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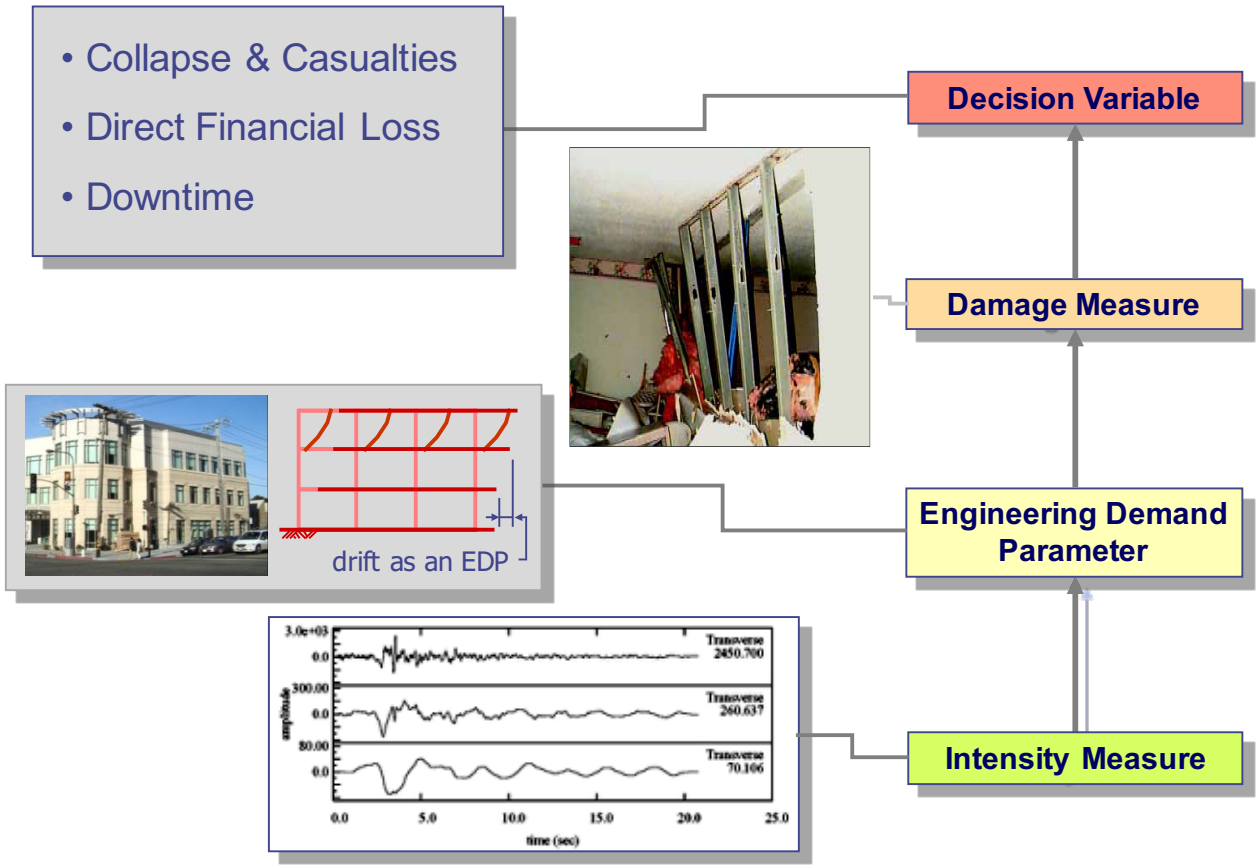
Center for Computational Modeling and Simulation

Computational Workflow Framework for Regional Disaster Simulations

Greg Deierlein
SimCenter Co-Director
Stanford University

NSF award: CMMI 1612843

Performance-Based Methodology



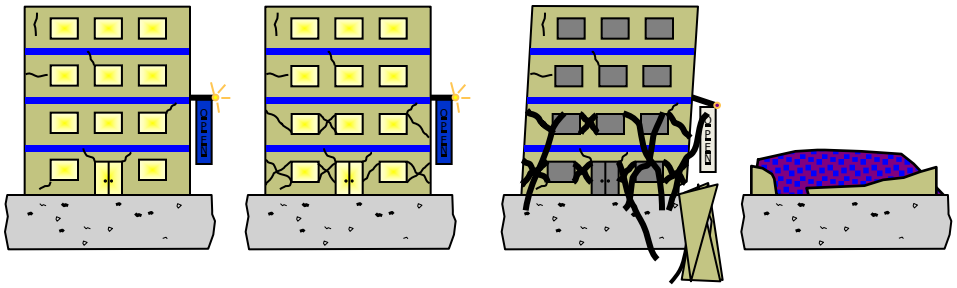
MAF of:

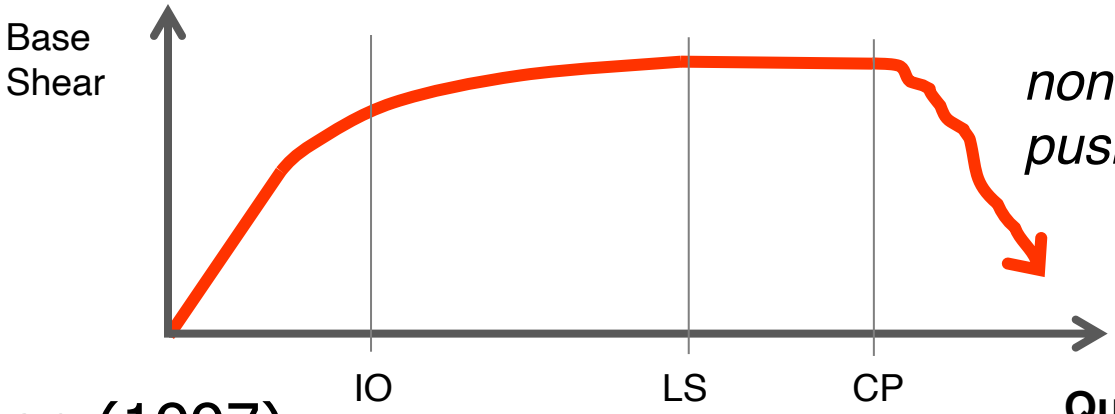
- *collapse*
- *loss > $*
- *downtime > t*

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

Impact | **Performance (Loss) Models and Simulation** | **Hazard**

Performance-Based Earthquake Engineering





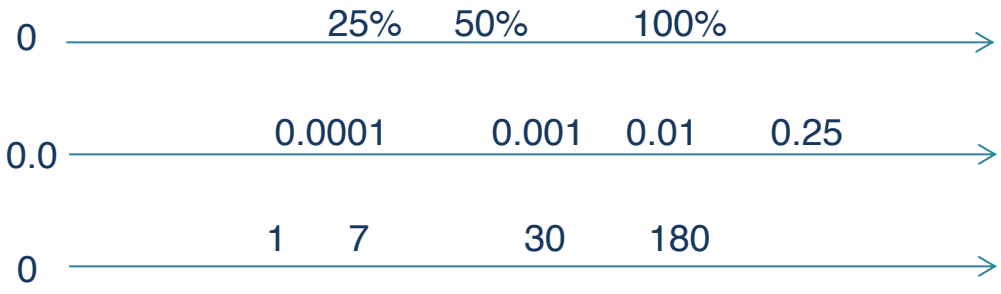
nonlinear static pushover analysis

Qualitative Targets (ASCE 41)

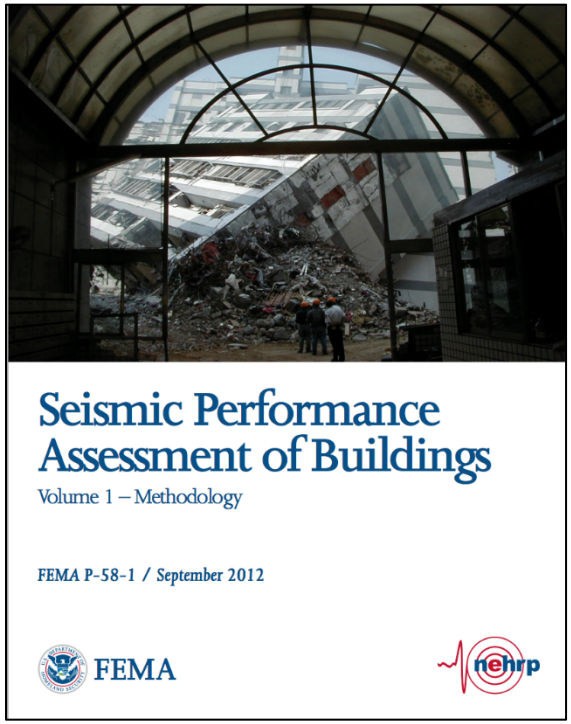
Explicit Measures (FEMA P-58)

1st-gen (1997)

Today



FEMA P-58 (2012) Performance Assessment of Buildings



Provides a methodology, basic building information, response quantities, fragilities and consequence data to evaluate the seismic performance of buildings

Procedures are probabilistic

Performance metrics:

- *life safety risks*
- *direct economic losses*
- *downtime and indirect losses*

Recommended Use –

- ✓ Evaluate performance of new and existing buildings
- ✓ Provide the basis for performance-based design of new buildings and retrofit of existing buildings

