SimCenter NHERI
Center for Computational Modeling and Simulation

Simulated Motion Applications with SimCenter R2D for Regional Damage

Frank McKenna

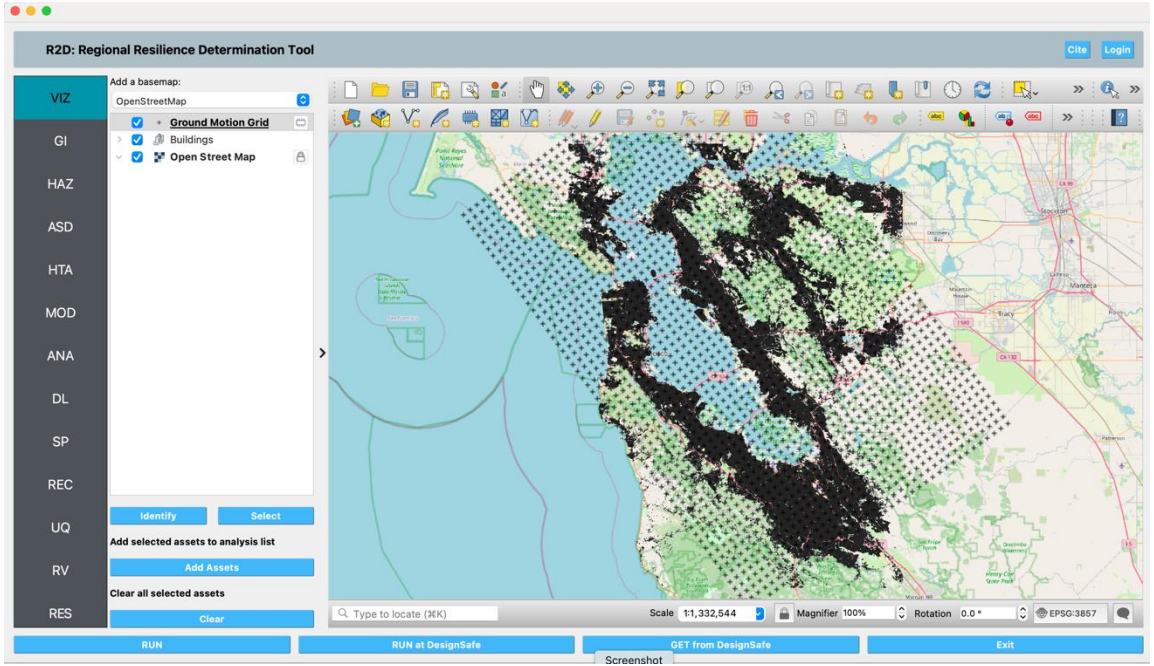
(slides from: **Greg Deierlein, Adam Zsarnóczay, Barbaros Cetiner, Sang-ri Yi, Pedro Arduino, Amin Pakzad Jinyan Zhao, Sina Naemi,** Nikola Blagojevic)

NHERI SimCenter

UC Berkeley

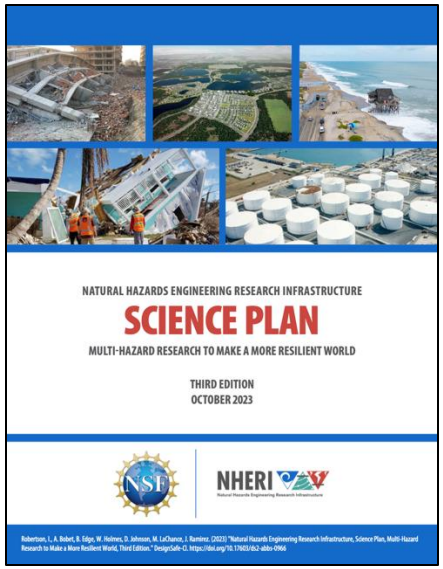
Outline

- SimCenter
- BRAILS++
- R2D
- Bay Area Testbed



NSF NHERI: National Hazards Engineering Research Infrastructure

"NHERI is a nationwide, shared-use network of facilities. It provides the natural hazards research community with state-of-the-art research infrastructure", source: NSF



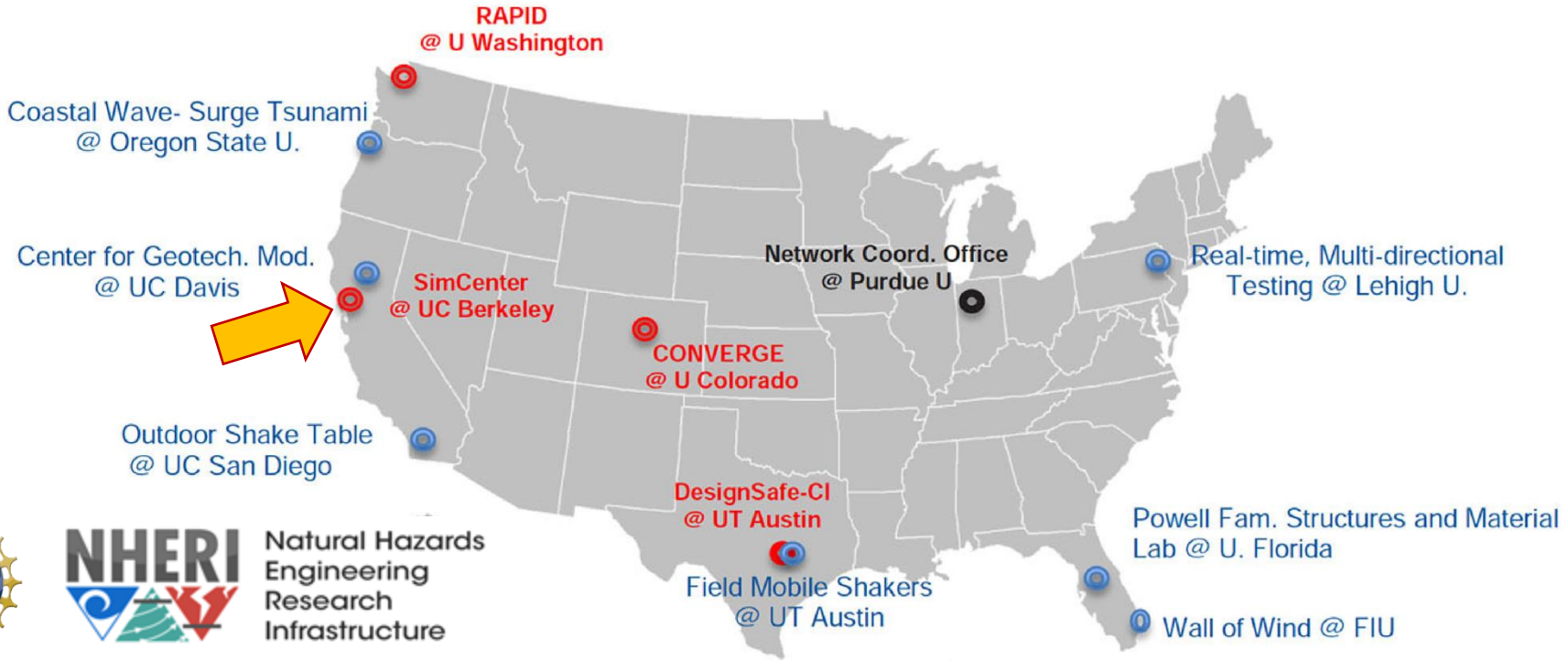
Three Grand Challenges:

1. **Quantify the damaging characteristics of earthquakes, windstorms**, and associated hazards—tsunamis, storm surge, and waves
2. **Assess** the and the **physical vulnerability of civil infrastructure** and the **social vulnerability of communities**
3. **Develop technologies and engineering tools** to design, construct, retrofit, and operate resilient and sustainable infrastructure

NSF NHERI SimCenter

A Distributed Collection of Facilities

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



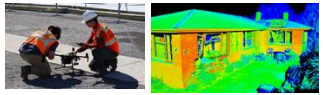
NSF NHERI Natural Hazards Engineering Research Infrastructure

NSF NHERI SimCenter

Working Together

NCO

7 Experimental facilities



2 Recon facilities

DESIGNSAFE-CI
A NATURAL HAZARDS ENGINEERING COMMUNITY

Data Storage

High-Performance Computing

Tapis (TACC web API)

SimCenter NHERI
Center for Computational Modeling and Simulation

Cloud-enabled research applications
Scalable to run on HPC with emphasis on UQ

SimCenter Tools & Resources

EE-UQ
WE-UQ
PBE
QUO FEM
Hydro UQ
R2D

Researchers
Industry
Government Agencies

NSF NHERI SimCenter

SimCenter Vision (2016-present)

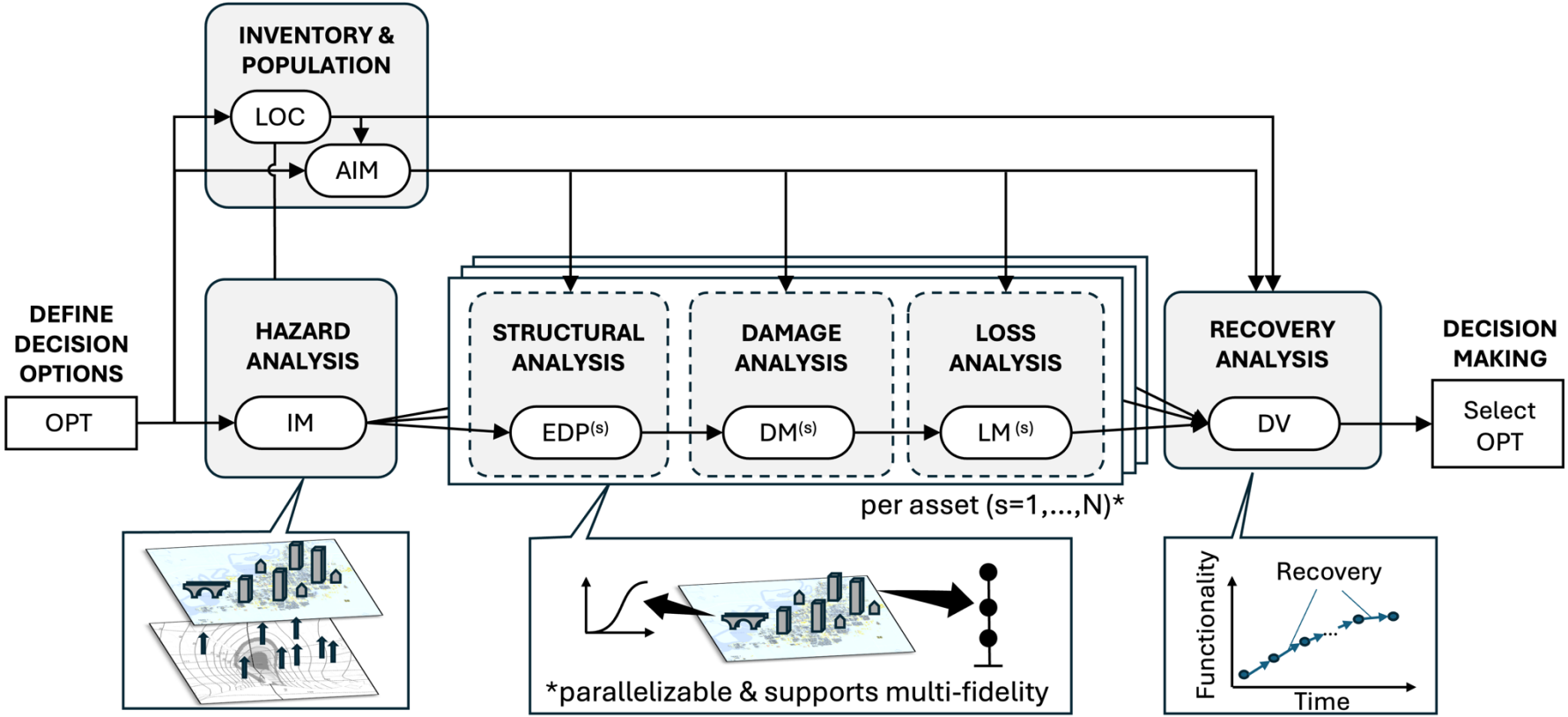
To transform the nation's ability to understand and mitigate adverse effects of natural hazards on the built environment **through a computational simulation framework**

"Grounded in the present
Five years focus
Twenty years vision"

