DESIGNSAFE-CI
A NATURAL HAZARDS ENGINEERING COMMUNITY

NSF award: CMMI 2022469

NHERI SimCenter
Center for Computational Modeling & Simulation

NSF award: CMMI 2131111

Machine Learning Training for Natural Hazards Engineering 2022

Frank McKenna
SimCenter

Outline

- Welcome
- Introduction to NHERI
- ML in Earthquake Engineering: Opportunities and Challenges

Presenters

Prof. Henry Burton
UCLA

Prof. Krishna Kumar
UT-Austin

Dr. Barbaros Cetiner
SimCenter

Syllabus

- Day 1: ML in Earthquake Engineering: Opportunities and Challenges
- Day 2: Explainable AI in Earthquake Engineering
- Day 3: Image Classification
- Day 4: Semantic Segmentation
- Day 5: Inventory Generation with BRAILS

These last 3 days are very hands on. They REQUIRE you to watch videos before the day presentation starts

Resources

GitHub Repo:

https://github.com/NHERI-SimCenter/SimCenter_DesignSafe_ML_2022

Workshop Website:

https://nheri-simcenter.github.io/SimCenter_DesignSafe_ML_2022/

Programming Help:

https://nheri-simcenter.github.io/SimCenterBootcamp2022/

Who is in the room?

20% report having used SimCenter tools

How many have used DesignSafe resources?

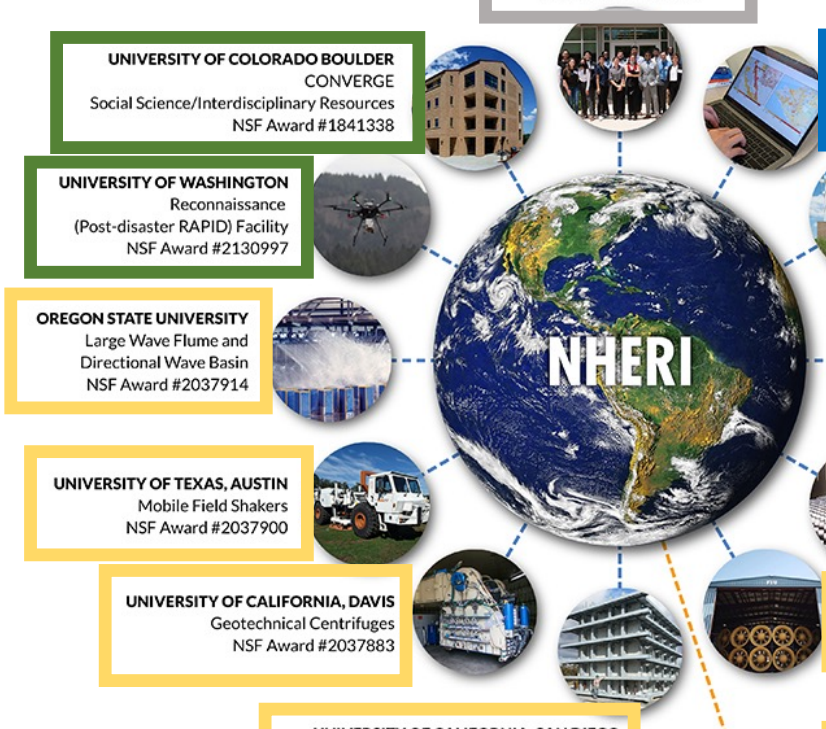
Undergraduate student	3%
Masters student	15%
PhD student	39%
Postdoc or Researcher	12%
Faculty	15%
Federal, state, or local government agency	1%
Practitioner	9%
Other	6%

Outline

- Welcome
- Introduction to NHERI
  - Introduction to DesignSafe (slides by Prof. Ellen M. Rathje, PI DesignSafe)
  - Introduction to SimCenter (slides by Prof. Sanjay Govindjee, PI SimCenter)
- ML in Earthquake Engineering: Opportunities and Challenges

NSF's Facilities/Programs

NHERI Natural Hazards Engineering Research Infrastructure



PURDUE UNIVERSITY
Network Coordination Office
NSF Award #2129782

UNIVERSITY OF COLORADO BOULDER
CONVERGE
Social Science/Interdisciplinary Resources
NSF Award #1841338

UNIVERSITY OF CALIFORNIA, BERKELEY
SimCenter
Computational Modeling and Simulation
NSF Award #2131111

UNIVERSITY OF WASHINGTON
Reconnaissance
(Post-disaster RAPID) Facility
NSF Award #2130997

UNIVERSITY OF TEXAS, AUSTIN
DesignSafe
Community Cyberinfrastructure
NSF Award #2022469