Component Performance Toolbox

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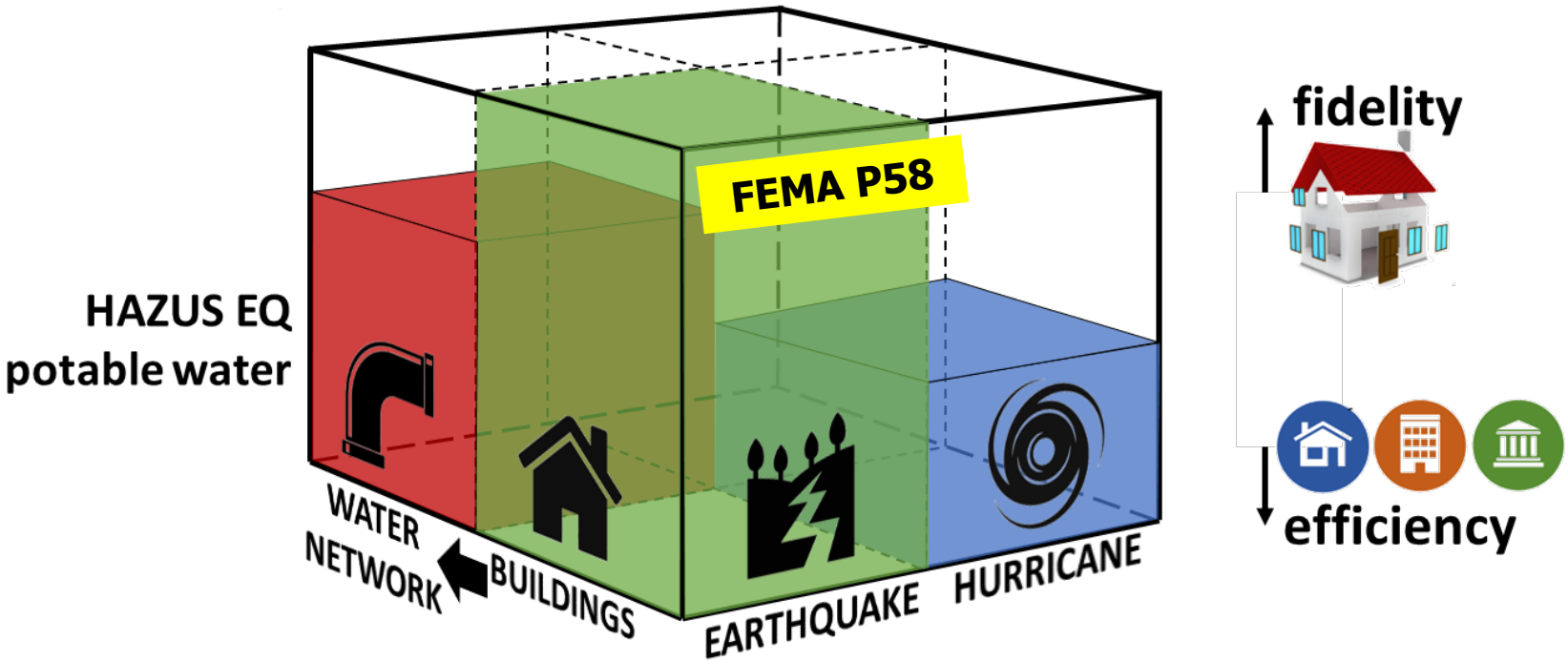
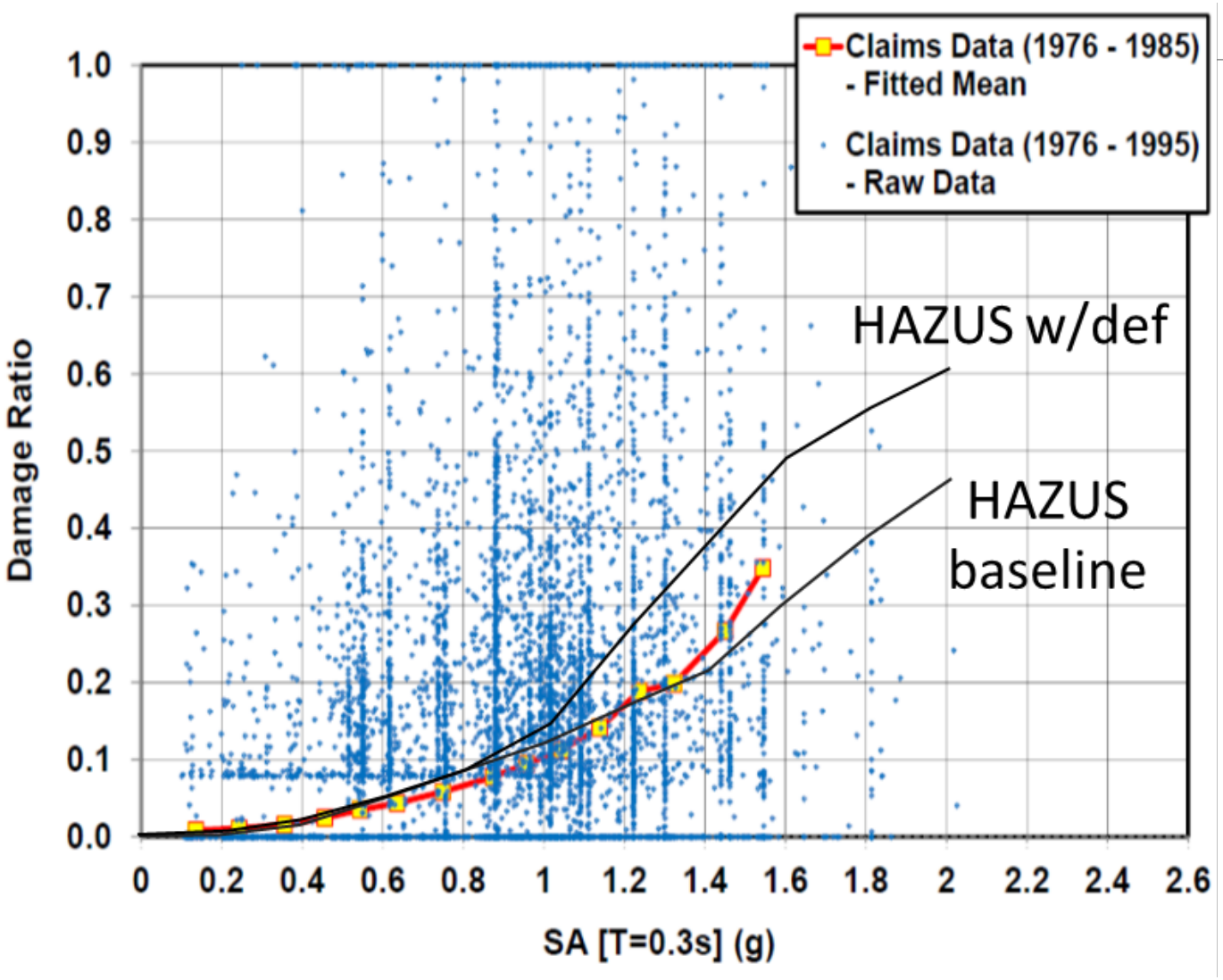


PELICUN *(**P**ROBABILISTIC **E**STIMATION OF **L**OSSES, **I**NJURIES, & **C**OMMUNITY RESILIENCE **U**NDER **N**ATURAL DISASTERS*

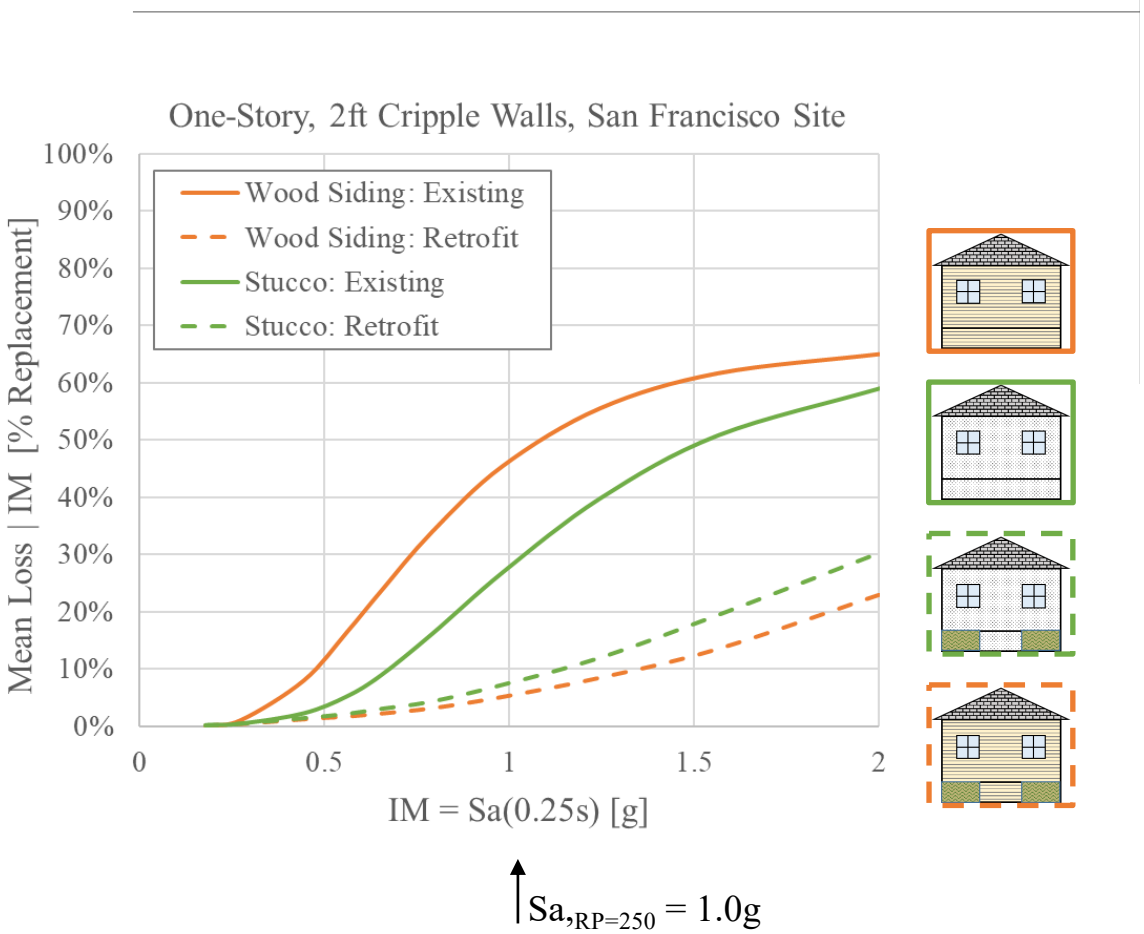
OpenSource :: Multi-Fidelity :: Multi-Hazard

Economic Benefits of Cripple Wall Retrofit

Limitations to "The Law of Averages"