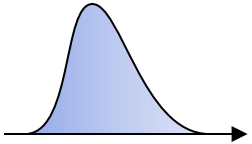
Steve Mahin, *founding PI and Director*

NSF NHERI SimCenter

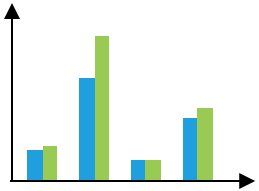
Components of Computational Framework



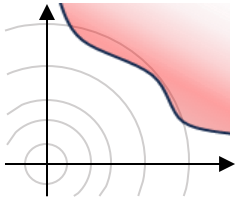
Add in Components to Framework for Uncertainty



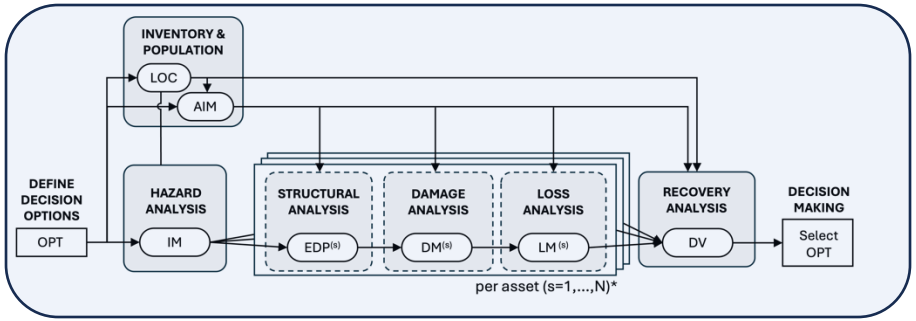
Forward propagation

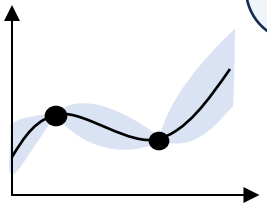


Sensitivity analysis

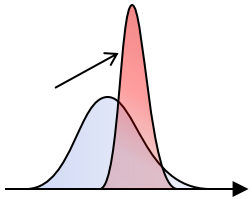


Reliability analysis

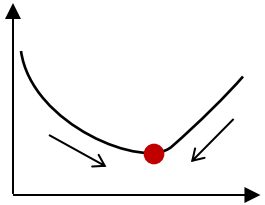




Surrogate modeling

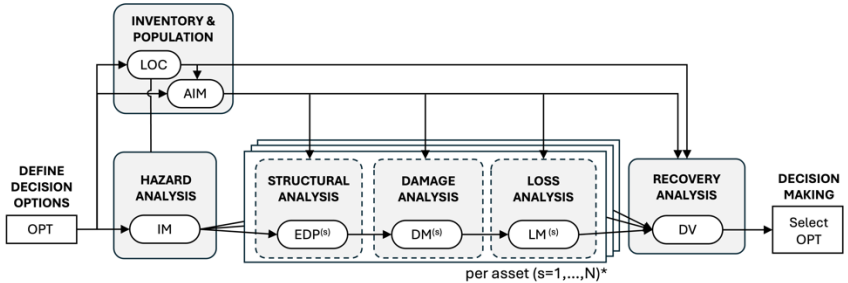


Bayesian calibration



Deterministic calibration

Enabling Different Workflows



provide **Software to allow multiple workflows**

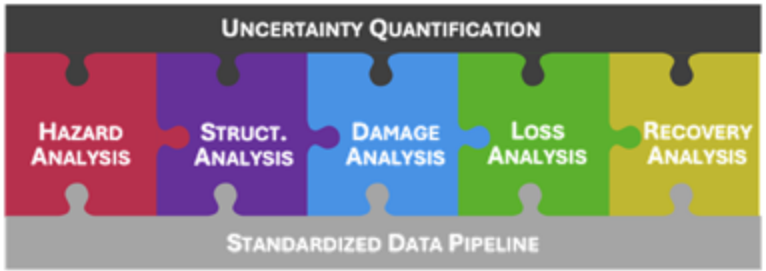
Frontend with Graphical User Interface (GUI)

User inputs → Input

Visualization ← Output

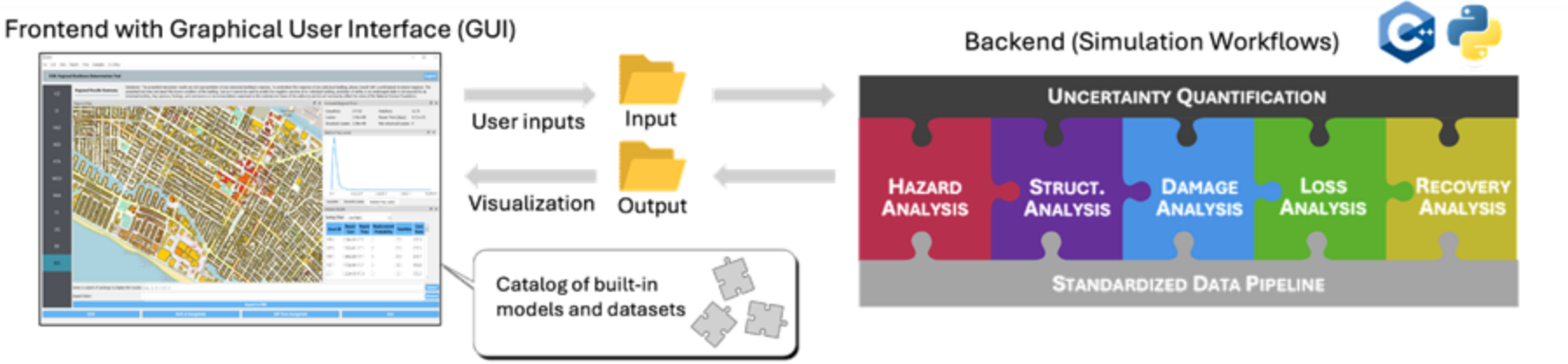
Catalog of built-in models and datasets

Backend (Simulation Workflows)