OREGON STATE UNIVERSITY
Large Wave Flume and
Directional Wave Basin
NSF Award #2037914

LEHIGH UNIVERSITY
Large-Scale Multi-Directional
Hybrid Simulation Testing
NSF Award #2037771

UNIVERSITY OF TEXAS, AUSTIN
Mobile Field Shakers
NSF Award #2037900

UNIVERSITY OF FLORIDA
Boundary Layer Wind Tunnel
NSF Award #2037725

UNIVERSITY OF CALIFORNIA, DAVIS
Geotechnical Centrifuges
NSF Award #2037883

FLORIDA INTERNATIONAL UNIVERSITY
Wind Simulation
NSF Award #2037899

UNIVERSITY OF CALIFORNIA, SAN DIEGO
Large High-Performance Outdoor Shaker Table
NSF Award #1520904

NICHE
Planning for the new, shared-used National
Full-Scale Testing infrastructure for Community Hardening
in Extreme Wind, Wave and Surge Events
NSF Award #2131961

For more information, visit the
NHERI DesignSafe website: DesignSafe-ci.org

What is DESIGNSAFE-CI ?

- A web-based research platform that enables transformative research to protect human life/reduce damage during natural hazard events

DesignSafe Vision

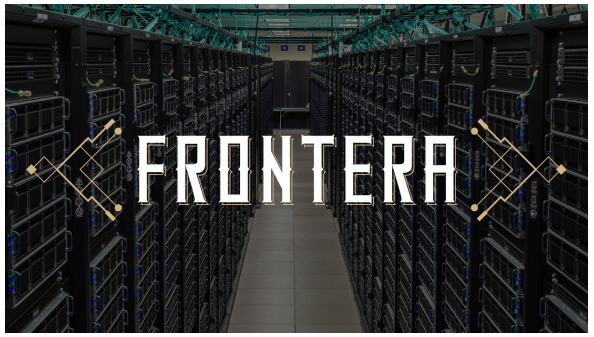
- Foster a cultural shift in natural hazards research towards the **pervasive use of cyberinfrastructure** and the **ubiquitous publishing/reuse of data**
  - **Provide a platform for data sharing/publishing**
  - **Enable research workflows and access to high performance computing (HPC)**
  - **Deliver cloud-based tools that support the analysis, visualization, and integration of diverse data types**

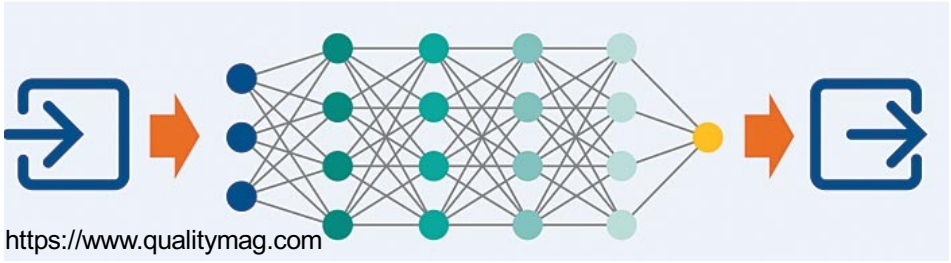
Research Ecosystem

Data

cyberinfrastructure

High Performance Computing (HPC)