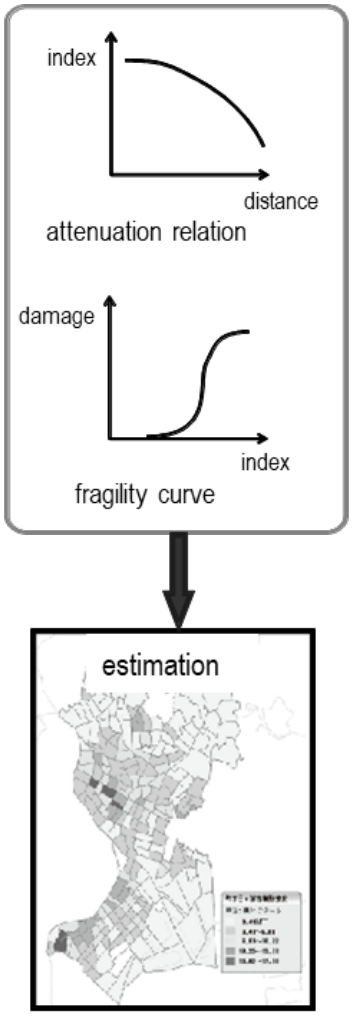
PEER-CEA Damage and Loss Assessment



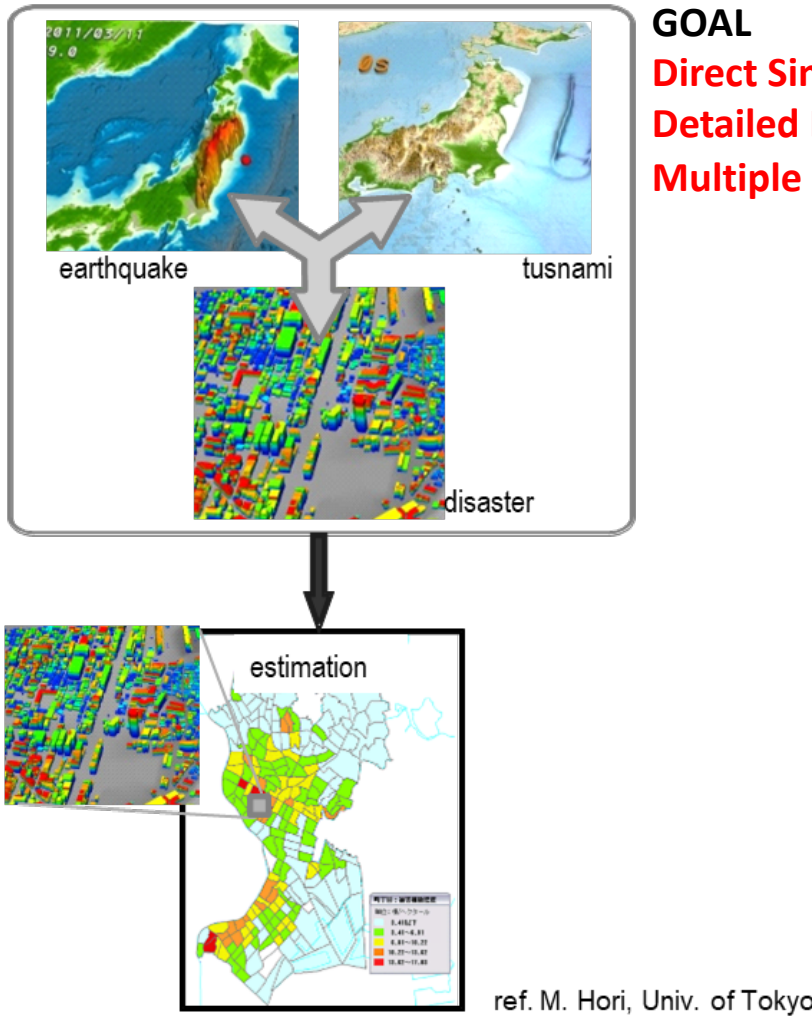
Loss versus Intensity (SF Site)

Simulation-Based Regional Risk/Resilience Assessment

CURRENT (e.g., HAZUS)
Empirical Models
Census Block Inventory



GOAL
Direct Simulation
Detailed Inventory
Multiple models



ref. M. Hori, Univ. of Tokyo

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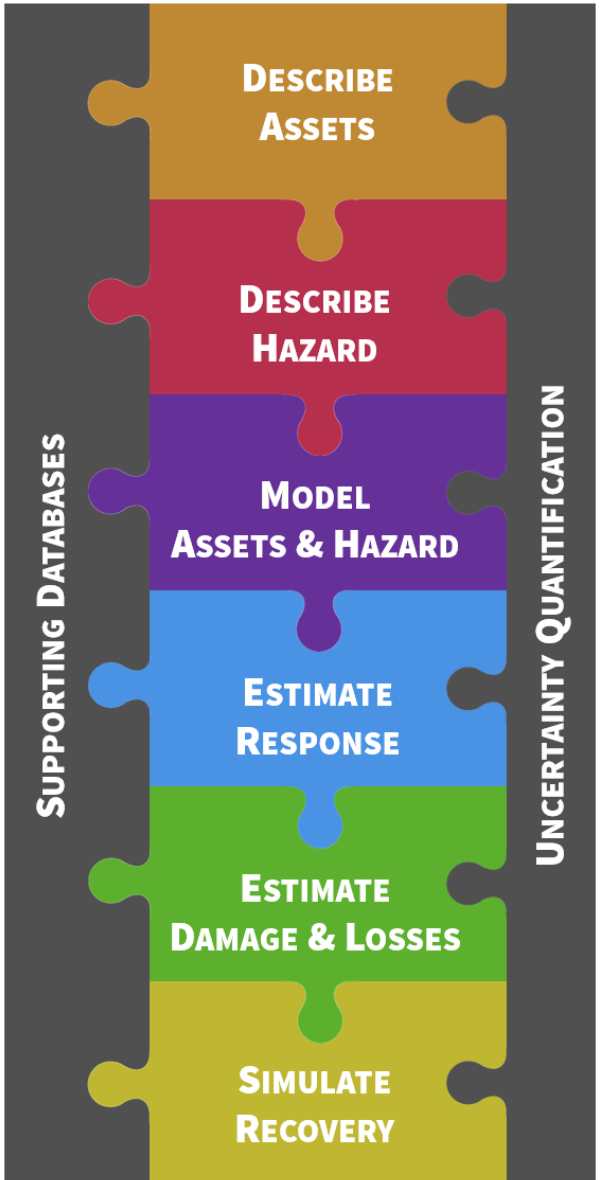

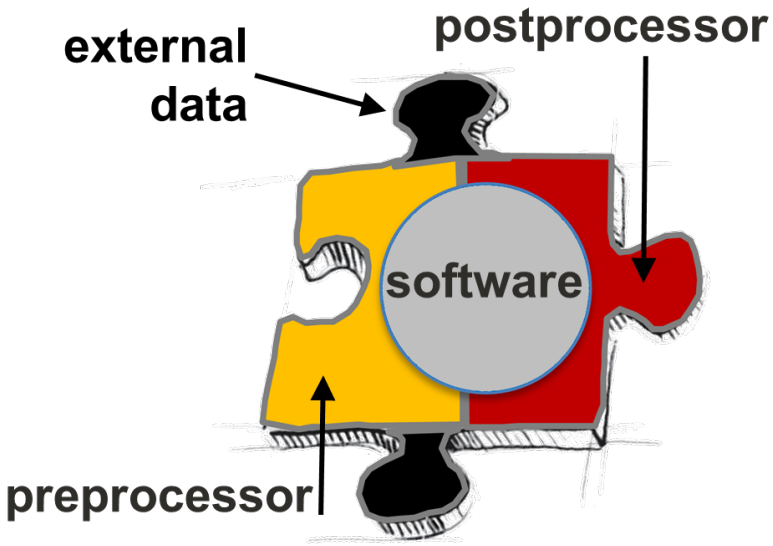

Application Framework (AF) is designed to assemble a **regional workflow** and streamline regional risk assessment.

State-of-the-art software is available for each task allowing researchers to tailor the workflow to their needs. **New software is easy to add.**

Workflows can run at DesignSafe using **HPC resources** at Texas Advanced Computing Center.

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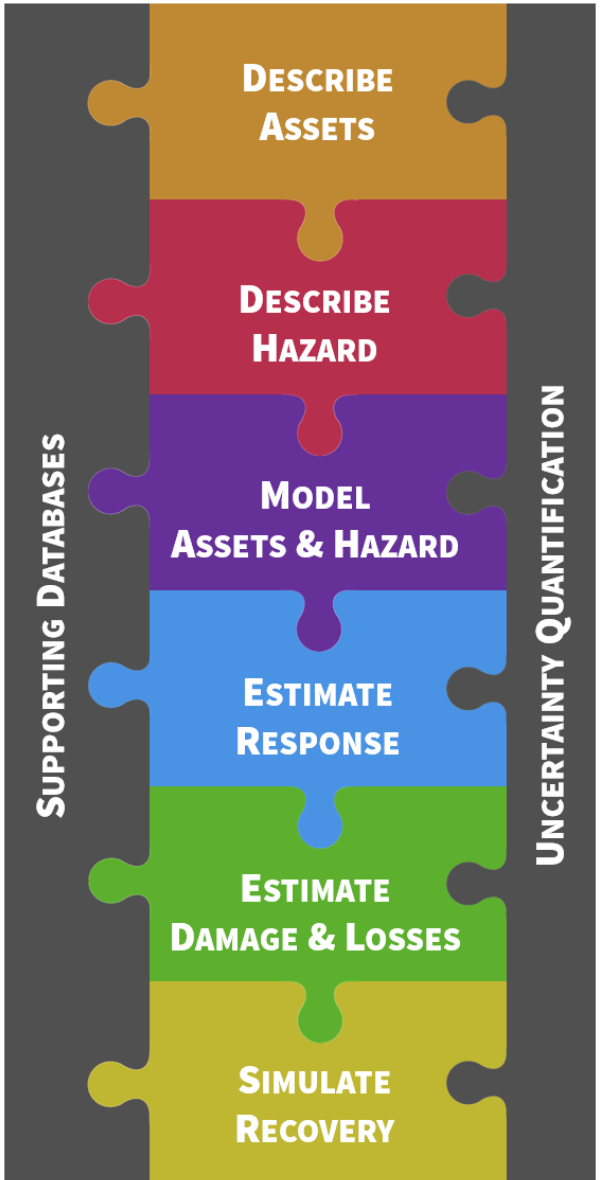

describe the region
specify characteristics of buildings and infrastructure in the region

describe the hazard
specify the regional distribution of ground shaking, wind, or water

for each random region-hazard sample:
propagate uncertain characteristics of the regional assets and the hazard

for each asset in the region:

describe the asset
create stochastic models for response, damage, and loss estimation

describe the event at the site
specify hazard-consistent loads for response estimation

for each random asset-event sample:
propagate uncertainties in asset models and event description

estimate asset response to the event
describe the response with engineering demand parameters

estimate asset damage and its consequences
prepare a stochastic description of damage and loss for the asset

describe regional damage and direct losses
aggregate damages and losses in the region considering dependencies

estimate indirect regional consequences
describe regional consequences of infrastructure- and social disruption

simulate regional recovery
estimate the temporal and spatial variation in the recovery of communities

AI tools

CWE UQ

EE UQ

UQ FEM

PBE

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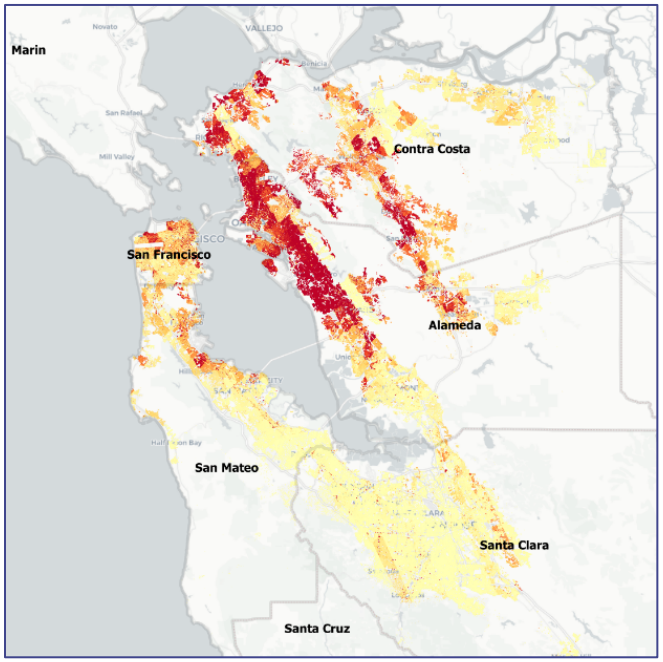
SF Bay Area Regional Testbed Study