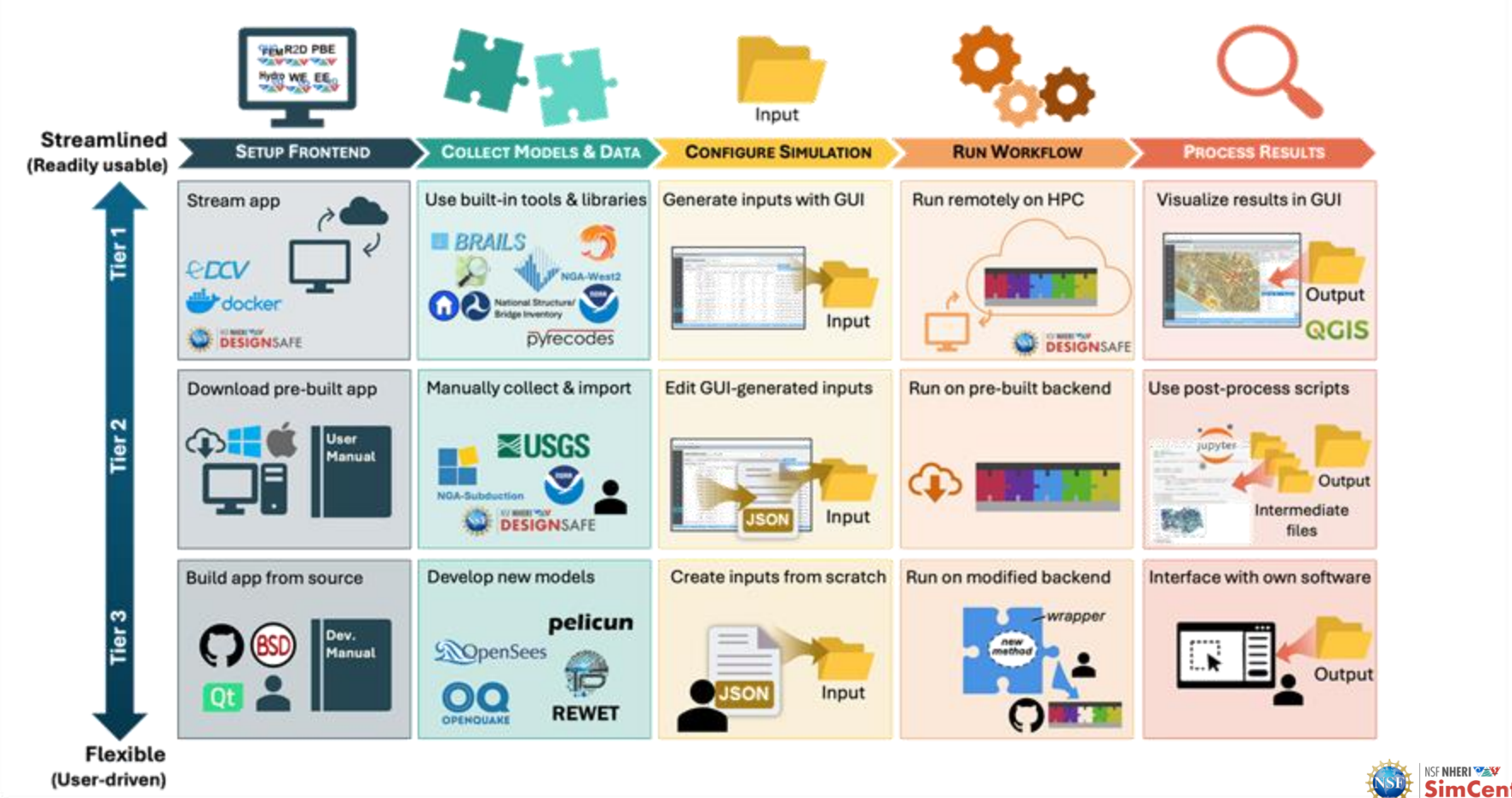
NSF NHERI SimCenter

Modular Simulation Platform

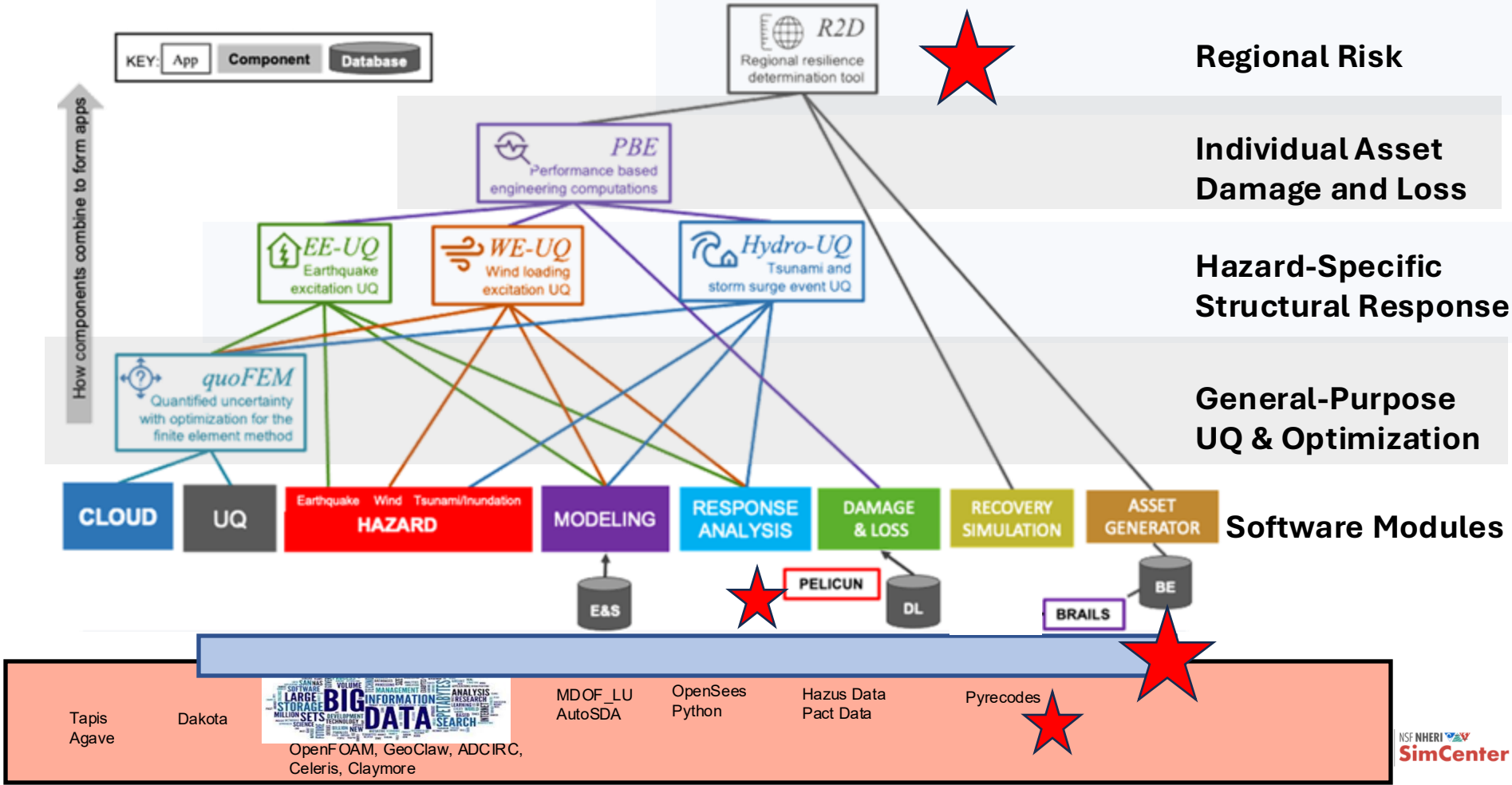


NSF NHERI SimCenter

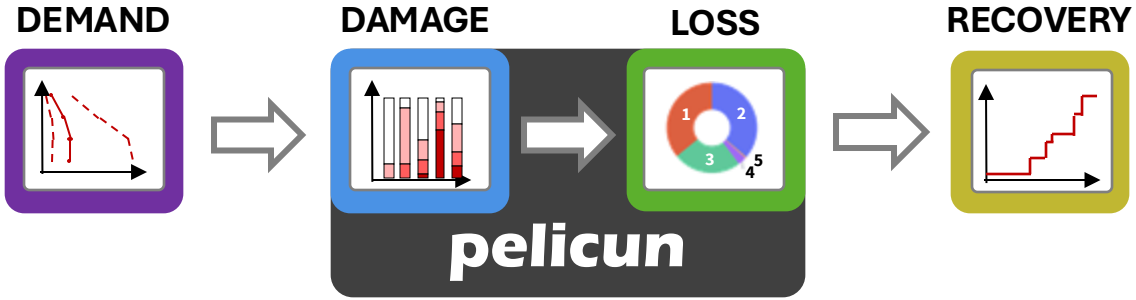
Address Different User Levels

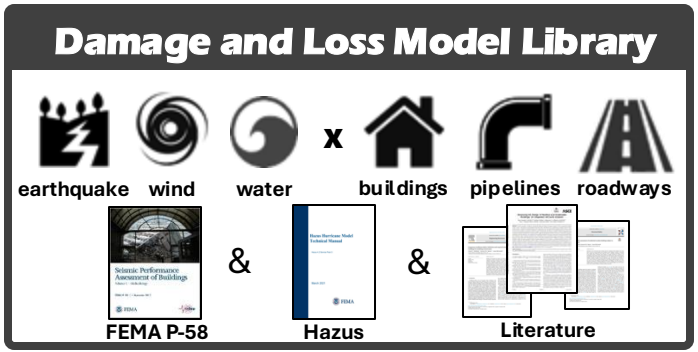


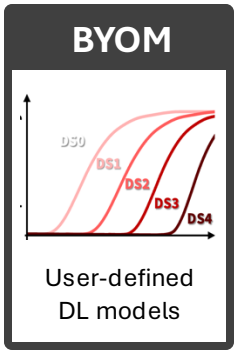
Released TIER 1 Applications built from Framework

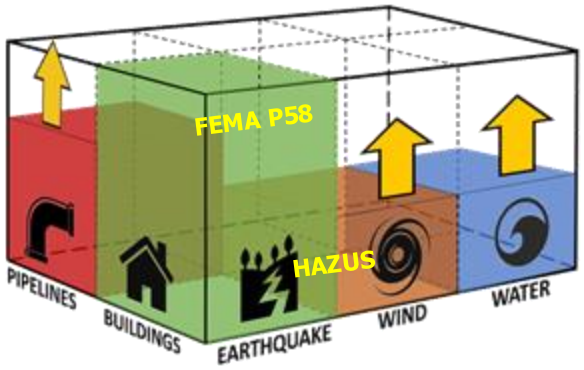


Pelicun – Modular Damage and Loss Simulation





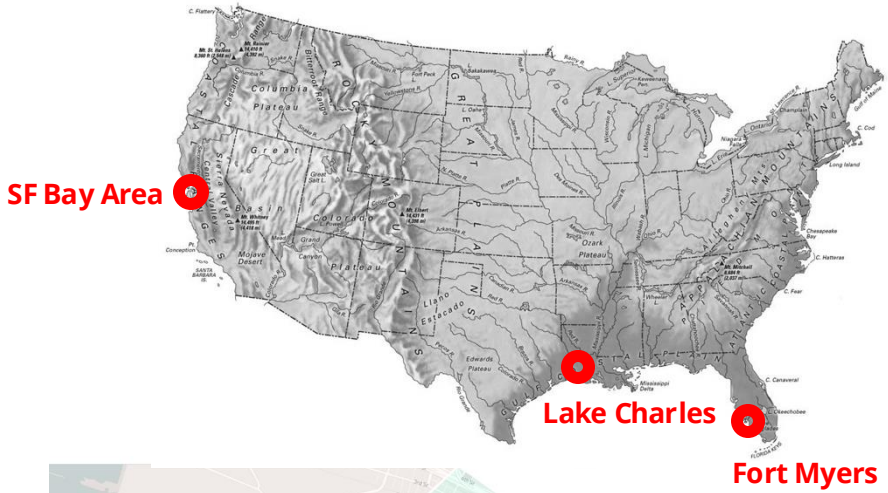


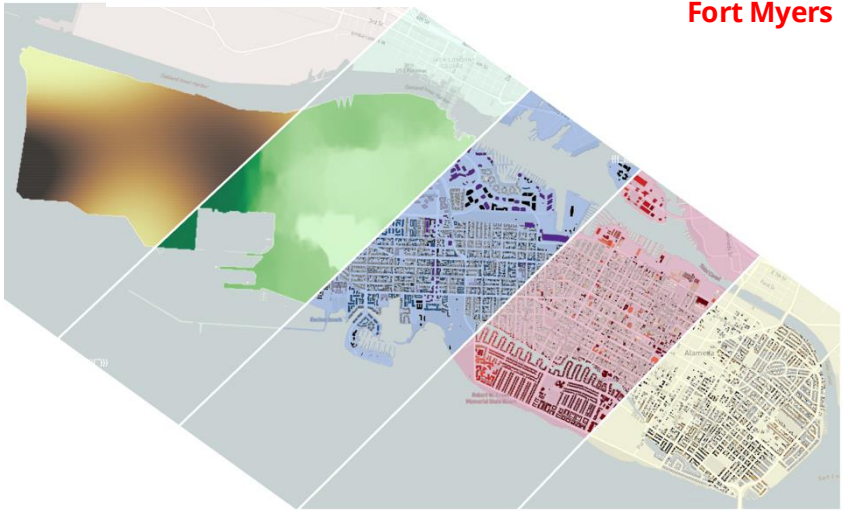


NSF NHERI SimCenter

Regional Testbeds for R2D

- **Foster benchmarking**, **collaboration**, and **research** with broader impacts
- Locations with rich historical data from multiple nat. haz. events
- **Generate and share inventories** of buildings, households, and lifelines
- Import or generate event information, and simulate impacts and recovery
- **Test surrogate models** to incorporate high-fidelity local-scale analyses
- Develop best practices to facilitate rapid deployment of regional studies



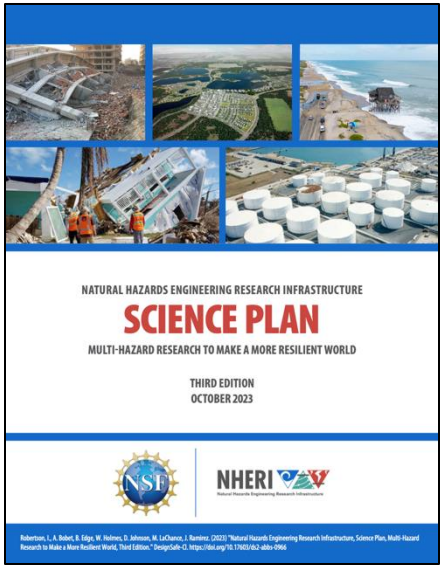


NSF NHERI SimCenter

Outline

- SimCenter
- BRAILS++
- R2D
- Bay Area Testbed

NSF NHERI: Science Plan



To Simulate the effects of a natural hazard on the Infrastructure & the community

YOU NEED information on:

Asset Inventory (buildings, lifelines (roads, gas, water, …) and **PEOPLE** in the community.

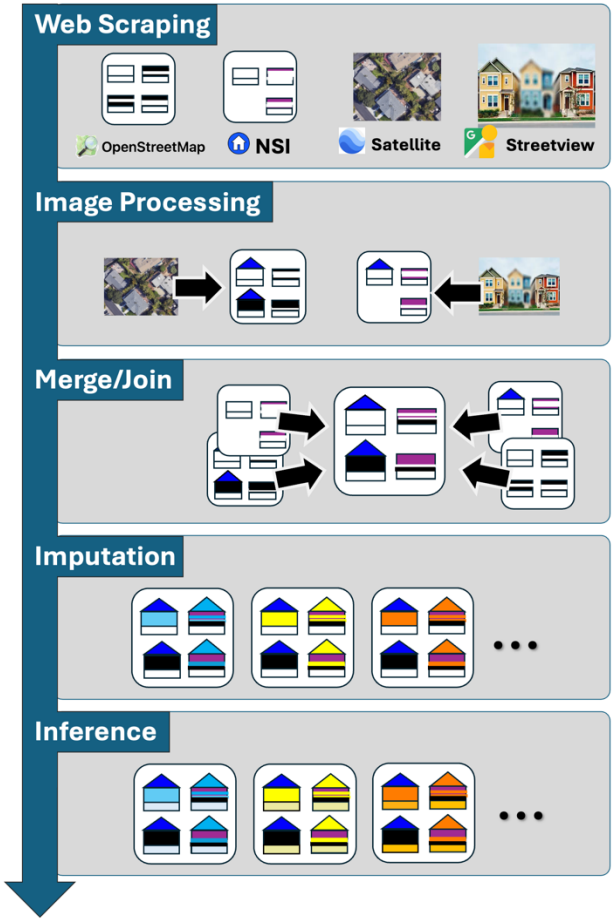
BRAILS++

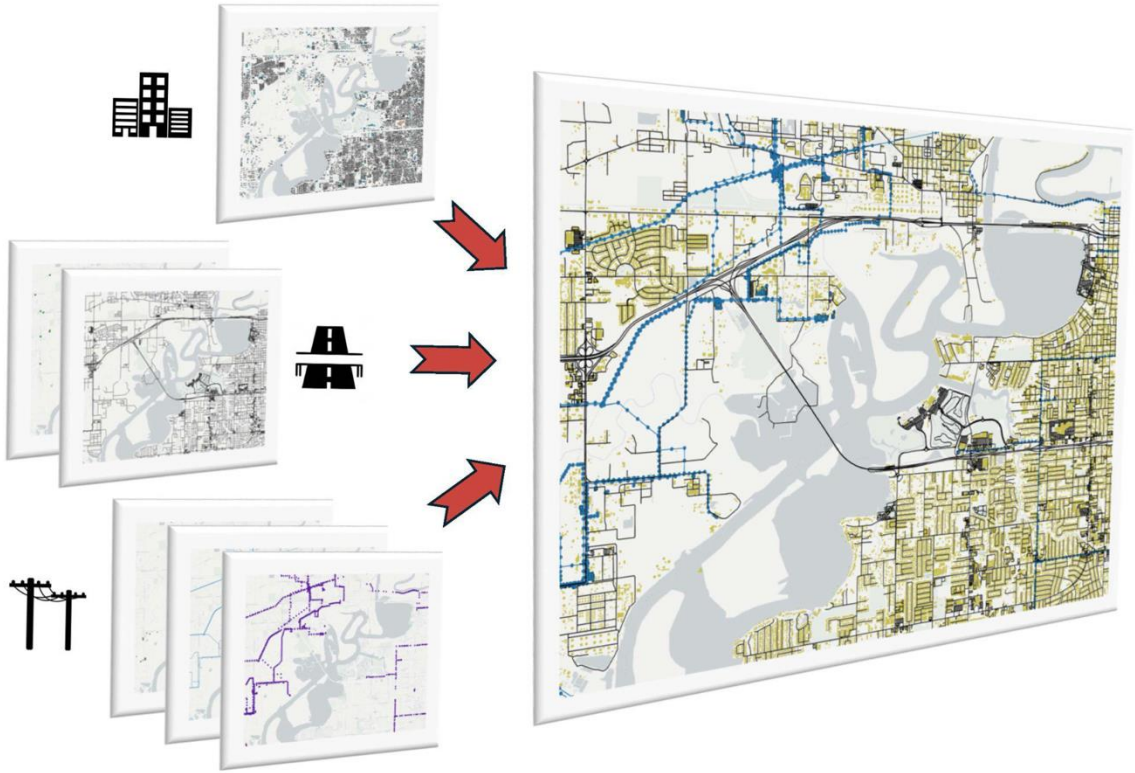
- **B**uilding **R**egional **A**sset **I**nventories for **L**arge **S**cale **S**imulations

