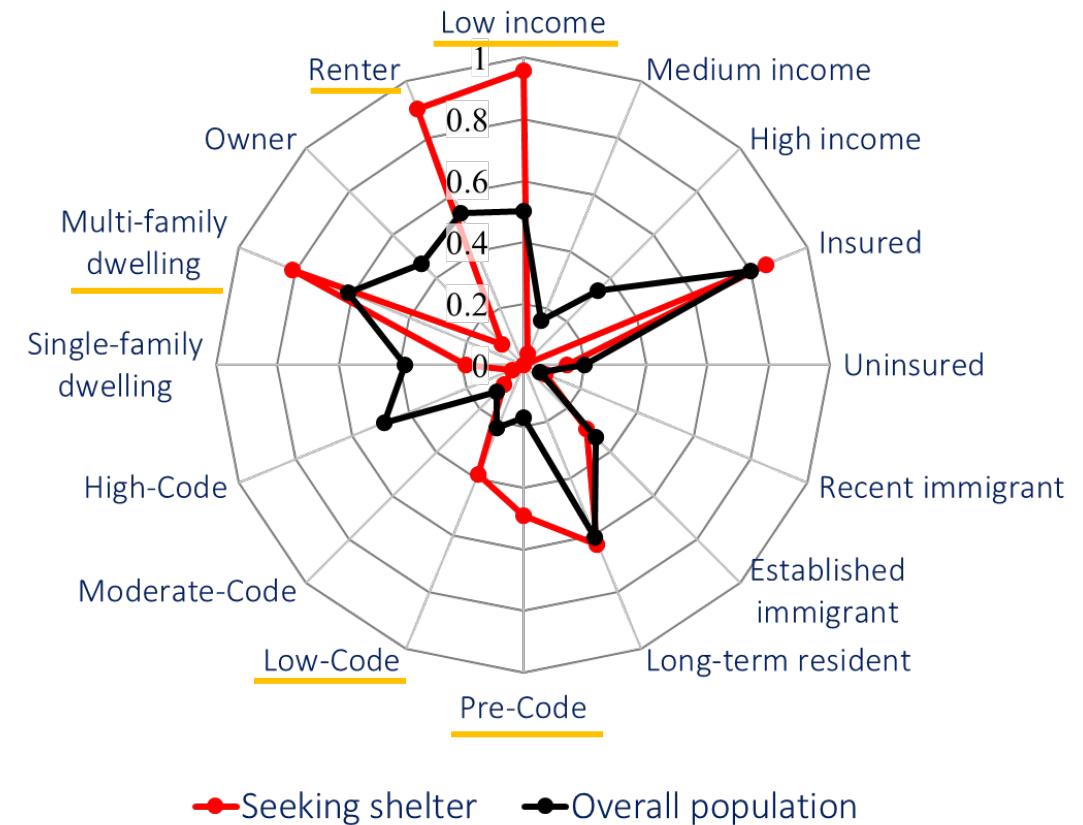
Costa, Zsarnoczay, Baker (Stanford)

Post-EQ Housing Recovery



Evaluating Available Workforce for Recovery

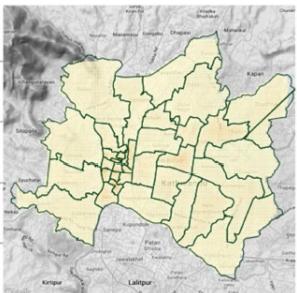
Costa, Zsarnoczay, Baker (Stanford)



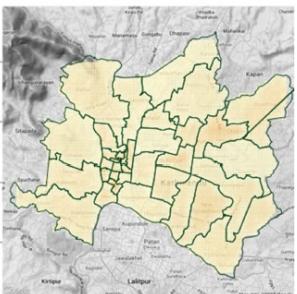
Evaluating Demographic Implications on Recovery

Costa, R., Haukaas, T., Chang, S.E. (2020) "Predicting population displacements after earthquakes," *Sustainable & Resilient Infrastructure*