- M7.0 Hayward rupture modeled using SW4 [1]
- 1.84 M buildings were included in the simulation
- Building information is based on UrbanSim data
- Damage and Loss is based FEMA_P58_LU [2]
- OpenSees structural analysis models are based on MDOF_LU
- Run on DesignSafe HPC Resources
- Example of Results:
  - *Red-tagged buildings 141,400*
  - *Net buildings damage ratio 5.6%*



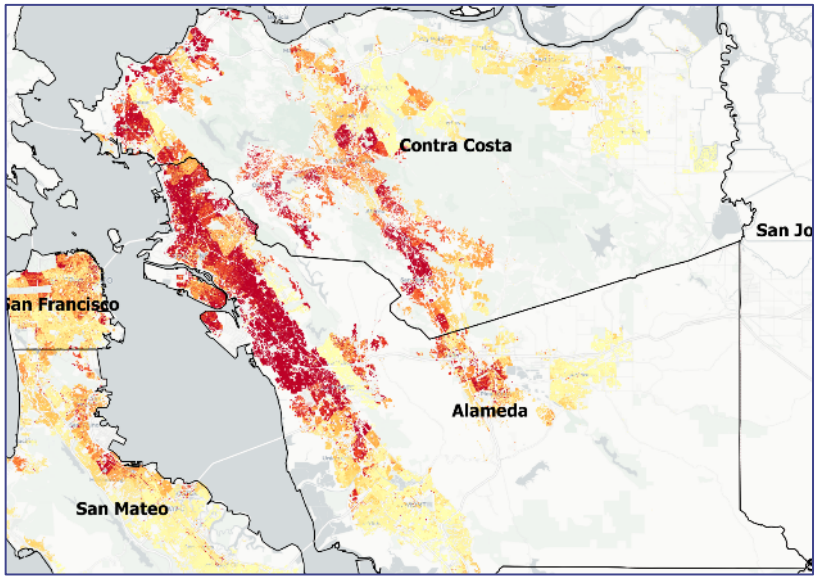
Building Loss Ratio

[1] Petersson, N.A.; Sjogreen, B. (2017), SW4, version 2.0 [software], Computational Infrastructure of Geodynamics, doi: 10.5281/zenodo.1045297, url: https://doi.org/10.5281/zenodo.1045297

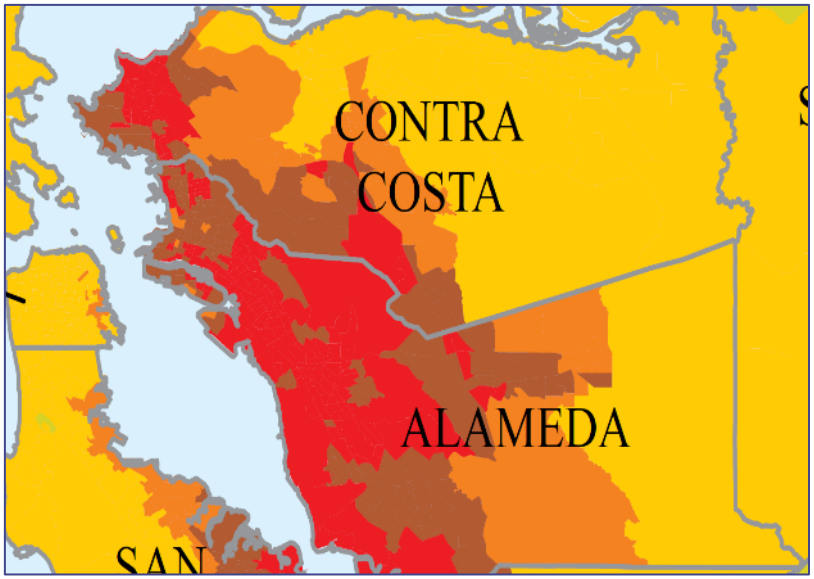
[2] Zeng X., Lu X.Z., Yang T., Xu Z., "Application of the FEMA-P58 methodology for regional earthquake loss prediction", Natural Hazards (2016), 10.1007/s11069-016-2307-z

High Resolution Models

Building parcel versus census block resolution of damage and downtime



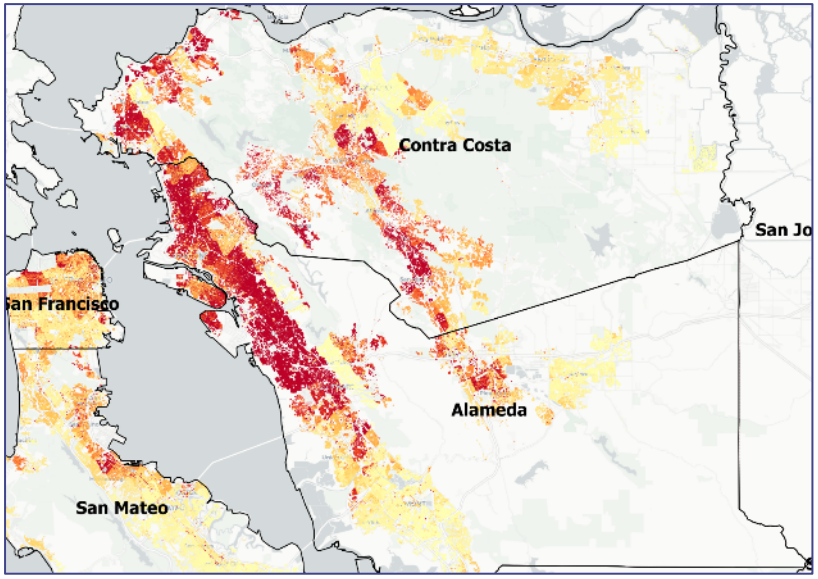
SimCenter Simulation



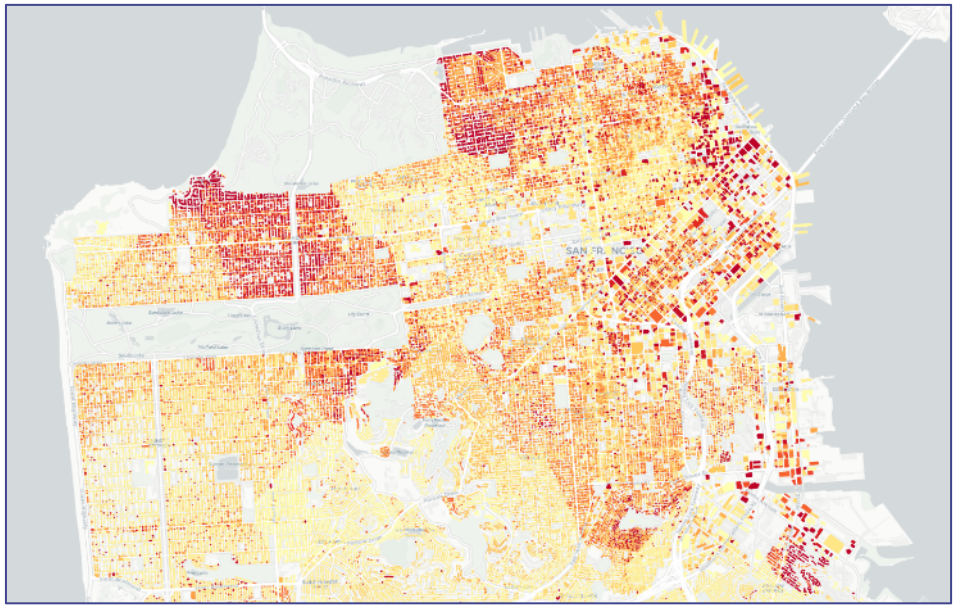
USGS Haywired (2018)

High Resolution Models

Parcel-level resolution enables unprecedented quantification of engineered interventions for policy level decisions