PURPOSE: Generate Asset Inventories for Regional Simulation

OUTPUTS: Probabilistic Asset Inventories, many “Possible Worlds”

BRAILS++ - Streamlined Inventory Generation





Scrapers: Obtain Data from Public Datasets on WWW

Building Footprints

OpenStreetMap
Overture Maps
Microsoft Global Footprints
FEMA USA Structures

Transportation Systems

US Census TIGER/Lines
National Bridge Inventory
National Tunnel Inventory
OpenStreetMap

Building Features

NSI
FEMA Flood Zone
ASCE Hazards
USGS NLCD

Power Infrastructure

HIFLD
OpenStreetMap

You can also ingest user-specified building footprints and inventory data into BRAILS!

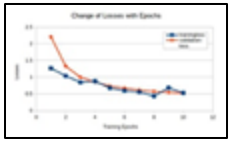
Processors: Obtain Information from Images

ML Classification and Segmentation & Image Processing

Aerial and street-level imagery

AI-based automated feature extraction

(Optional) model retraining or fine-tuning



High-fidelity inventories from AI models

ML-Based Building Attribute Prediction Capabilities

Approach	Attribute	Output	Model Version
Image Classification	Roof Type	Flat, Gable, Hip	1.1.0
	Roof Cover	Shingles, Tiles, Metal, BUR, SPM	1.0.0
	Occupancy	Residential/Other	1.1.0
	Construction Type	Wood, Concrete, Steel, Masonry, Manufactured	1.0.0
Object Detection + Post-processing	Number of Floors	Integer	1.1.0
	Garage	Yes/No	1.0.0
	Chimney	Yes/No	1.0.0
Image Segmentation + Image Rectification + Post-processing	Building Height	Float	1.1.0
	Roof Pitch	Float	1.1.0
	Roof Height	Float	1.1.0
	First Floor Height	Float	1.1.0
	Window Ratio	Total Window Area/Facade Area	1.1.0

New Large Language Models are a game changer

Grounded-SAM

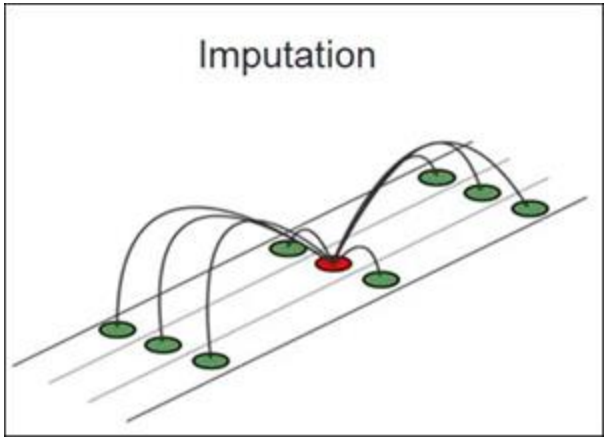
Florence-2

OpenAI CLIP

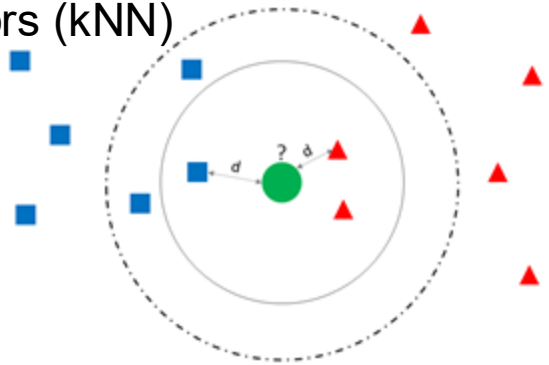
OpenAI ChatGPT

Vision Language Models Integrated BRAILS++

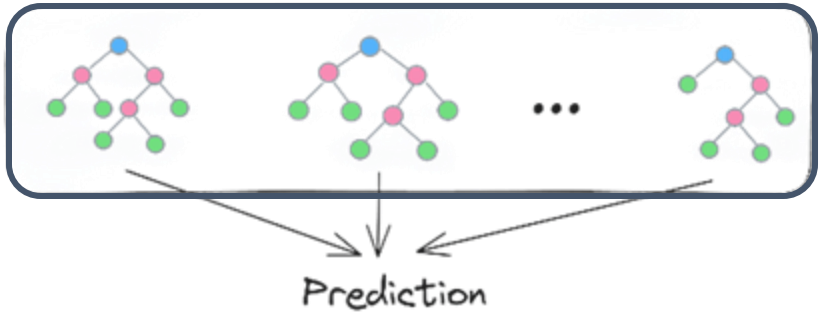
Imputation: Predicting Missing Data: Imputation



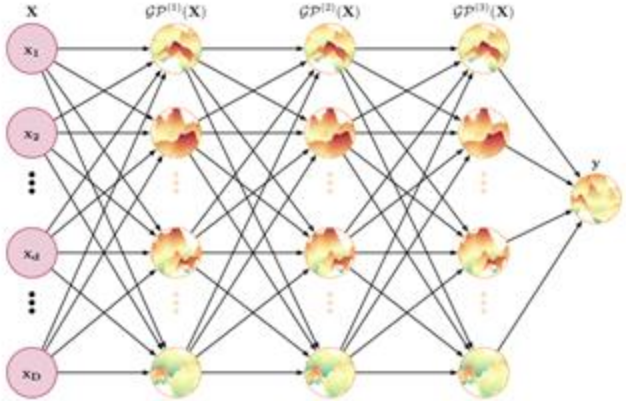
K-nearest neighbors (kNN)



Random forest

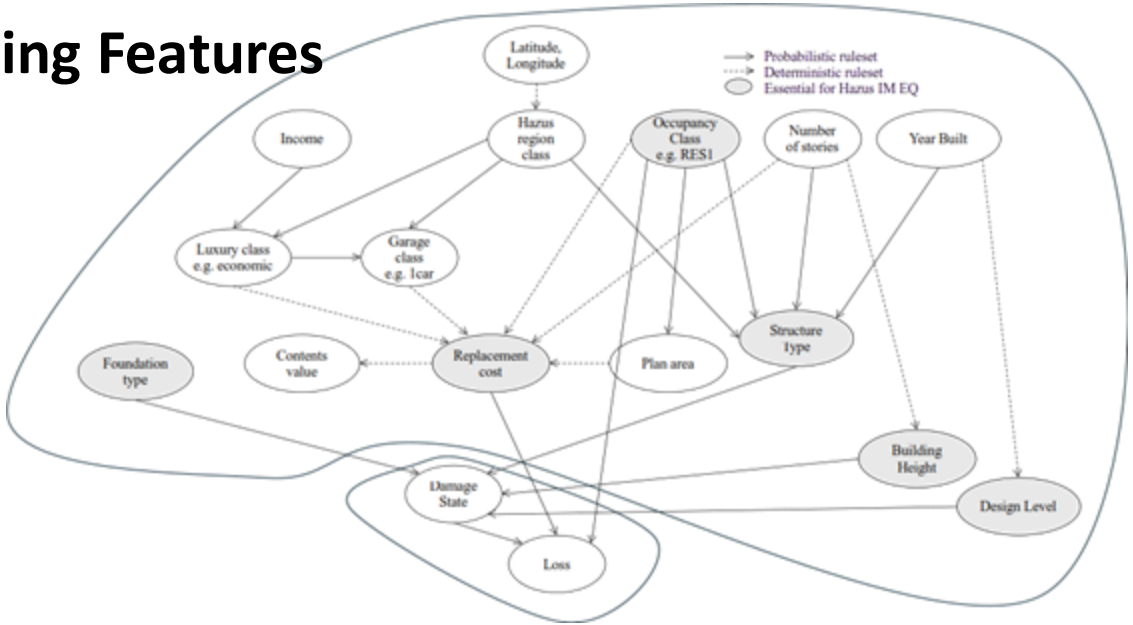


Gaussian Process



Inference: Predicting new features based on existing

1. Rulesets for building Features



2. Algorithms for Lifeline Systems

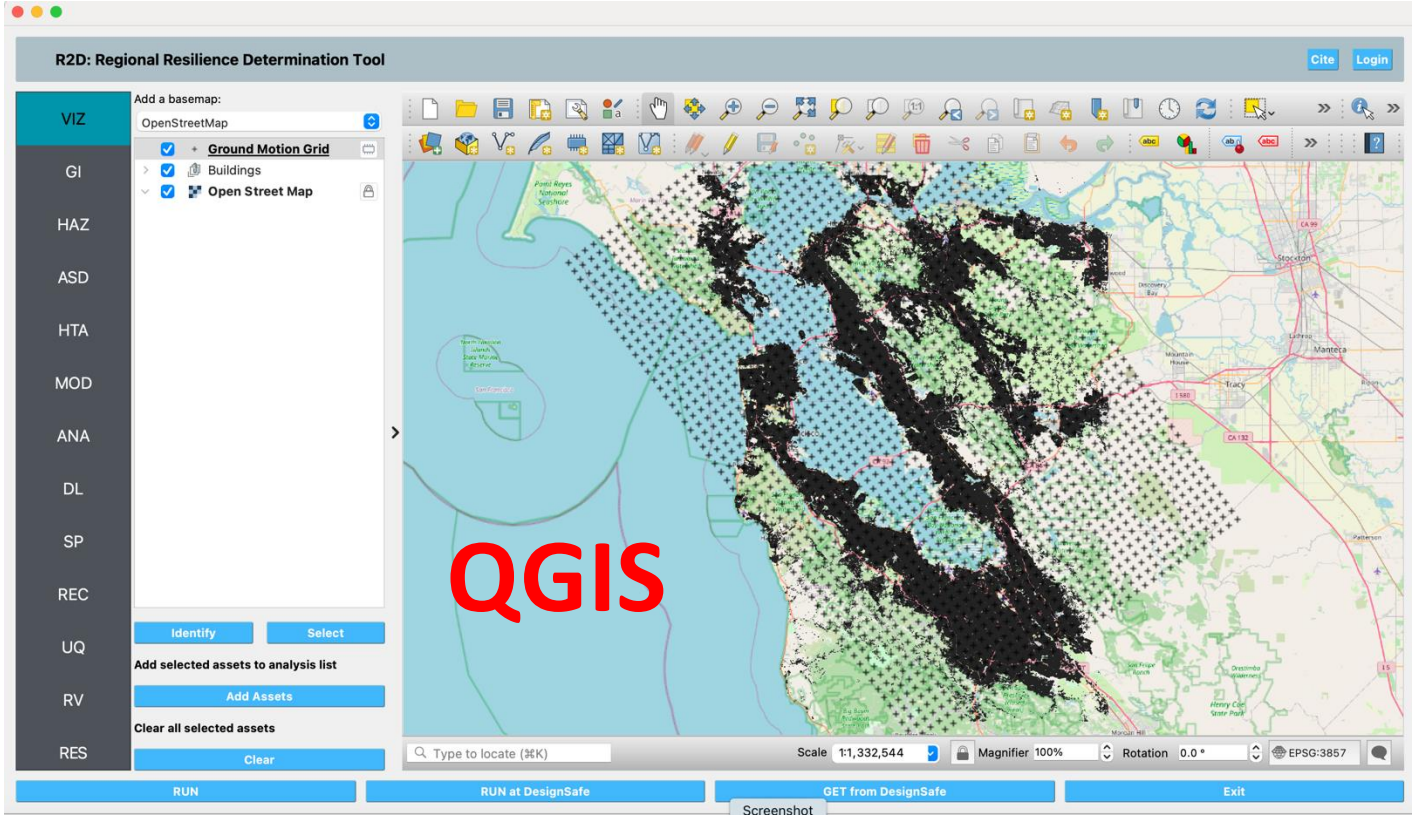
e.g. utilizing household & roadway info for generating water, power networks, etc.