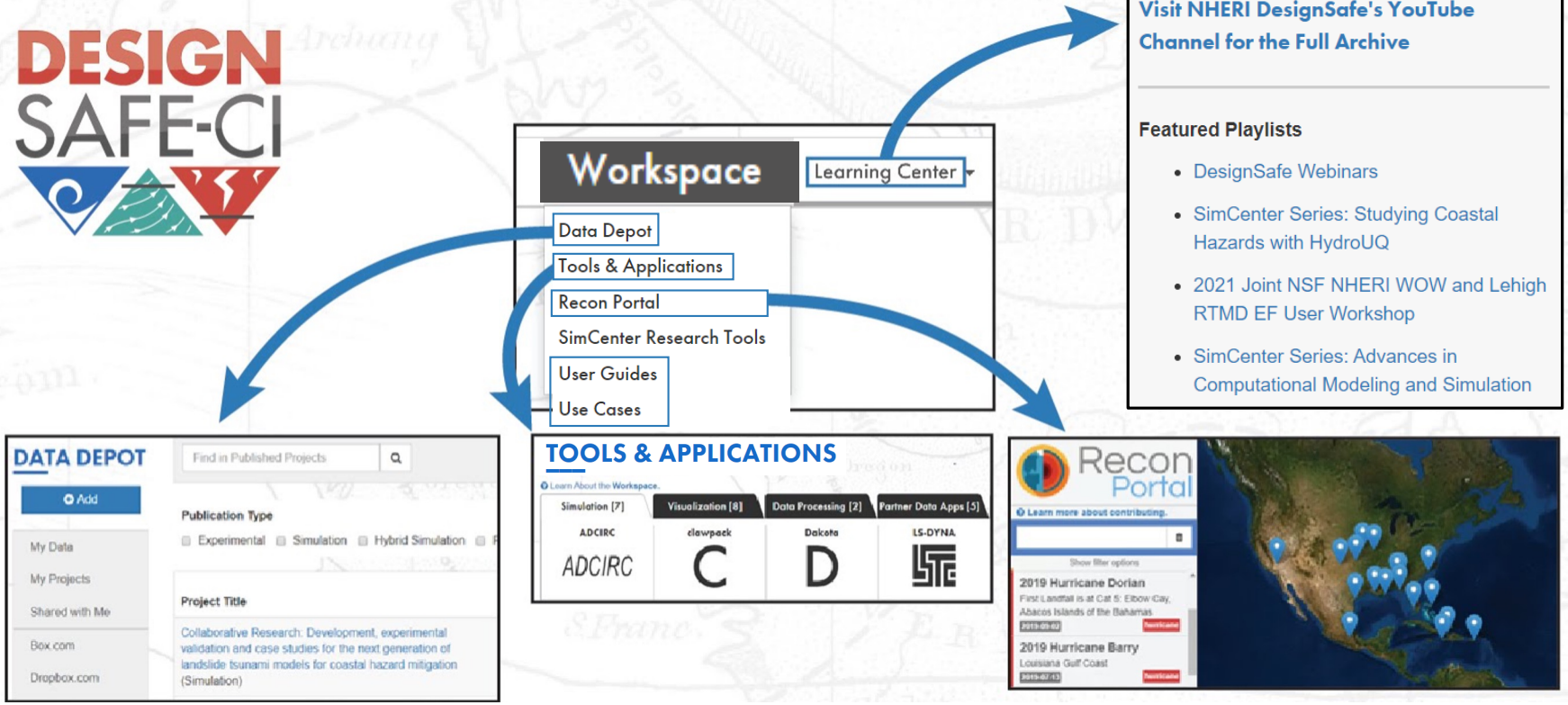




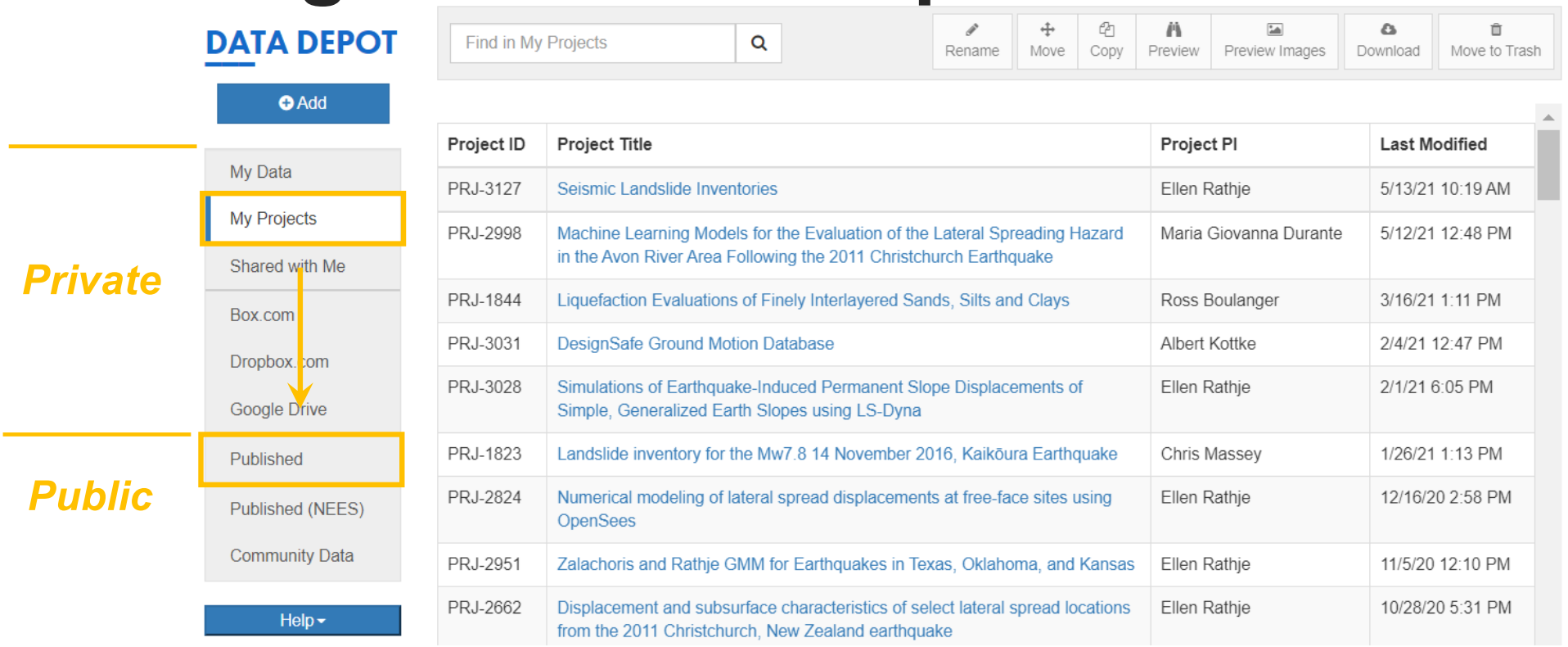
Scripts/Codes/Algorithms

DesignSafe Components

www.designsafe-ci.org

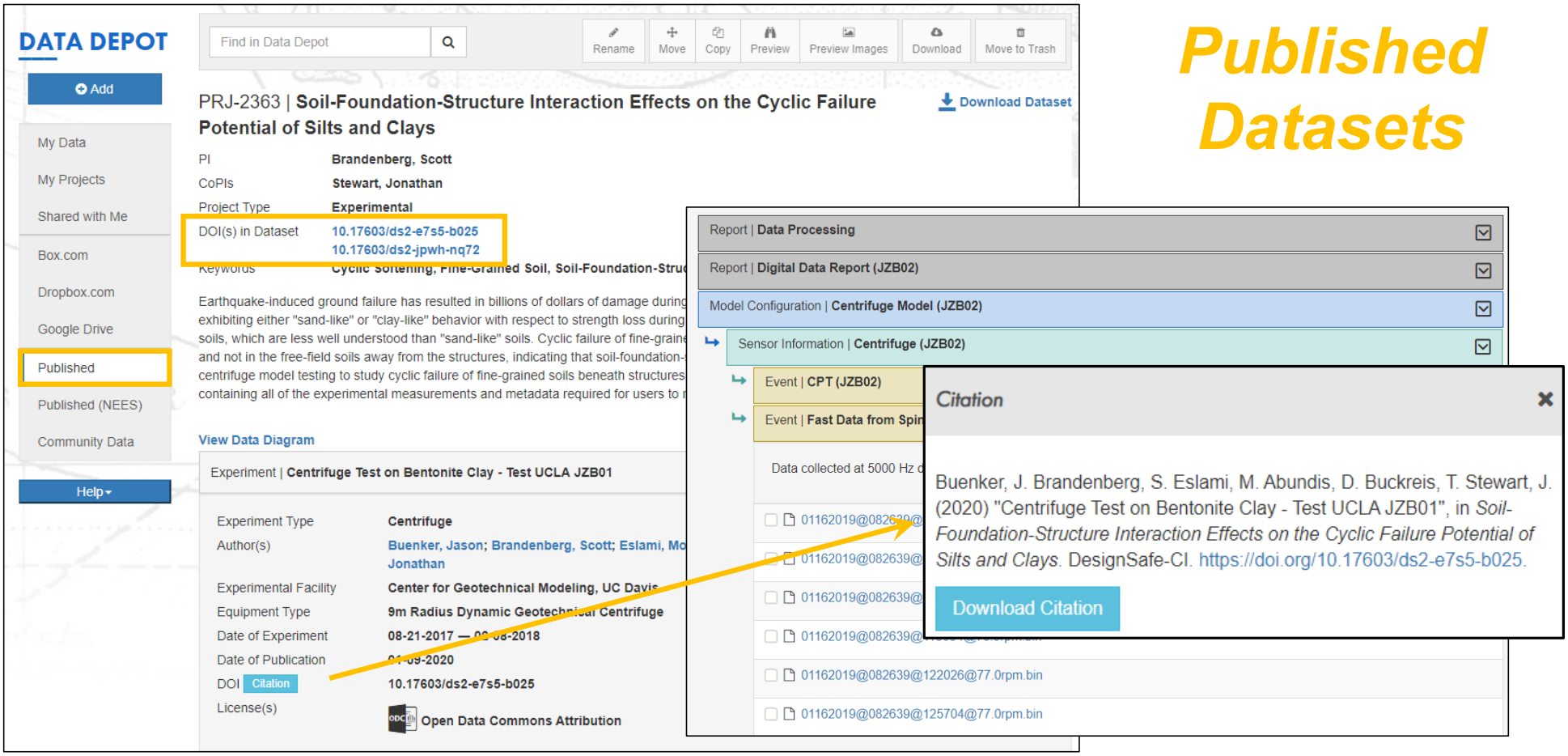


DesignSafe Data Depot



Project ID	Project Title	Project PI	Last Modified
PRJ-3127	Seismic Landslide Inventories	Ellen Rathje	5/13/21 10:19 AM
PRJ-2998	Machine Learning Models for the Evaluation of the Lateral Spreading Hazard in the Avon River Area Following the 2011 Christchurch Earthquake	Maria Giovanna Durante	5/12/21 12:48 PM
PRJ-1844	Liquefaction Evaluations of Finely Interlayered Sands, Silts and Clays	Ross Boulanger	3/16/21 1:11 PM