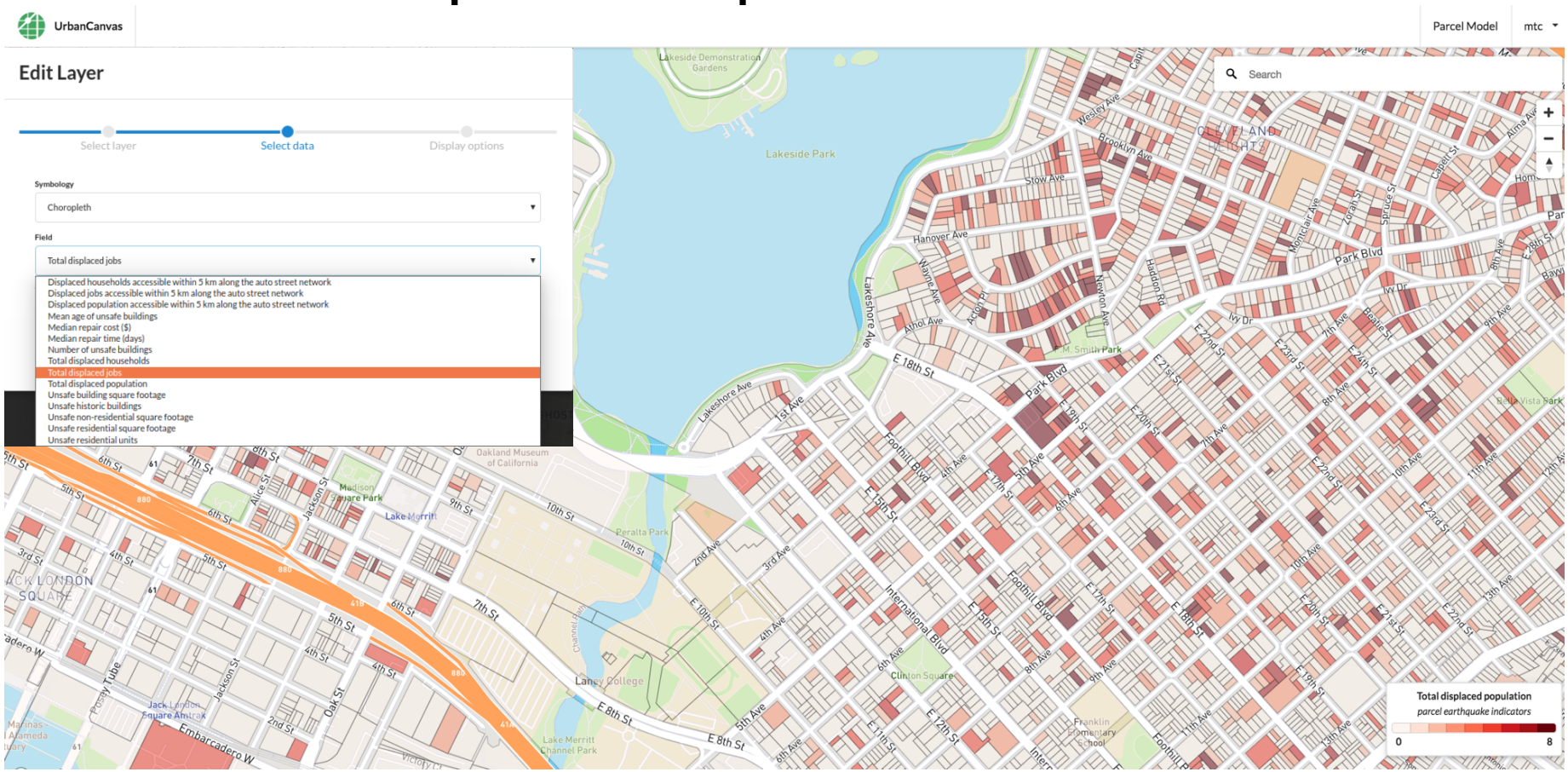
SimCenter Simulation



San Francisco Parcels

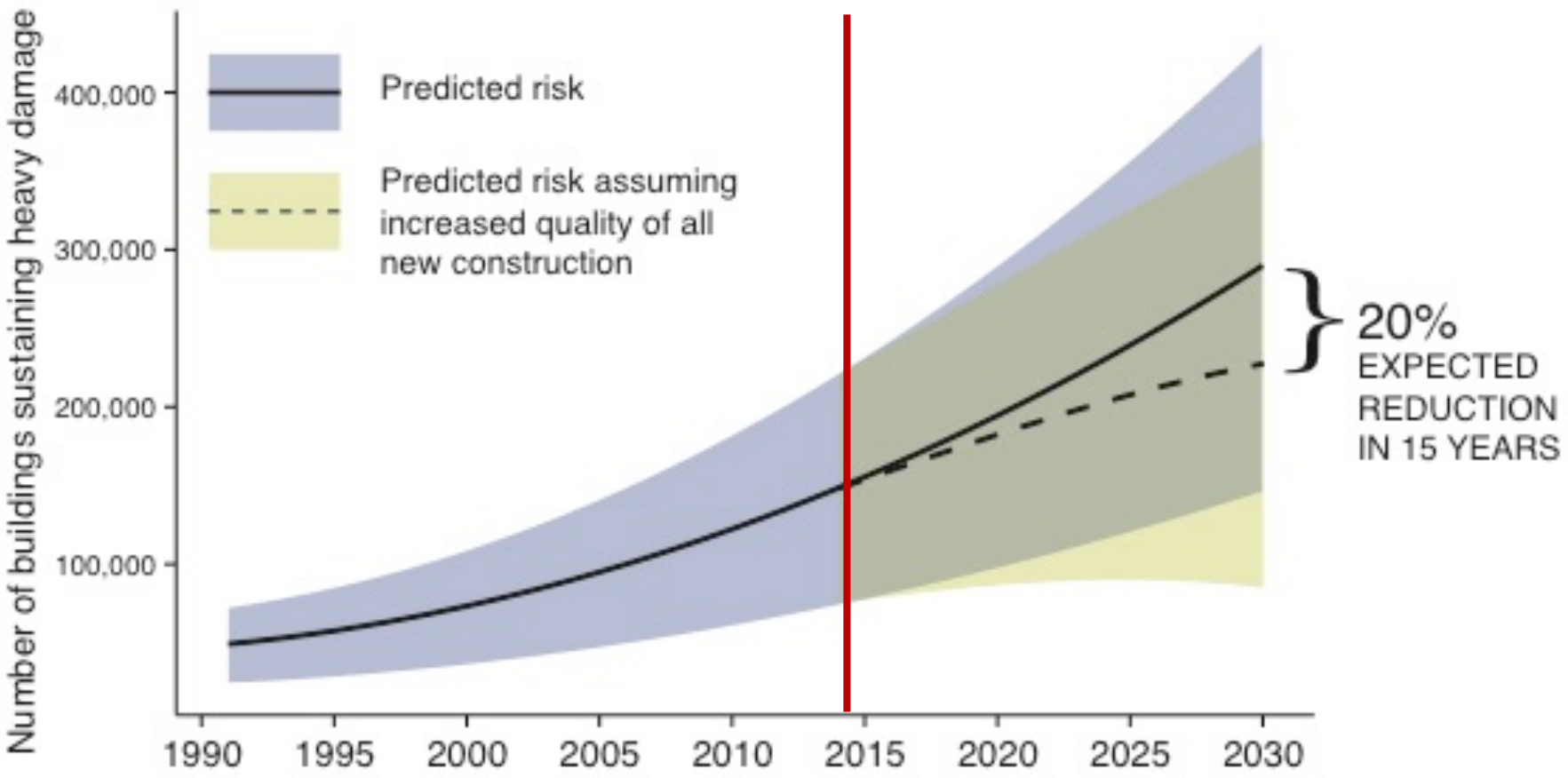
Opportunities to evaluate planning and policy decisions (retrofit, land use, recovery planning, etc.)

UrbanSim Output - Sample Results



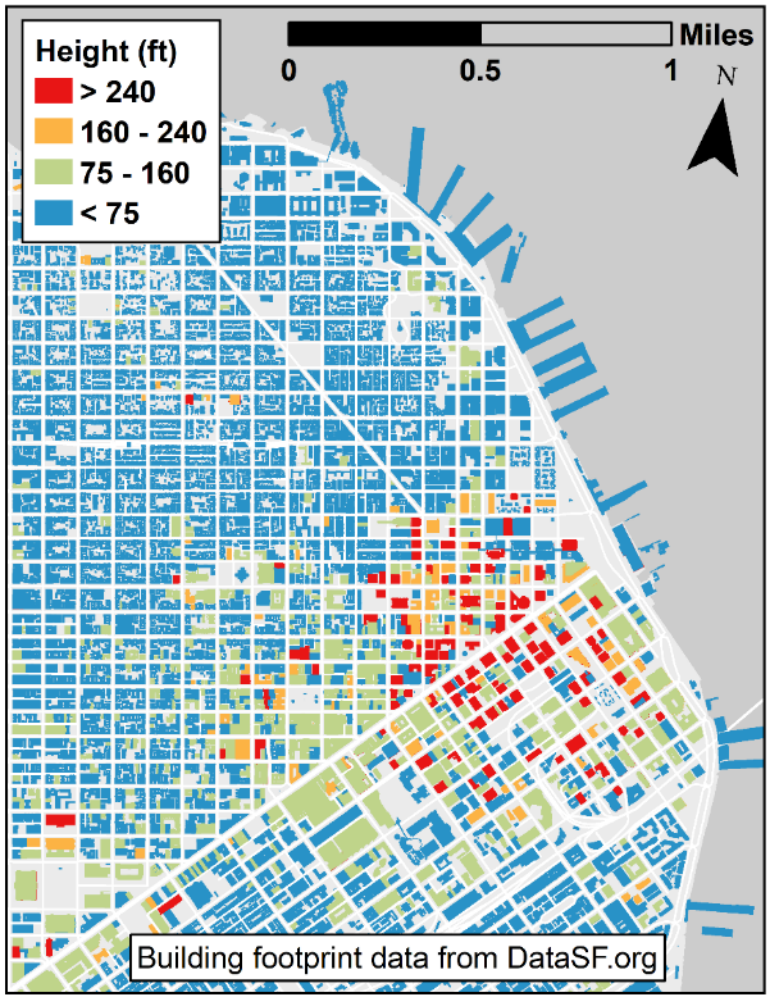
Displaced Population in Residential Construction (person/parcel; Oakland, Lake Merritt Area)

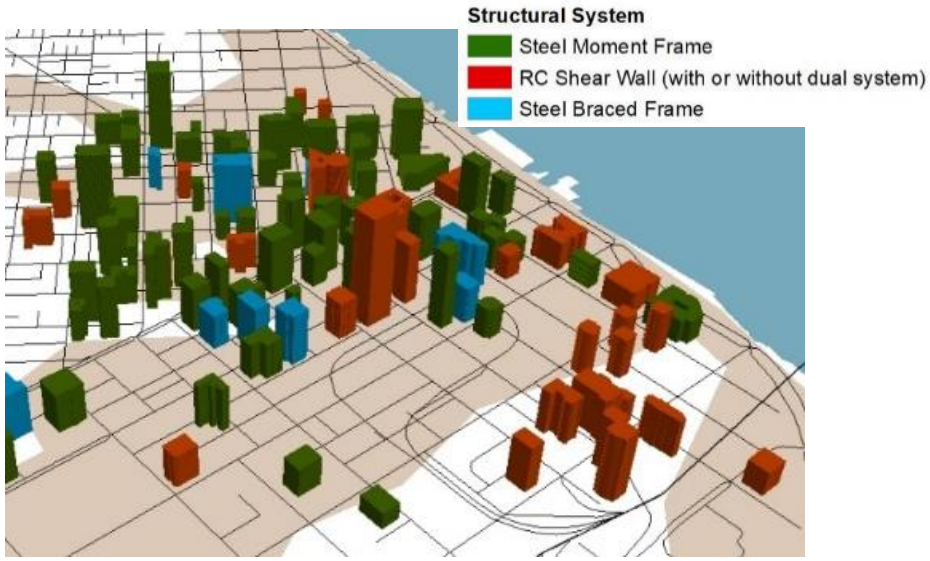
Urban Growth & Evolving Risk



D. Lallemant, 2015

San Francisco – Tall Building Inventory





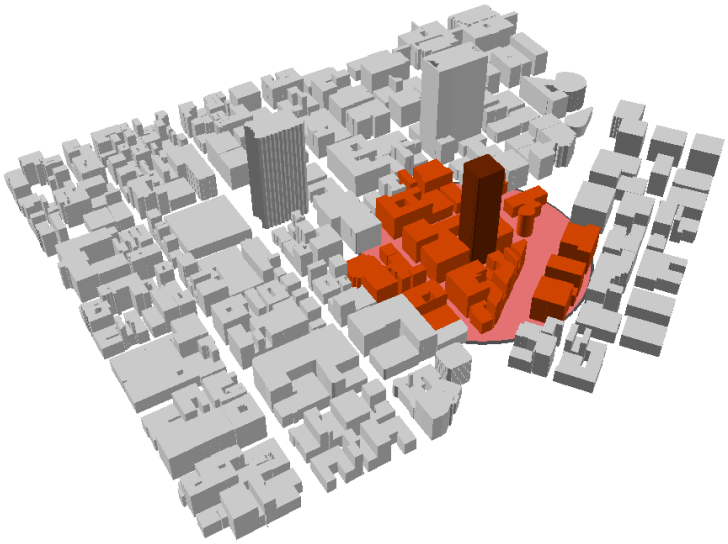
156 Tall Buildings (Over 240 ft)