Outline

- SimCenter
- BRAILS++
- R2D
- Bay Area Testbed

R2D

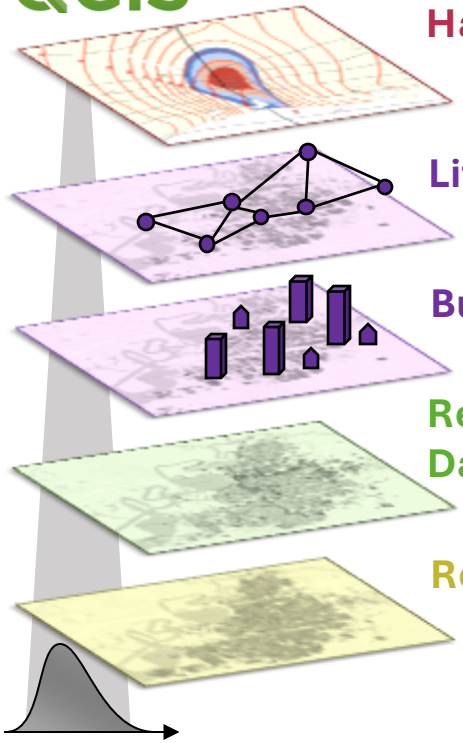
- **R**egional **R**esilience **D**etermination Application



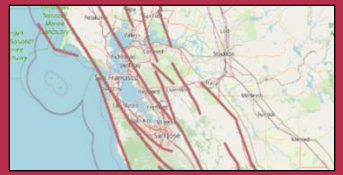
NSF NHERI SimCenter

R2D TIER 1 Desktop Application

QGIS



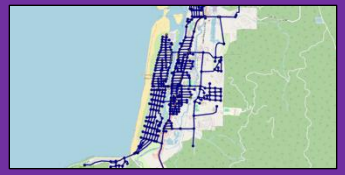
Multi-hazard → Interfaces & Event Generators


Earthquake

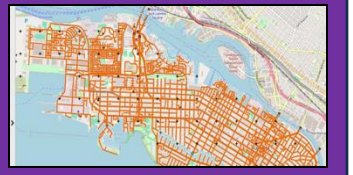

Wind


Water

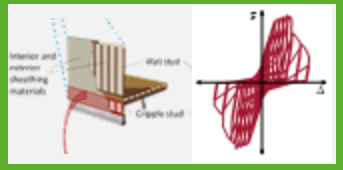
Multiple asset types → BRAILS++ Inventory Generator

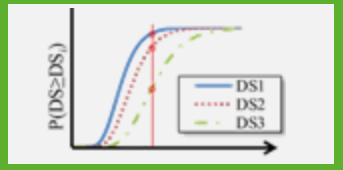

Utility networks


Buildings

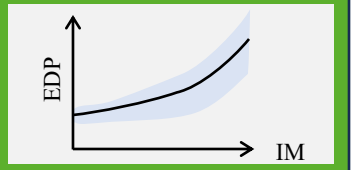

Transportation

Multi-fidelity → Model Libraries & Simulation Tools


Hi-res FEM / CFD



Fragility Curves

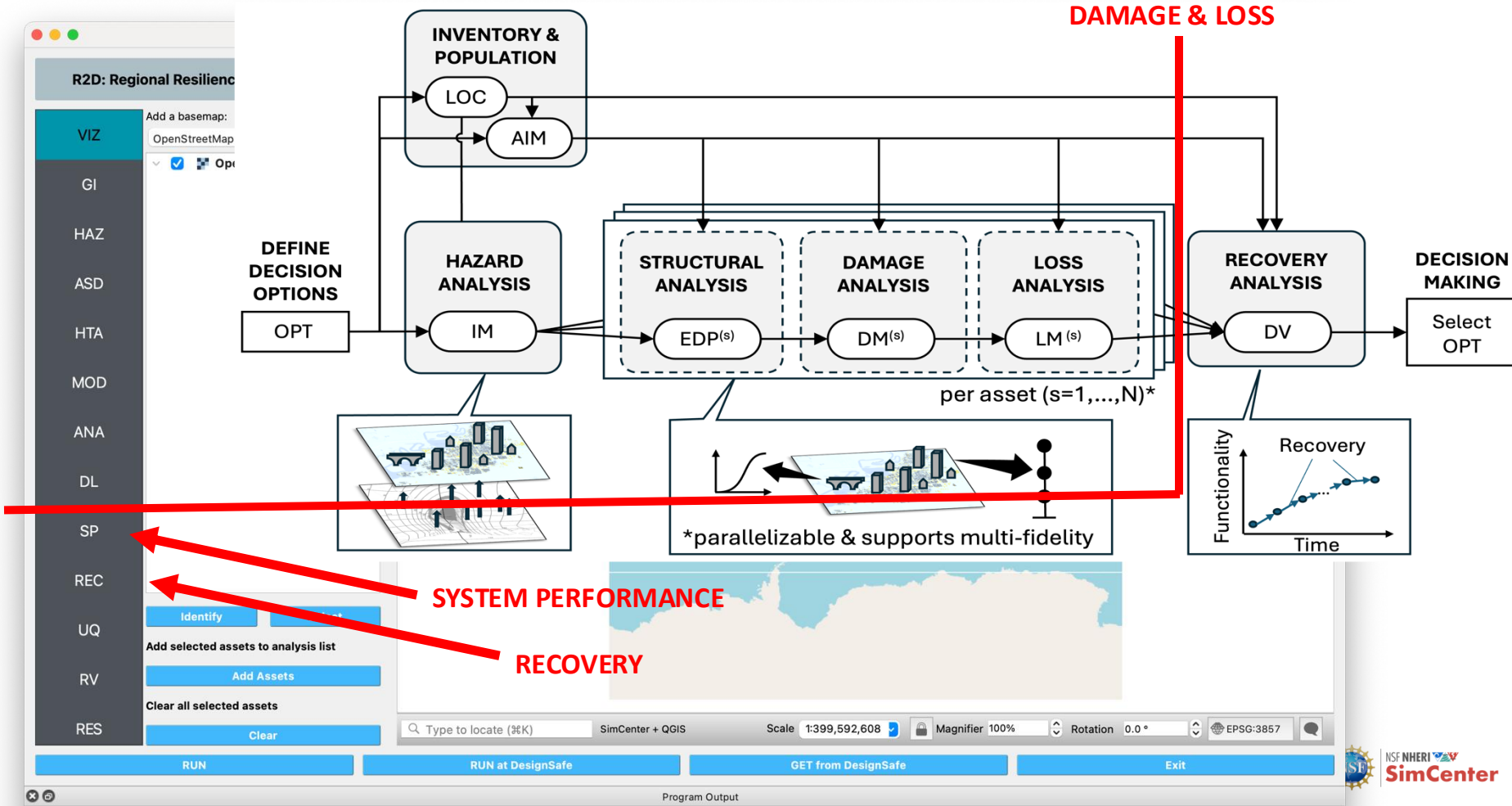


Surrogate models

R2D Webpage

NSF NHERI SimCenter

Building Workflows



NSF NHERI SimCenter

System Performance

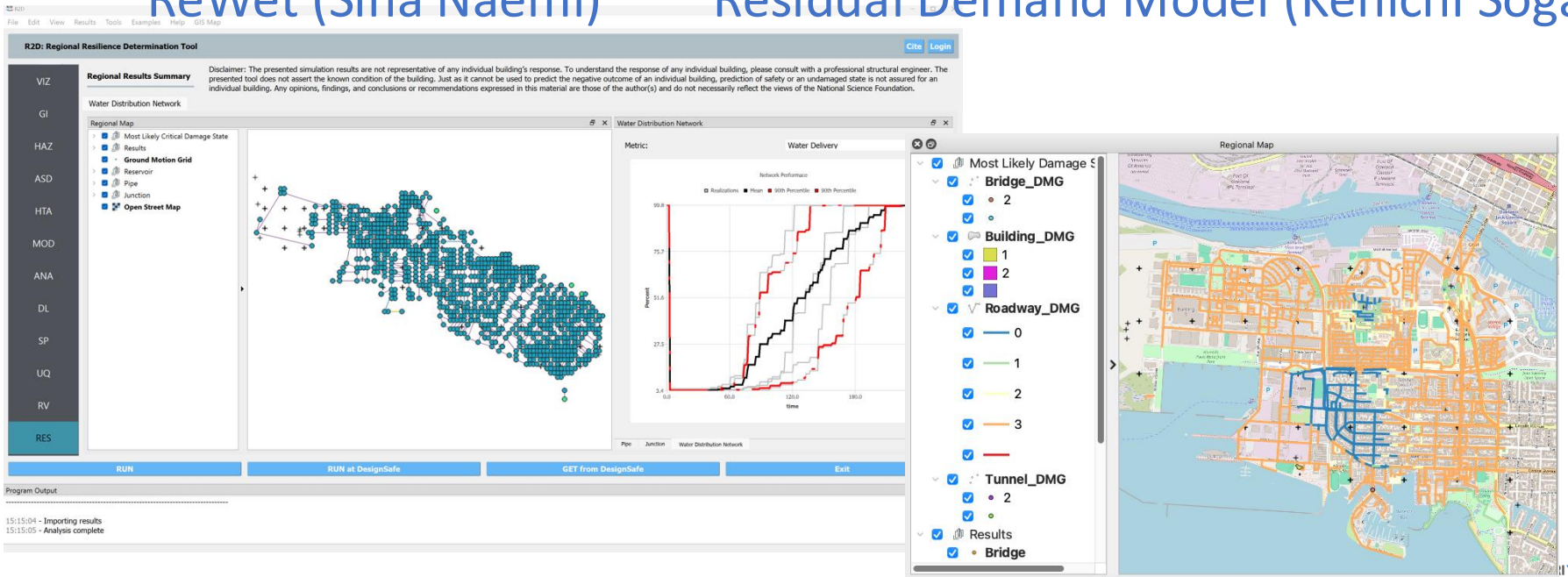
performance of a system AFTER the event

Water System

ReWet (Sina Naemi)

Transportation System

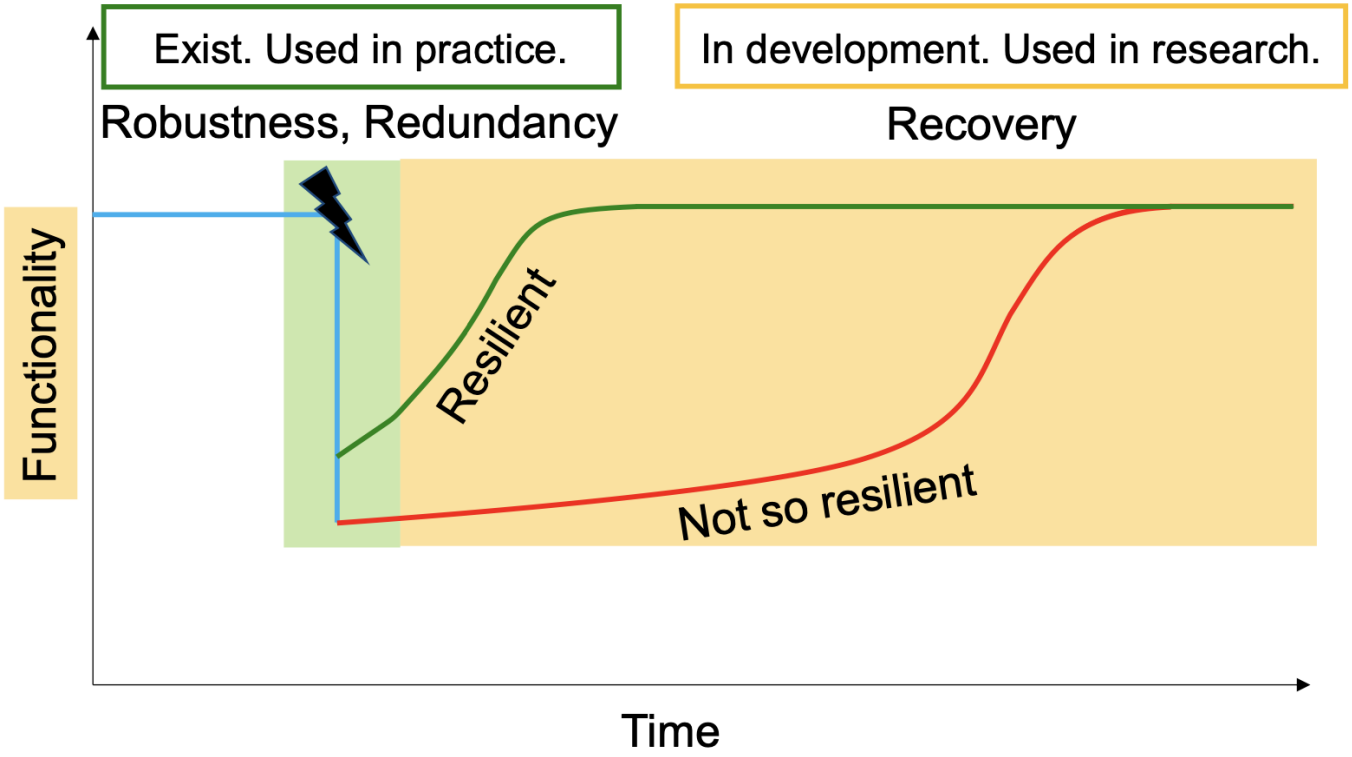
Residual Demand Model (Kenichi Soga)