PRJ-3031	DesignSafe Ground Motion Database	Albert Kottke	2/4/21 12:47 PM
PRJ-3028	Simulations of Earthquake-Induced Permanent Slope Displacements of Simple, Generalized Earth Slopes using LS-Dyna	Ellen Rathje	2/1/21 6:05 PM
PRJ-1823	Landslide inventory for the Mw7.8 14 November 2016, Kaikōura Earthquake	Chris Massey	1/26/21 1:13 PM
PRJ-2824	Numerical modeling of lateral spread displacements at free-face sites using OpenSees	Ellen Rathje	12/16/20 2:58 PM
PRJ-2951	Zalachoris and Rathje GMM for Earthquakes in Texas, Oklahoma, and Kansas	Ellen Rathje	11/5/20 12:10 PM
PRJ-2662	Displacement and subsurface characteristics of select lateral spread locations from the 2011 Christchurch, New Zealand earthquake	Ellen Rathje	10/28/20 5:31 PM

Published Datasets



Make ★your★ data count!

Make your research re-producible and your data re-usable

- ***Formally publish*** data sets in stable data repositories
  - DesignSafe, Zenodo, Dataverse, figshare, Dryad, others
- Data needs a permanent, ***digital location (DOI)*** not just a URL
  - List curated data sets on your CV, just like papers
- Cite data publication ***in your reference list*** of your paper using DOI, citation language

provided here. Additionally, the probabilistic approaches described in this paper are implemented as executable Jupyter notebooks (Saygili 2018a, b). These notebooks can be accessed in the Data