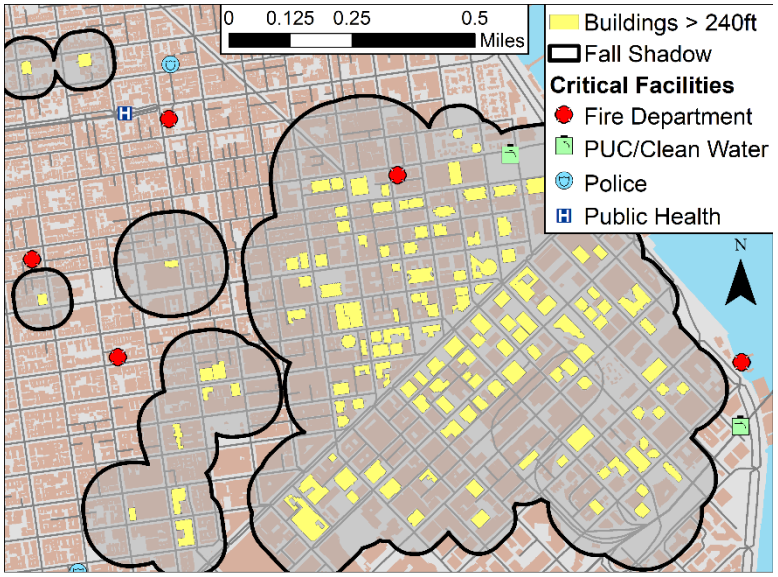
- Occupancy
- Height & Date/Age
- Structural System & Materials
- Façade, Foundation
- BORP, Instrumentation

Impediment of Building Cordons on Recovery

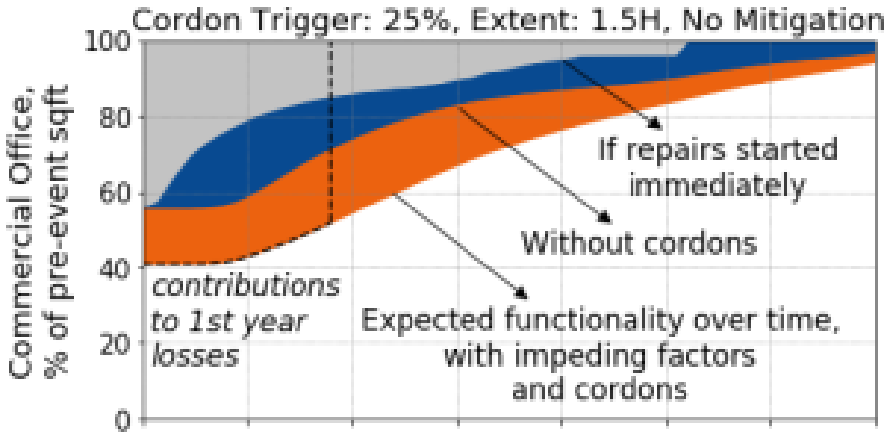
Impact on:

- Emergency Response
- Neighboring Buildings
- Recovery/Reconstruction
- Downtown Economy

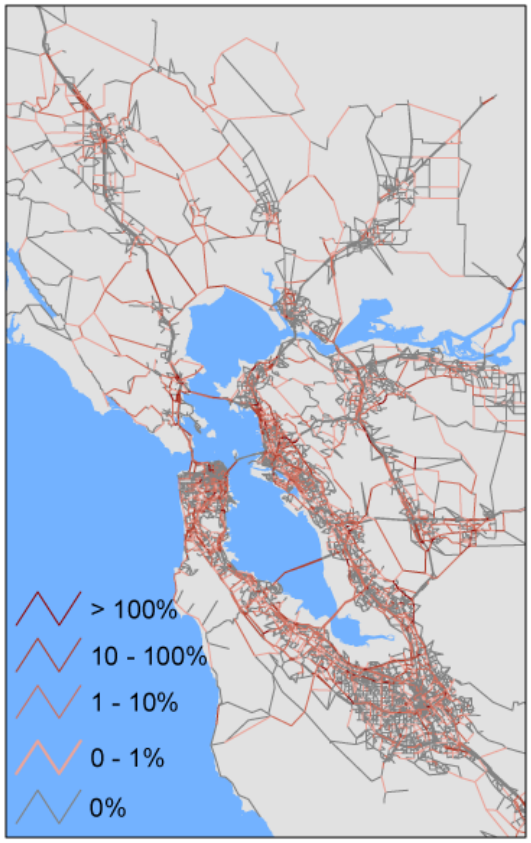


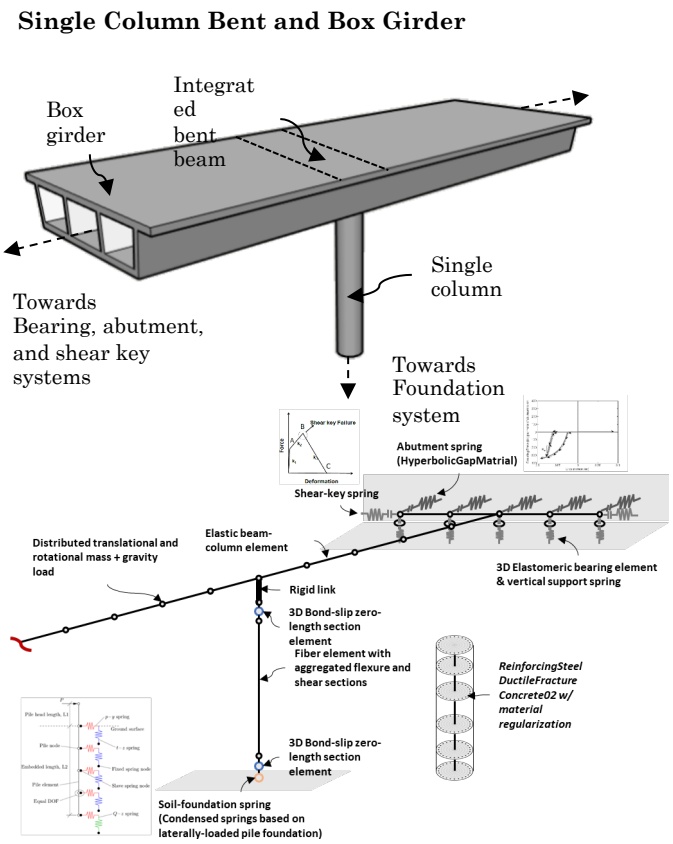


Data Sources: Critical Facilities, Building Footprints, and Streets from DataSF.org



Distributed Transportation Systems



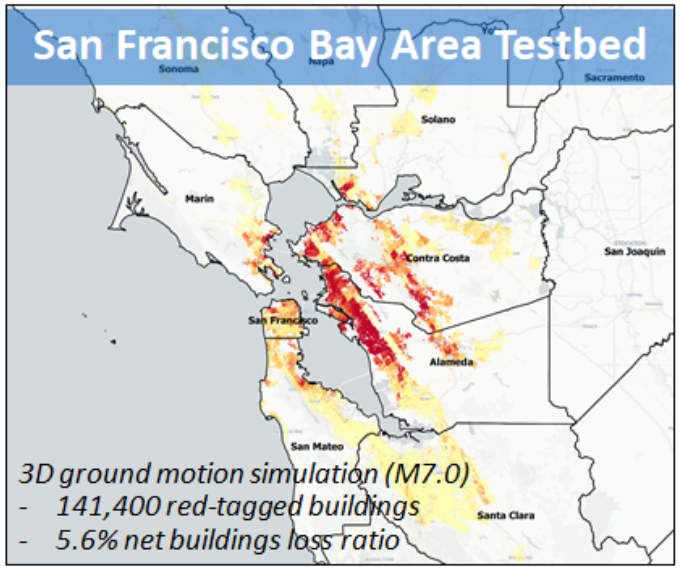


Detailed Component Models Linked with Rigorous System Evaluation

1. Risk Landscape
2. Hazards
   - Ground Shaking
   - Liquefaction
   - Landslides
   - Tsunami
   - Flooding
   - Fire
3. Risk/Consequence
4. Capabilities
5. Strategy

Regional Simulation Testbeds

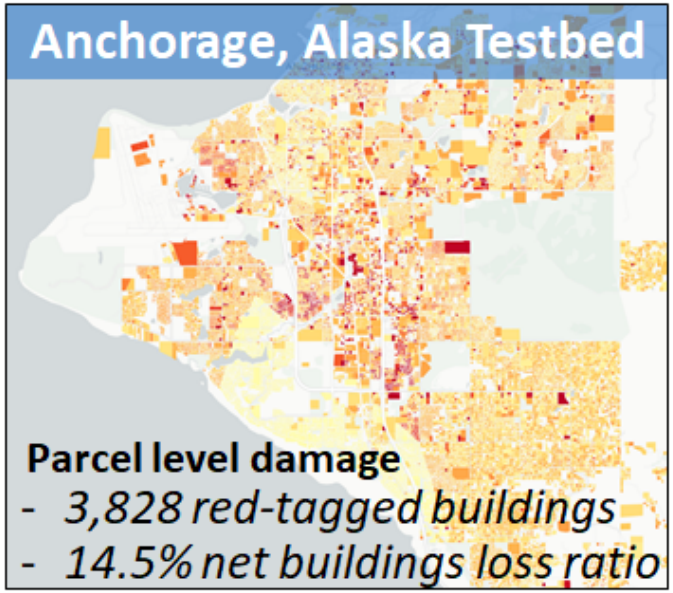
San Francisco Bay Area Testbed



3D ground motion simulation (M7.0)
- *141,400 red-tagged buildings*
- *5.6% net buildings loss ratio*

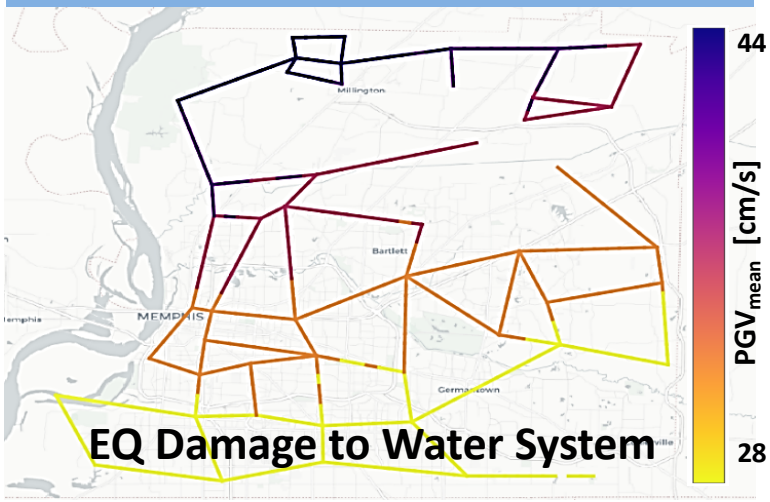
Atlantic City, NJ Storm Testbed

Anchorage, Alaska Testbed



Parcel level damage
- *3,828 red-tagged buildings*
- *14.5% net buildings loss ratio*