SimCenter

Recovery

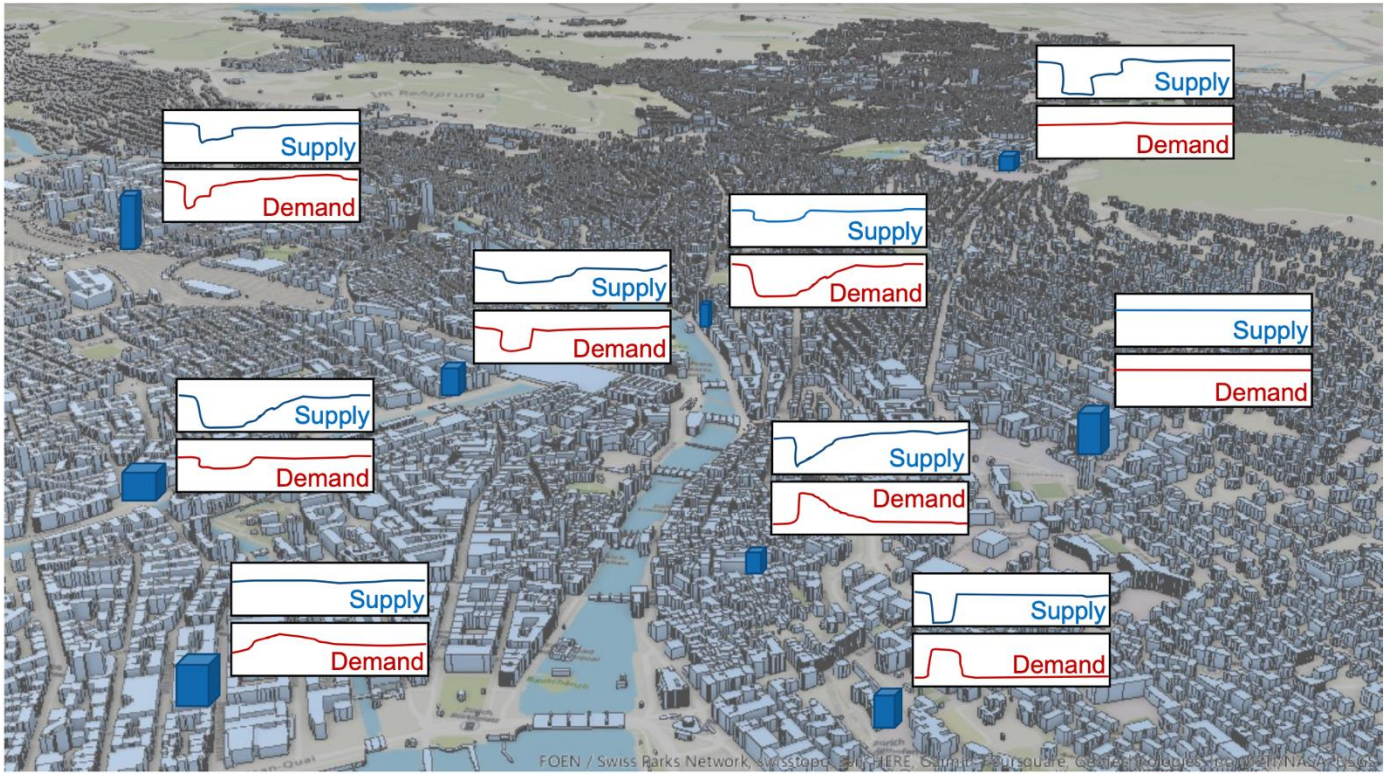
Understanding resilience requires understanding the recovery of urban systems



courtesy of Nikola Blagojevic

Simulating Recovery with Pyrecodes/iRe-CoDeS

Characterize and simulate component resource supply and demands over time



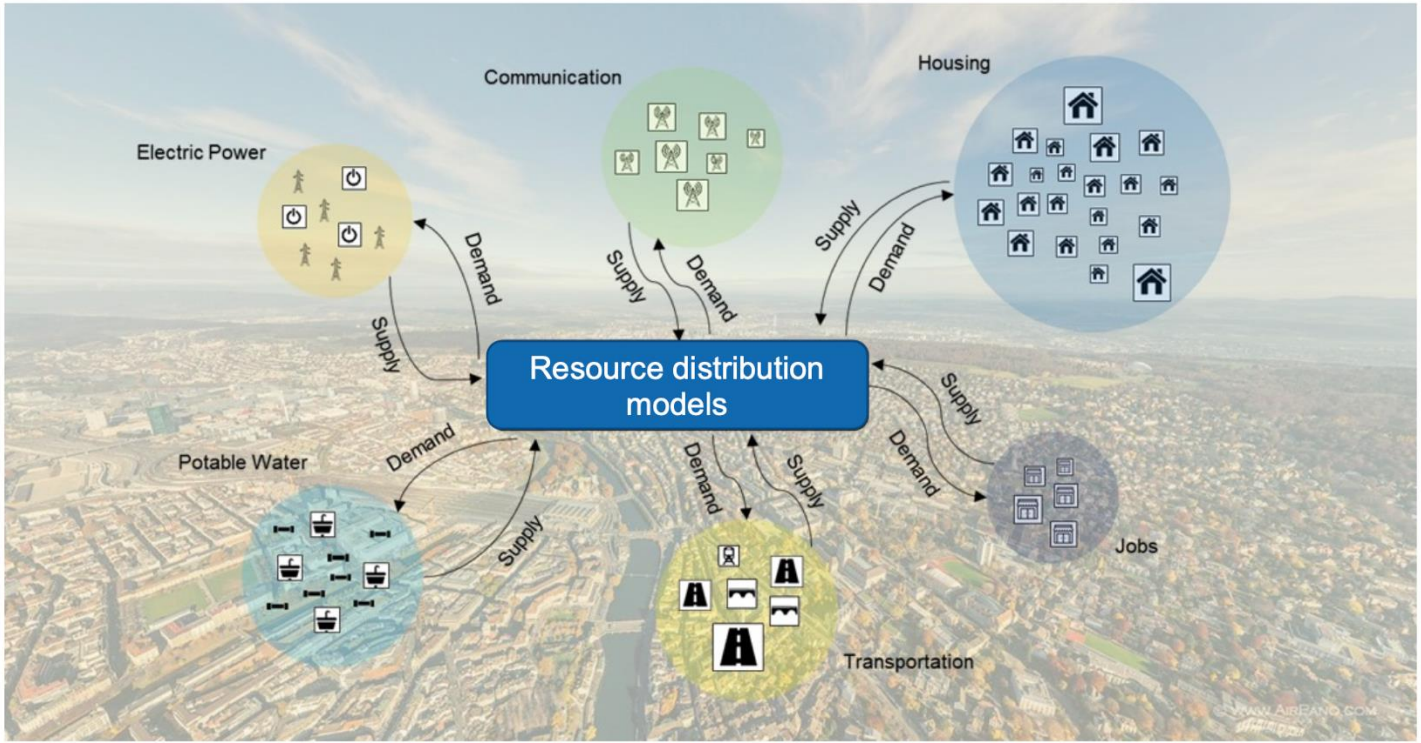
[Pyrecodes Website](#)