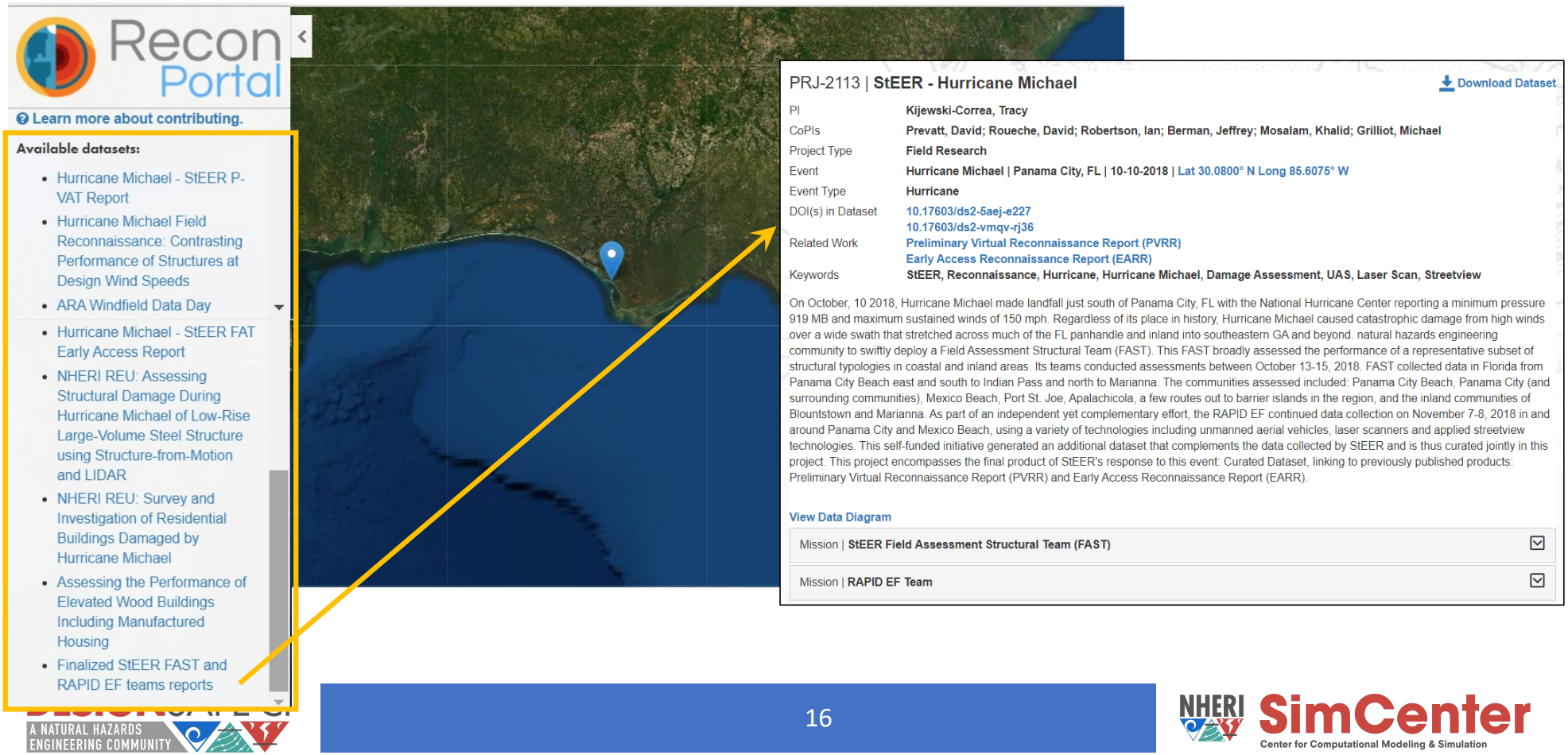
References

Saygili, G., Rathje, E., and Wang, Y. (2018a). "Probabilistic seismic hazard analysis for the sliding displacement of rigid sliding masses [Data set]." Designsafe-CI ⟨https://doi.org/10.17603/ds22d6k⟩