Memphis, TN Lifelines Testbed

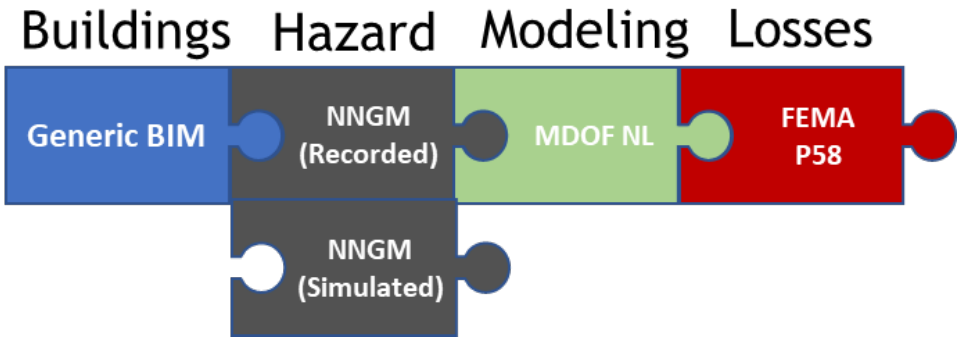


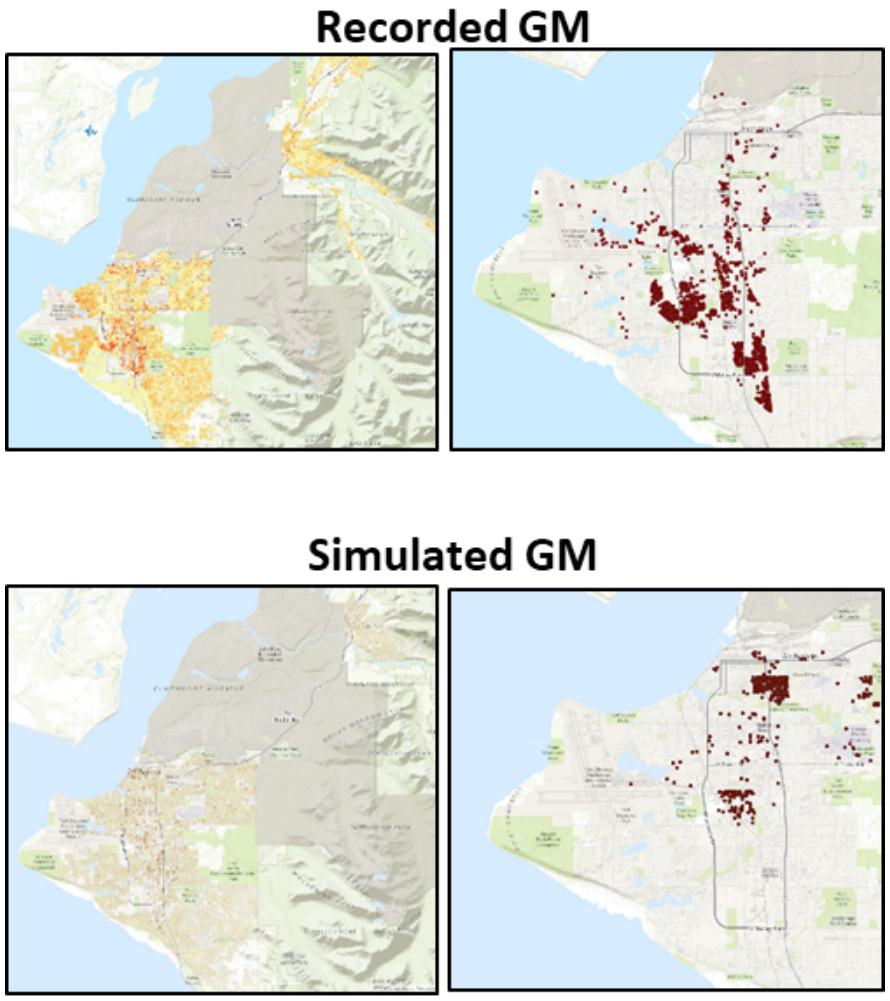
EQ Damage to Water System

Regional Simulation – Anchorage Example

Estimated Losses

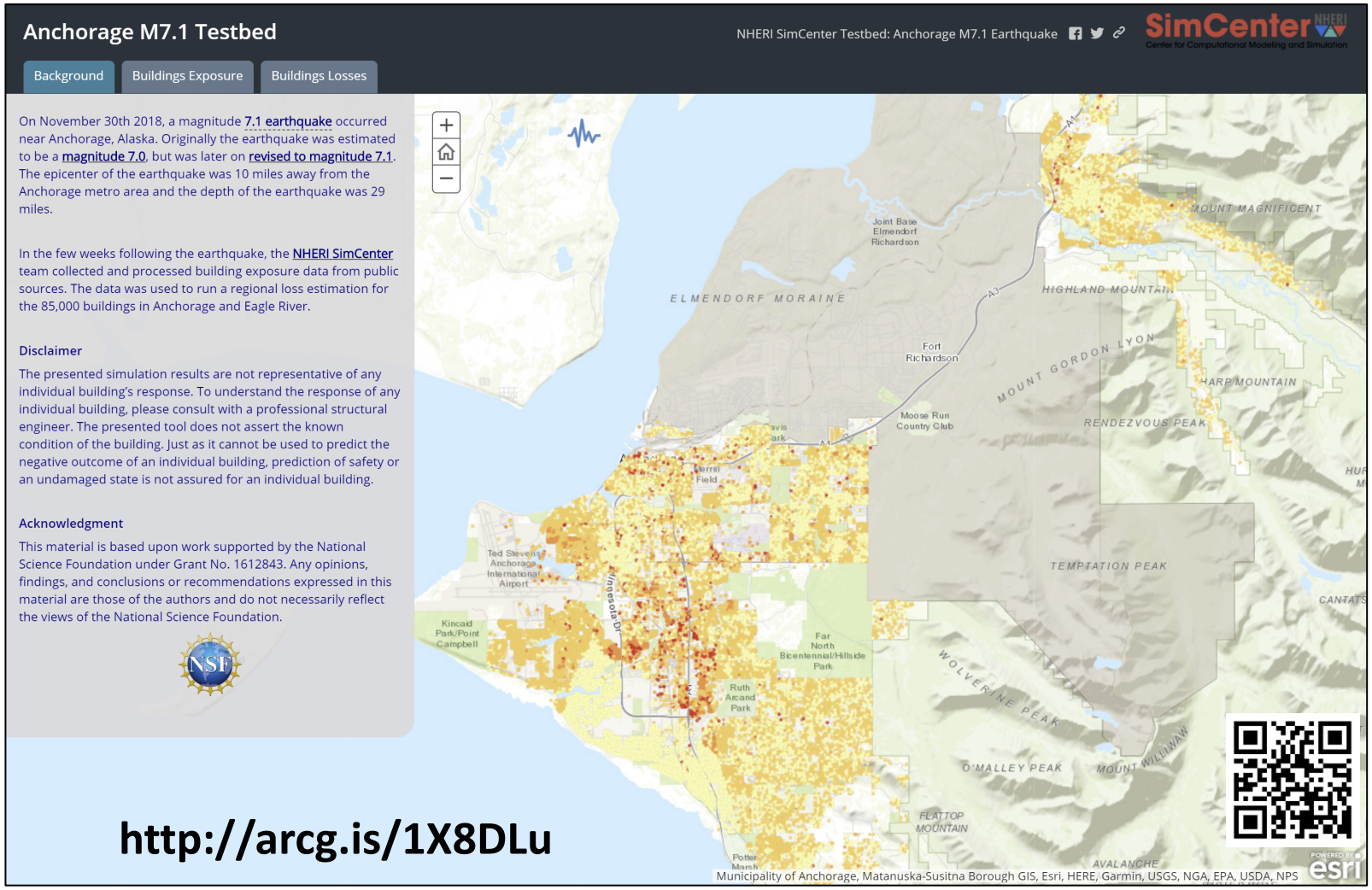
	Recorded GM	Simulated GM
Repair Cost [$Billion]	7.5	7.3
Red Tags	3800	626
Loss Ratio [%]	14.5	12.5



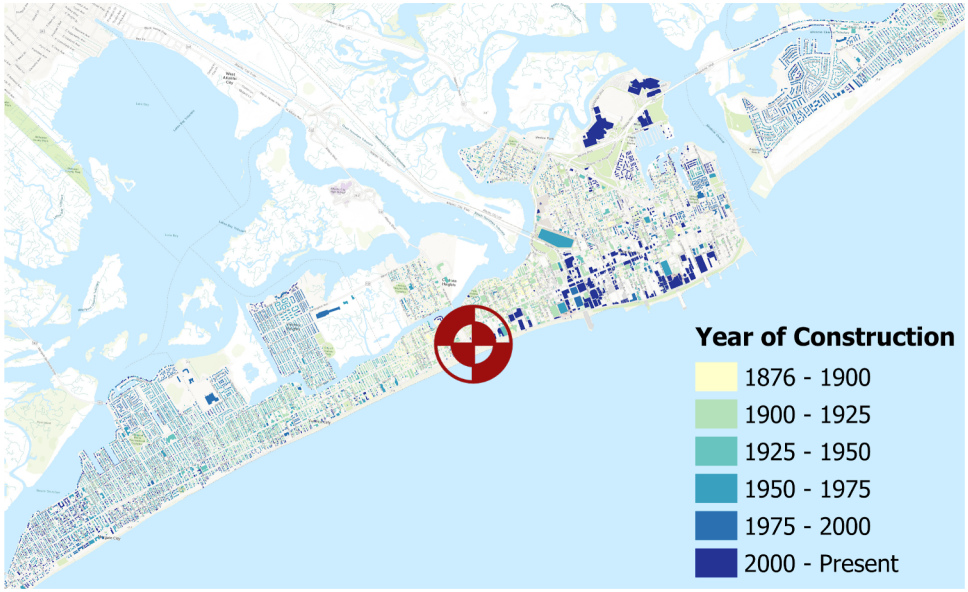


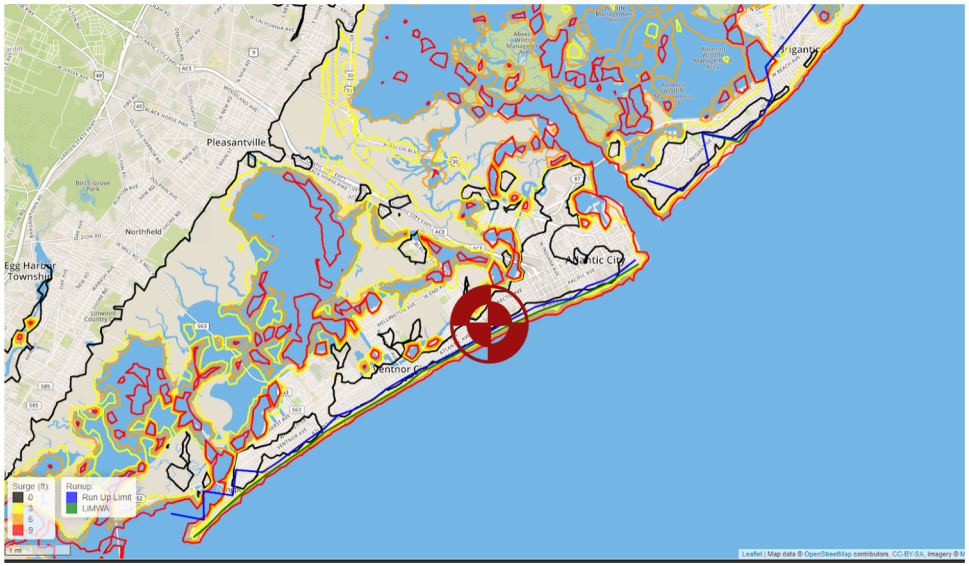
Regional Simulation: Anchorage Story Map