courtesy of Nikola Blagojevic

NSF NHERI SimCenter

Simulating Recovery with Pyrecodes/iRe-CoDeS

Simulate interdependencies through the flow of resources and services

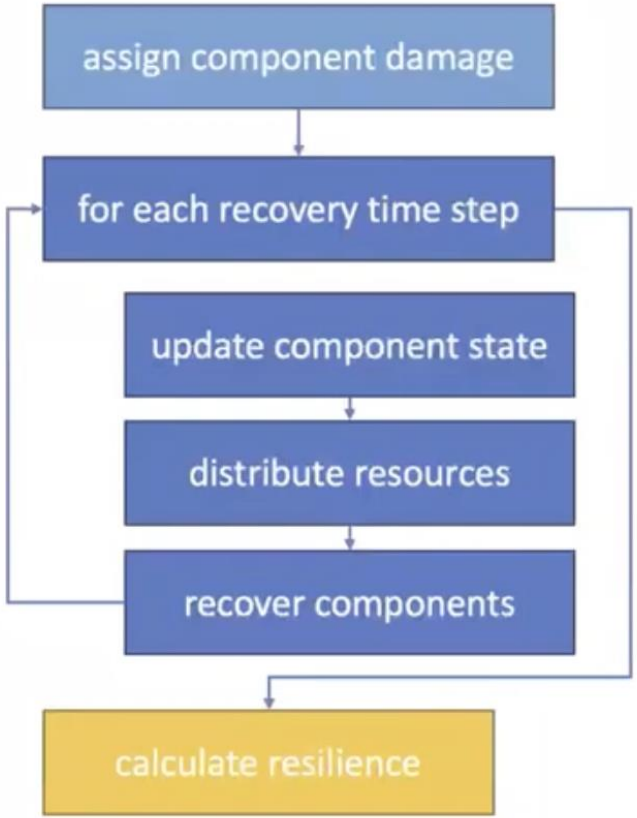


Pyrecodes Website

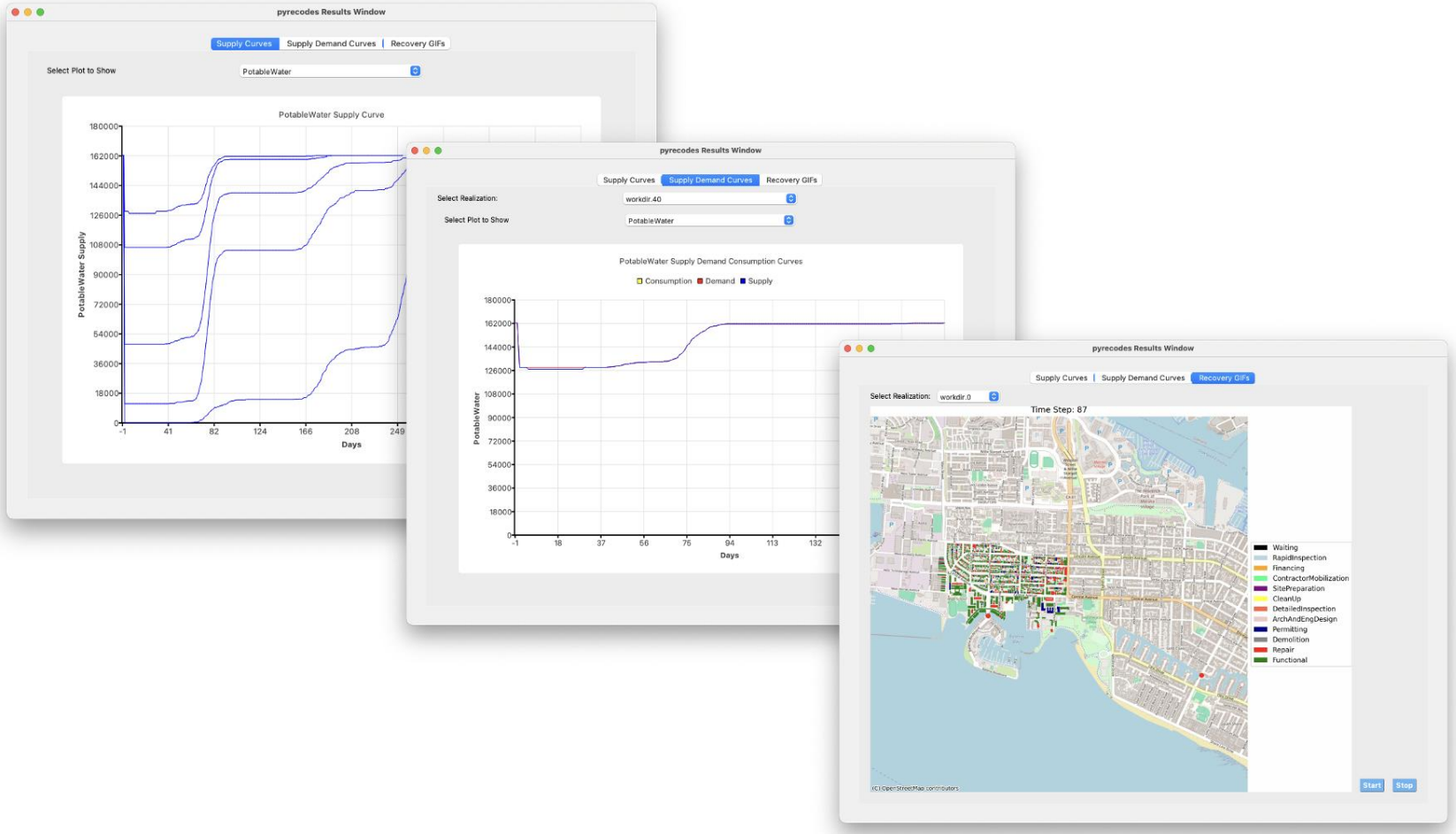
courtesy of Nikola Blagojevic

NSF NHERI SimCenter

pyrecodes resilience assessment algorithm

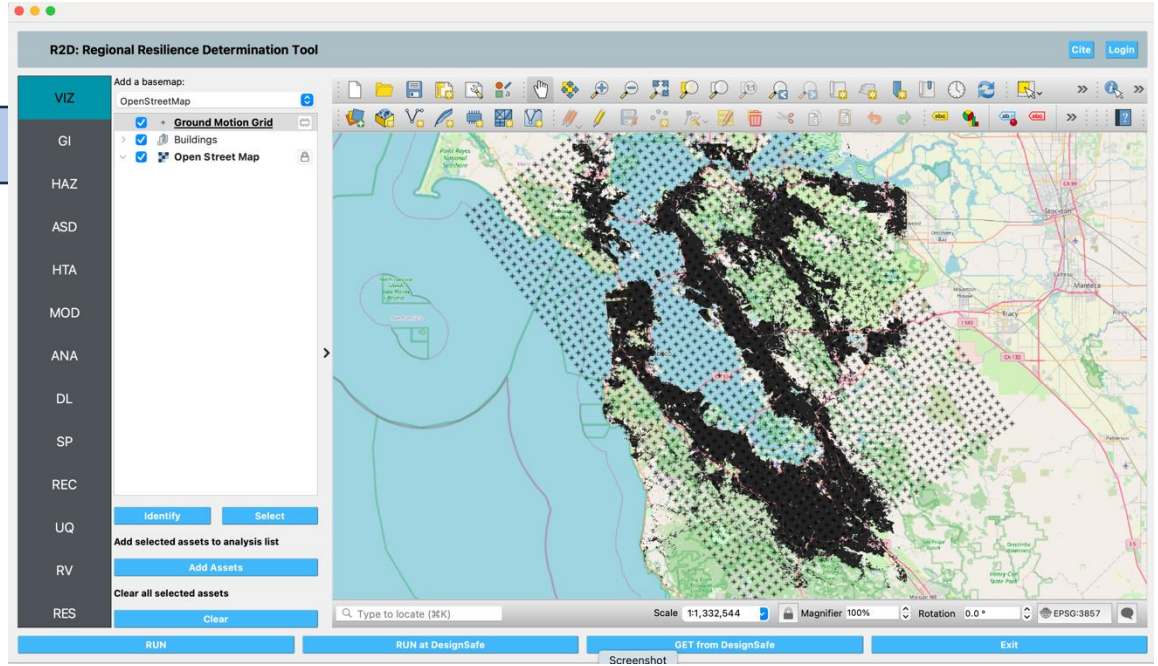


PyRecodes in R2D



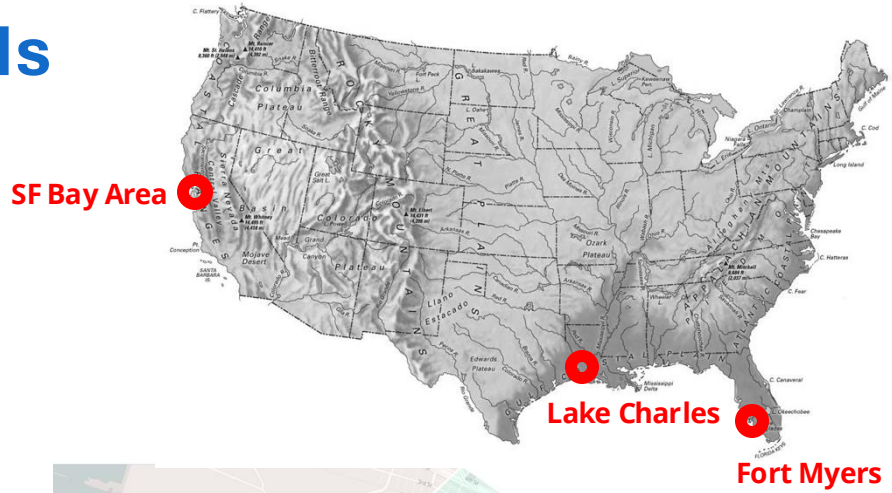
Outline

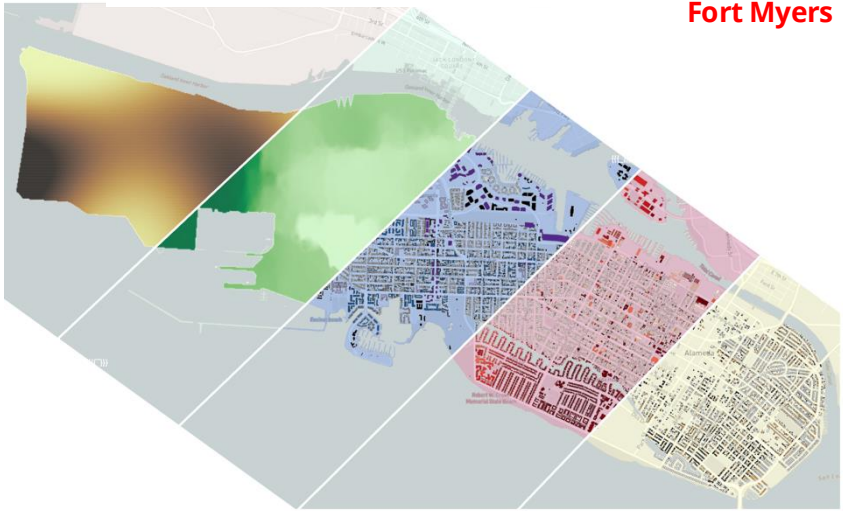
- SimCenter
- BRAILS++
- R2D
- Bay Area Testbed



SimCenter Regional Testbeds

- Foster benchmarking, collaboration, and research with broader impacts
- Locations with rich historical data from multiple nat. haz. events
- Generate and share inventories of buildings, households, and lifelines
- Import or generate event information, and simulate impacts and recovery
- Test surrogate models to incorporate high-fidelity local-scale analyses
- Develop best practices to facilitate rapid deployment of regional studies

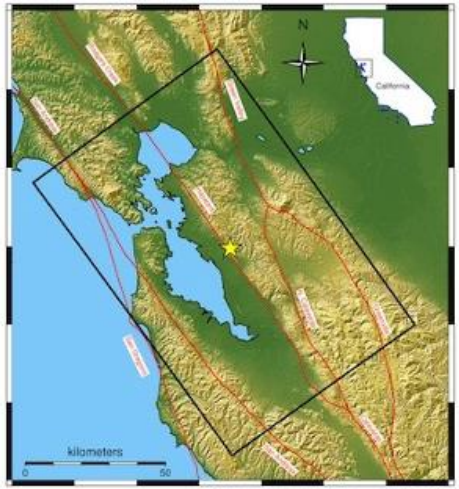




NSF NHERI SimCenter

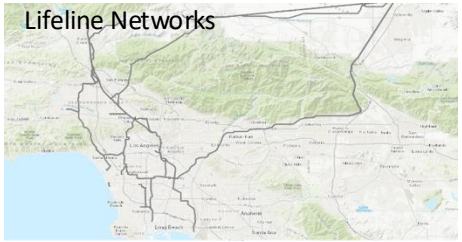
SF Bay Area Testbed

Hazard



source:https://www.exascaleproject.org/research-project/eqsim/

Multi-asset Analysis



e.g. “The buildings are mostly likely in moderate damage states. The non-structural damage would dominate the economic losses. The repair costs range from 1% to 7% of the total replacement costs, and the repair time range from 1 to 20 days.”

Step 1

Obtain Ground Motion records
EQSIM

Step 2

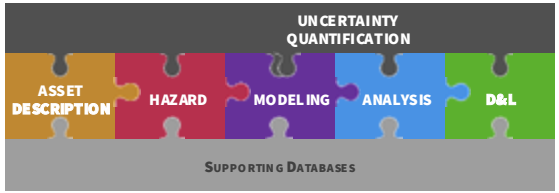
Generate Inventory data for Bay Area Region using BRAILS ++

Step 3

Run Workflows using R2D

What Workflows?

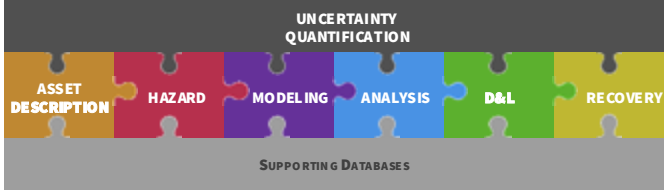
Building Damage & Loss (1.35M bldgs.)