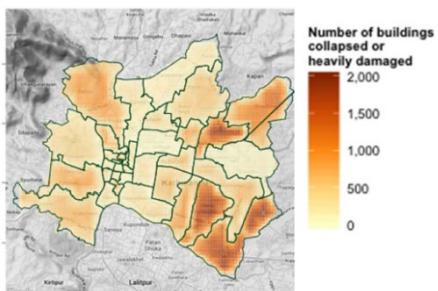
Urban Risk Forecasting



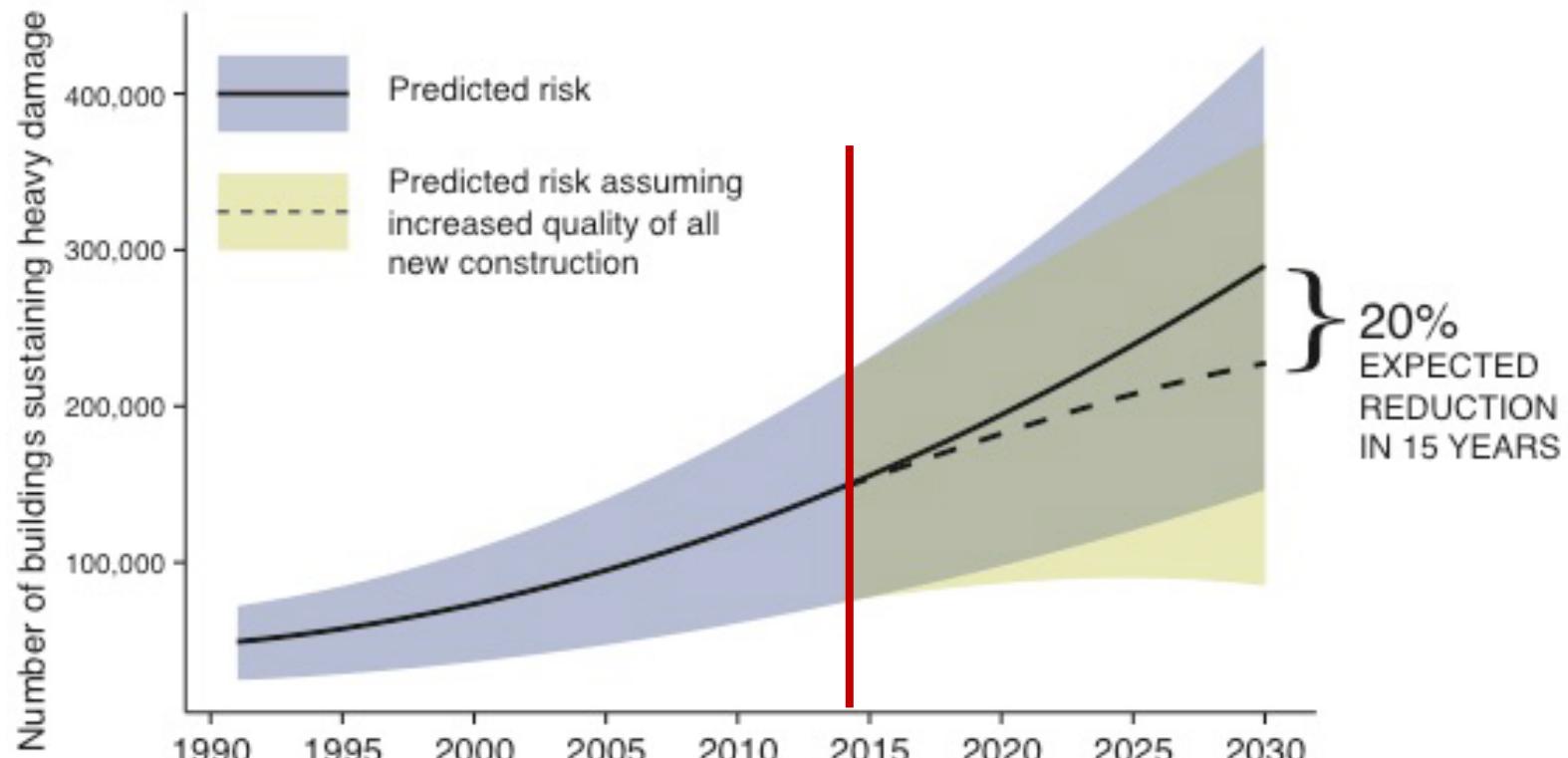
1991 Inventory



2010 Inventory (est)



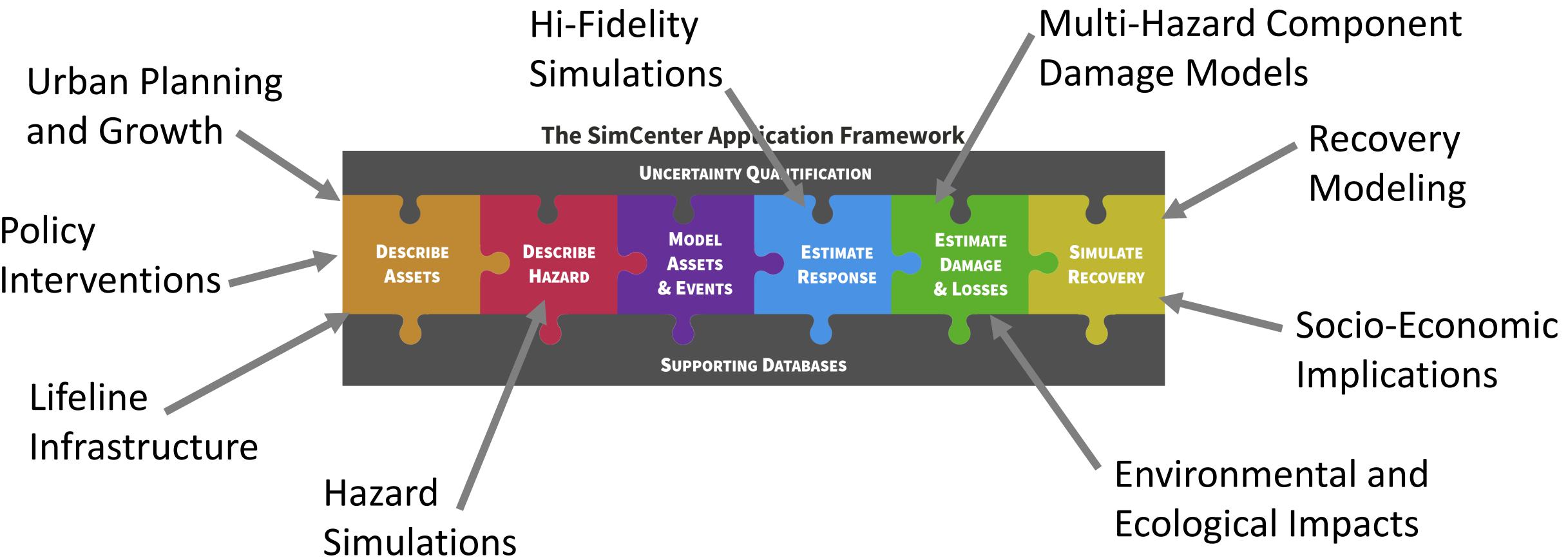
2020 Inventory (est)



**Urban Growth & Evolving Risk
(Kathmandu, Nepal)**

Lallemand, D., Wong, S., Morales, K., Kiremidjian, A. (2014), "A Framework and Case study for Urban Seismic Risk Forecasting," *Proc.10NCEE, Los Angeles.*

Framework for Multi-Disciplinary Collaboration



Learn more at: <https://simcenter.designsafe-ci.org/>

GAO Recommendation (GAO-22-105016)

The Director of NIST should, in collaboration with FEMA, NSF, and USGS and in coordination with federal, state, local, territorial, and tribal governments and stakeholders, **conduct a national risk assessment to identify the progress made by communities to strengthen earthquake resilience since 2015, and the gaps in resilience that remain.**

Issues and Considerations:

1. Timeframe over which to implement meaningful changes

- Building Code Provisions
- Government/Utility Programs (e.g., SF PUC and LAWP upgrades to water supply)
- Mandatory Policies (e.g., SF soft story retrofit, LA non-ductile concrete building retrofit)
- Subsidized Programs (e.g., California Earthquake Authority “Brace and Bolt” Program)
- Voluntary Incentives (e.g., USRC Building Seismic Rating System)

2. Quantifying “Risk” versus “Progress Made by Communities to Strengthen Earthquake Resilience”

- Definition of “Risk” metrics (life safety, direct \$ losses, recovery time, indirect \$ losses)
- Resolution of technologies used for regional risk assessment (inventories, damage/loss models, recovery and indirect loss models)

3. Federal versus State, City or Industry/Owner Actions

GAO Recommendation (GAO-22-105016)

Suggestions:

1. Critical review of past efforts to quantify risk trajectories and the impact of mitigation measures
2. Develop strategies to track “*Progress Made by Communities to Strengthen Earthquake Resilience*”
 - Summarize federal programs/initiatives (NEHRP and other agencies)
 - Survey programs/actions implemented by state/local governments and other organizations (e.g., CEA, utilities, universities, companies)
 - Identify and *track risk measures in ‘indicator’ cities/organizations* through risk assessments that track the impact of mitigative actions
3. Identify “*Gaps in Resilience*”
 - Survey constituents
 - Identify research, implementation, or other gaps