- Documents the input data, results and process

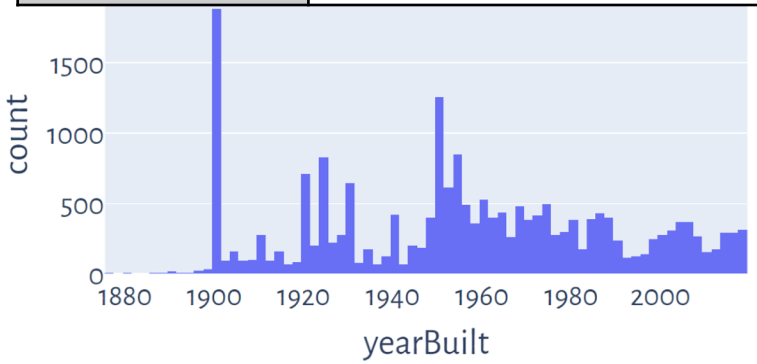


Atlantic City Hurricane Testbed





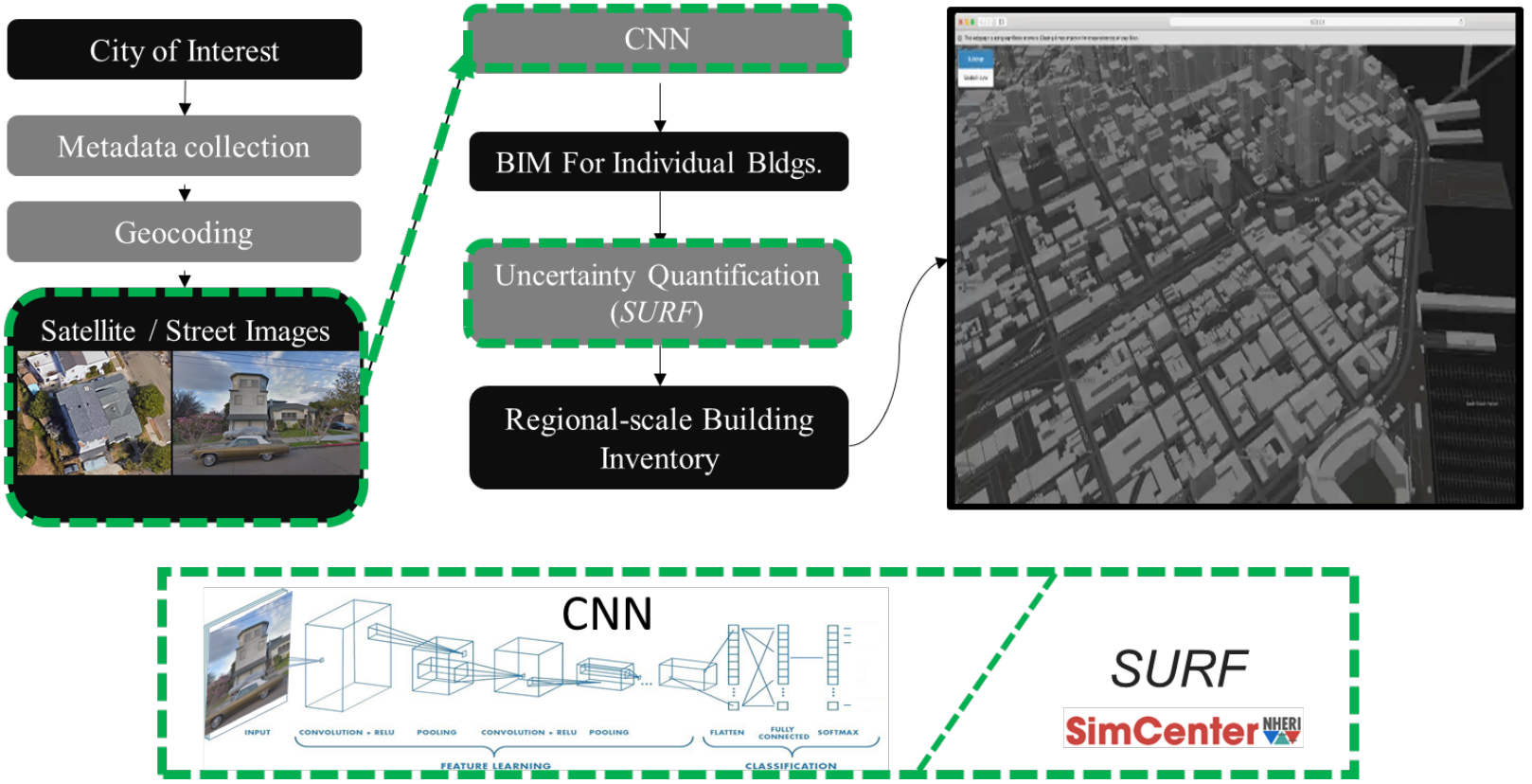
N parcels	20,654
Occupancies	Single & multi-family residential, commercial and industrial
Typologies	Wood, steel, masonry, RC, metal buildings



Intensity	Cat 5 (Surrogate Model)
RoM	15.4 to 98 miles
Cp differential	75 to 100 mbar

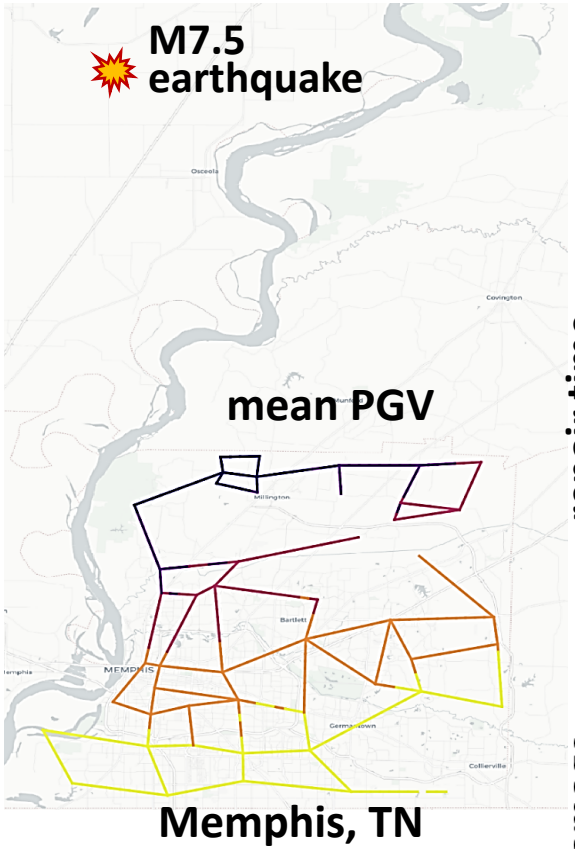
AI Tools for Building Feature Identification

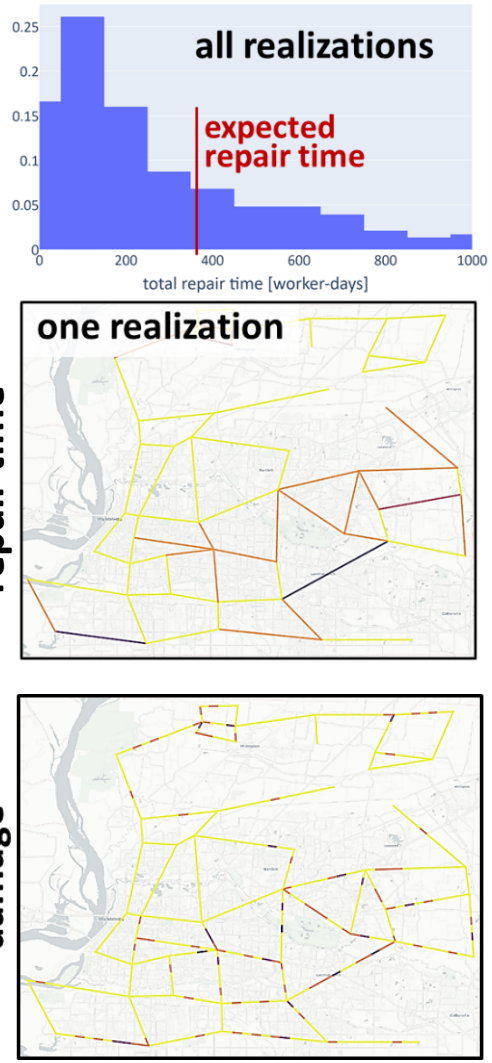
Building Feature Identification using AI-enabled Evaluation of Images



Regional Simulation: Memphis Water System

- **pelicun** to estimate pipe damage and pipe repair times
- **rWHALE** to estimate ground PGV (using OpenSHA) and to integrate with pelcun to calcuate pipe damage, pipe repair times
- scenario assessments with multiple realizations preserve spatial correlation in ground motions, damage, repairs
- high resolution damage and loss estimates
- support Bayesian approach for model updating and simulation of network interdependencies





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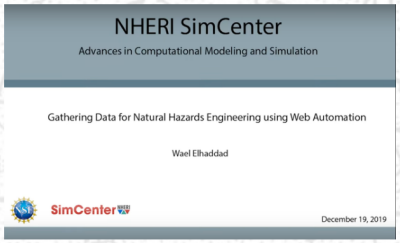
- Overview
- quoFEM Application
- CWE Application
- WE-UQ Application
- Turbulence Inflow Tool
- EE-UQ Application
- PBE Application
- Regional Workflow for Hazard And Loss Estimation (rWHALE)
- BIMtoSAM.AI
- SURF
- BRAILS

The SimCenter p **nulation**
software tools, u **hazards**
engineering resea **pability**
to simulate the im **unities.**

Upcoming Events

- **SimCenter Workshop: Simulation and Data Needs to Support Disaster Recovery Planning**
  - **January 30-31, 2020 at UC Berkeley**
- **Workshop: Artificial Intelligence on Natural Hazards Engineering**
  - **February 18-19, 2020, Texas Advanced Computing Center, University of Texas at Austin**

Recent News (News Archive)



NEW SimCenter Webinar: **Gathering Data for Natural Hazards Engineering Using Web Automation**
Presenter: Wael Elhaddad

The NHERI REU Summer Program provides research opportunities at the ten NHERI multi-hazard engineering sites during a 10-week summer research program. Applications for the 2020 NHERI REU Summer Program will close **February 1, 2020 at 11:59pm Central**.