Reconnaissance Portal

Identifying Archived Datasets from Recon Events

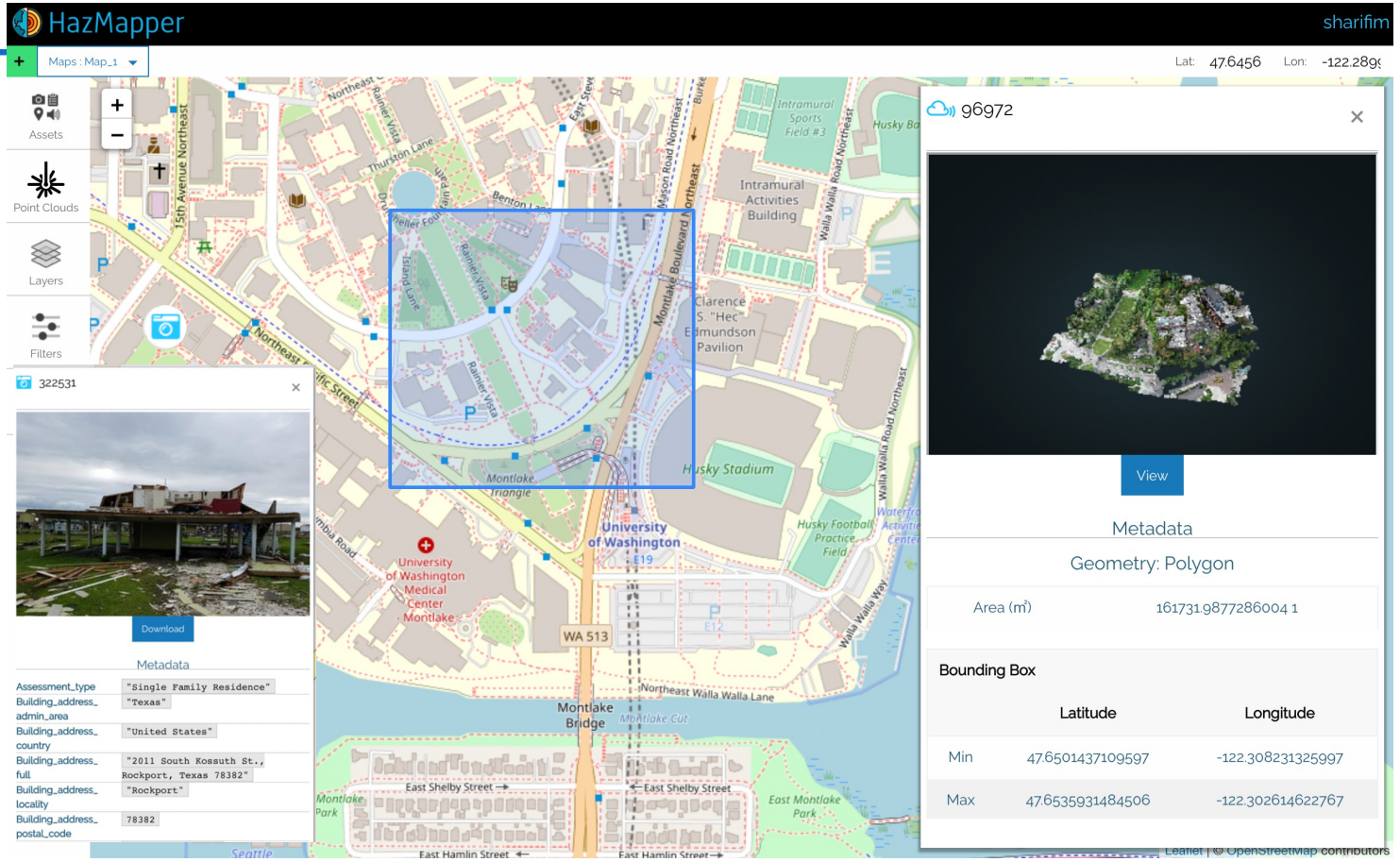
Recon Portal → Data Depot



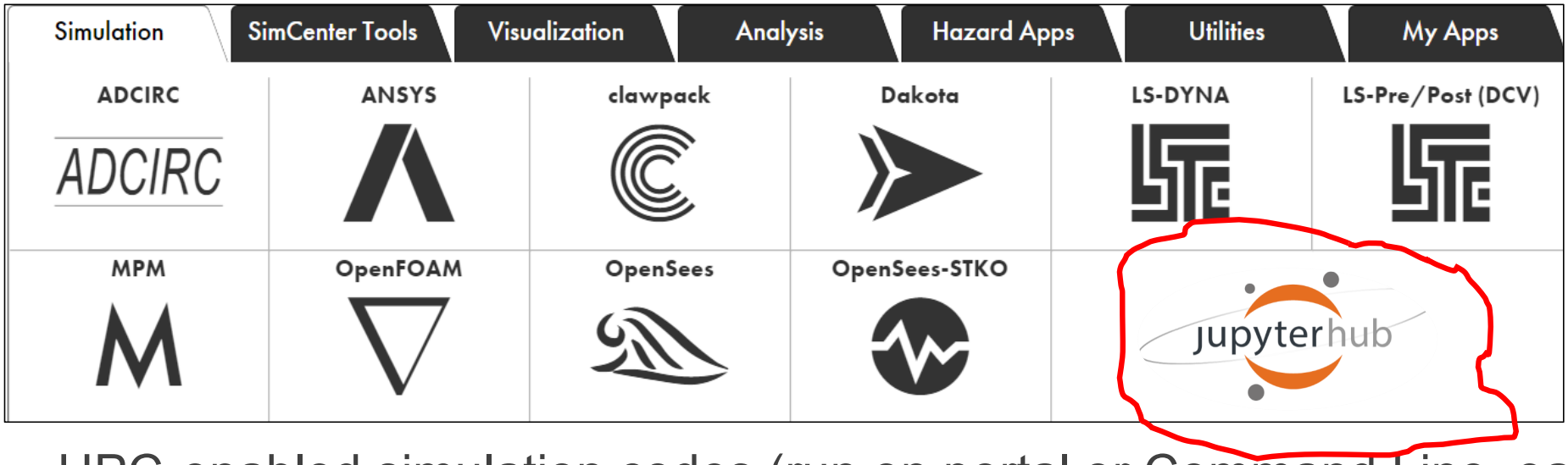
NHERI SimCenter
Center for Computational Modeling & Simulation

HazMapper

- Easy access to images and point cloud data
- Location and preview exposed
- Link to Potree point cloud viewer
- Links to Street View imagery (Mapillary)



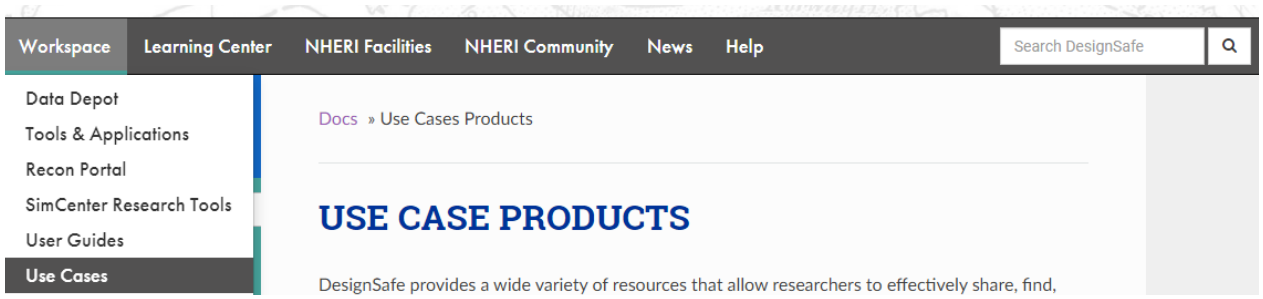
Tools and Applications



- HPC-enabled simulation codes (run on portal or Command Line, easy access to HPC allocation (CPUs, GPUs) through DesignSafe
- Cloud-based tools for data analysis and visualization