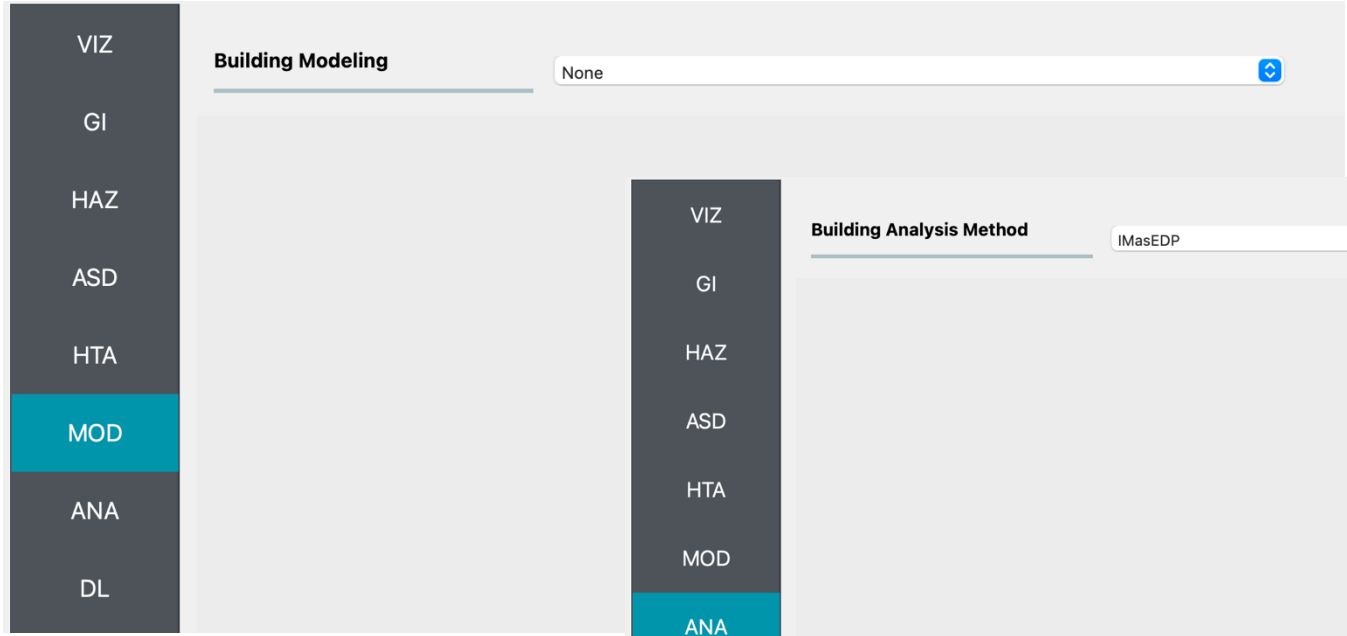


1. **Surface Motions**:
    1. FEMA Hazus Level ✓
    2. Capacity Spectrum Method ✓
    3. Transient Nonlinear MDOF Analysis ✓
    4. Transient Nonlinear Analysis, generic building models from DB
    5. Surrogate

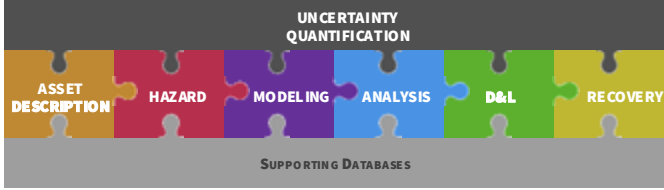
2. **Sub Surface Motions (Pedro Arduino, Amin Pakzad)**

FEMA HAZUS


UNCERTAINTY QUANTIFICATION
ASSET DESCRIPTION
HAZARD
MODELING
ANALYSIS
D&L
RECOVERY
SUPPORTING DATABASES


VIZ
GI
HAZ
ASD
HTA
MOD
ANA
DL
Building Modeling
None
VIZ
GI
HAZ
ASD
HTA
MOD
ANA
DL
Building Analysis Method
IMasEDP

Capacity Spectrum Method



VIZ
GI
HAZ
ASD
HTA
MOD
ANA
DL

Building Modeling None

VIZ
GI
HAZ
ASD
HTA
MOD
ANA
DL

Building Analysis Method Capacity Spectrum Method

Demand Spectrum Model HAZUS

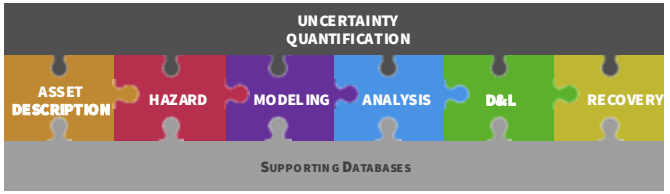
Moment Magnitude 7

Capacity Curve Model Cao and Peterson (2006)

Damping Model Cao and Peterson (2006)

SF NHERI SimCenter

Nonlinear Dynamic MDOF Analysis



VIZ
GI
HAZ
ASD
HTA
MOD
ANA
DL

Building Modeling MDOF-LU

Hazus Data File

std deviation Stiffness:

std deviation Damping:

Default Story Height: (Optional)

This backend application used by this selection was provided by Prof.Xinzheng Lu,Tsi

(1) Lu X.Z.,McKenna F,Cheng Q.L.,Xu Z.,Zeng X.,and Mahin S.A.,"An open-source fran
36(2): 806-831.

(2) Lu X.Z.,Han B.,Hori M.,Xiong C.,and Xu Z.,"A coarse-grained parallel approach for
Engineering Software,2014,70: 90-103.

VIZ
GI
HAZ
ASD
HTA
MOD
ANA
DL

Building Analysis Method OpenSees

Analysis: Transient -numSubLevels 2 -numSubSteps 10

Integration: Newmark 0.5 0.25

Algorithm: Newton

ConvergenceTest: NormUnbalance 1.0e-2 10

Solver: Umfpack

Damping Model Rayleigh Damping

Selected Tangent Stiffness: Initial

Mode 1: 1

Mode 2: 0

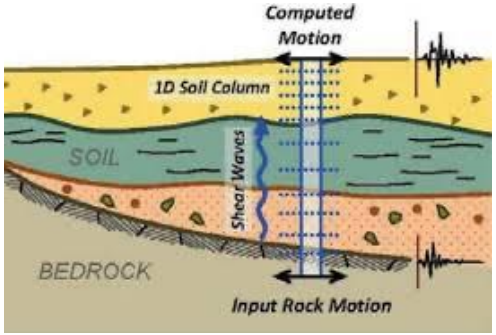
Analysis Script: (Optional) Choose

NSF NHERI SimCenter

Sub Surface Motions: Site Response & DRM (sub region)

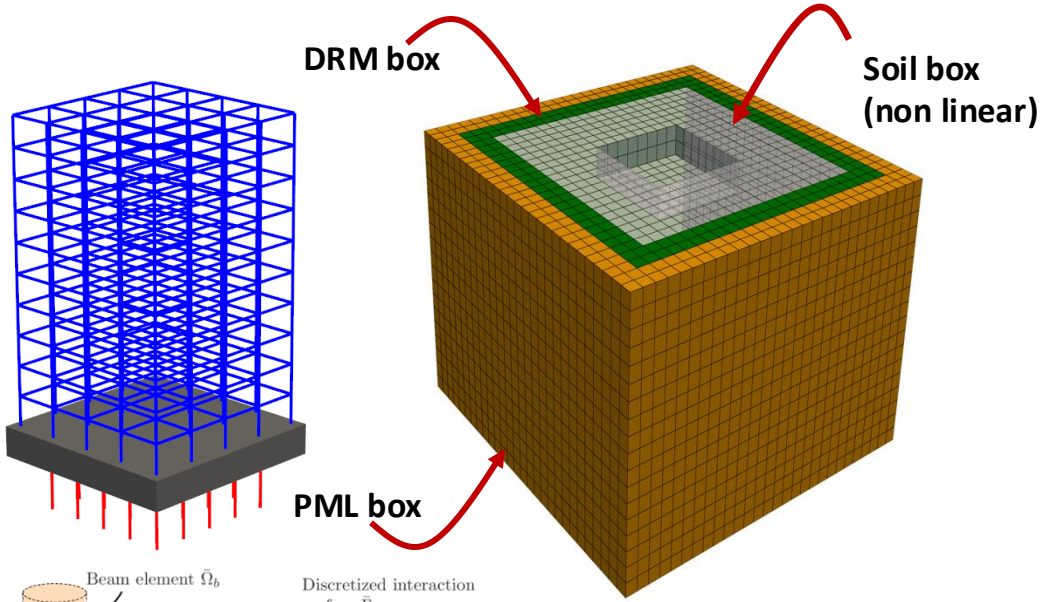
Pedro Arduino

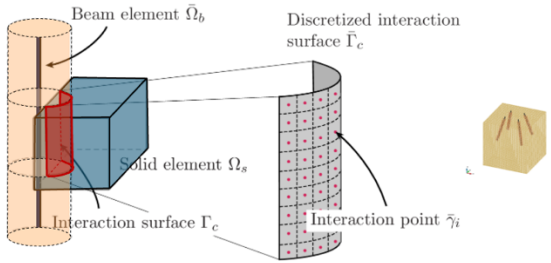
Amin Pakzad



1. Site Response

WORK IN PROGRESS



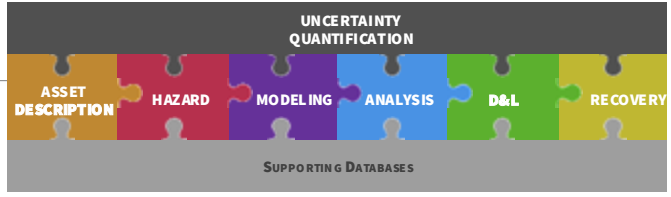


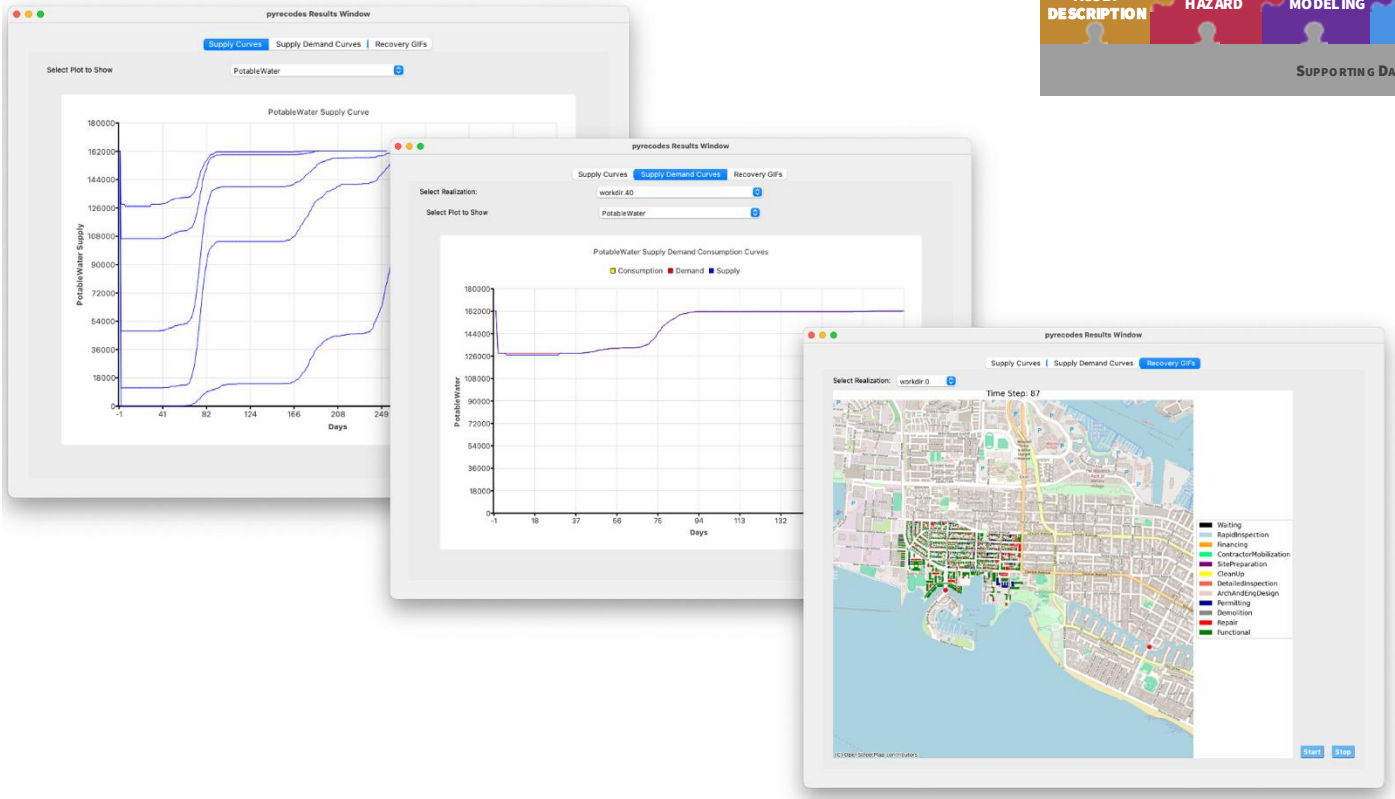
2. DRM (Domain Reduction Method)

WORK IN PROGRESS

NSF NHERI SimCenter

Recovery: (subregion)





Why all The Workflows for 1 Testbed!

- Test Scalabilty of Software & Improve Efficiency
- Modify R2D Interface for displaying Results
- Develop Juypter Notebooks for TIER 2 Users
- Create a Dataset for bay area buildings
- Explore Minimal building information for successful imputation
- Benchmark different methods
- Further Develop workflows for using surrogates in regional simulations
- Develop best practices to facilitate rapid deployment of regional studies
- Foster Collaboration (SimCenter WG's)

SimCenter Portal

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

- Software & Documentation
- Education and Training Webinars
- Forum & Other Communication
- **Working Groups**

If Interested JOIN Earthquake,
Lifelines and Socio Economic WGs

NSF NHERI SimCenter

QUESTIONS?