DesignSafe Use Cases

- Expanding the use of DesignSafe is facilitated by demonstrated use cases in Natural Hazards Eng
  - Use cases include project descriptions, scripts, documented Jupyter notebooks, etc.
- Twelve use cases documented within DesignSafe



DesignSafe Use Cases

DS Use Case Products

Search docs

- Use Cases Products
  - General Use Cases
  - Geohazard Use Cases
  - Hurricane and Windstorm Use Cases
  - Seismic Use Cases
- Taggit
- ML and AI
- NGL Database
- MPM Landslide
- Large-Scale Storm Surge
- Visualizing Storm Surge
- Wind Flow
- Field Sensing Wind Events

USE CASE PRODUCTS

DesignSafe provides a wide variety of resources that allow researchers to effectively share, find, analyze, and publish data; perform numerical simulations and utilize high performance computing (HPC); and integrate diverse datasets.

General Use Cases

- Damage Tagging of Field Images (Taggit, HazMapper)
- Machine Learning and AI Resources (Jupyter, Interactive Data Analytics, HPC)

Geohazard Use Cases

- Data Analysis using Next Generation Liquefaction (NGL) Database (NGL, Jupyter, SQL, Interactive Data Analytics)
- Landslide Runout Simulations (MPM, Jupyter, Paraview, HPC)

Hurricane and Windstorm Use Cases

- Large-Scale Ensemble Simulations of Storm Surge (ADCIRC, pylauncher, Jupyter, HPC)
- Visualization of Storm Surge Impacts (ADCIRC, Jupyter, QGIS)
- Simulation of Wind Flow around Buildings (OpenFOAM, Jupyter, Paraview, HPC)
- Analysis of Field Sensor Data from Wind Events (Jupyter, Interactive Data Analysis)

Seismic Use Cases

- Site Response Analysis and Model Calibration (OpenSees, SimCenter quoFEM, .
- Simulating the Seismic Performance of Reinforced Concrete Walls (OpenSees, .
- Soil-Structure-Interaction Simulations (OpenSees, STKO, Jupyter, HPC)
- Experimental Visualization of Shaking Table Data (Jupyter, Interactive Data Ana NHERI Facility)

DS Use Case Products

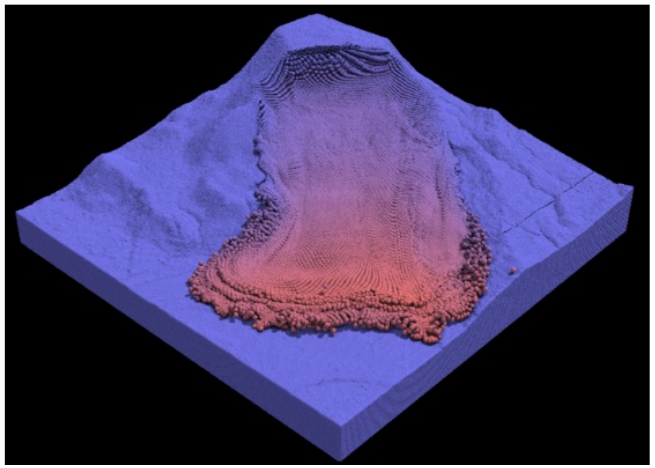
Search docs

- Use Cases Products
- Taggit - Image Tagging
- ML and AI
- NGL Database
- MPM Landslide
  - Background
  - Input generation
  - Running the MPM Code
  - Post Processing
- Large-Scale Storm Surge
- Visualizing Surge for Regional Risks
- CFD Analysis of Winds on Structures
- Field Sensing Wind Events
- OpenSees Model Calibration
- Seismic Response of Concrete Walls
- Soil Structure Interaction
- Experimental Shake Table Testing

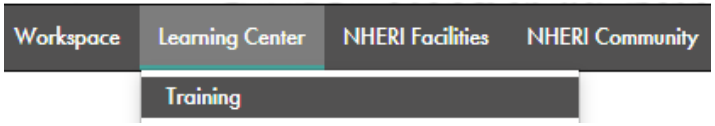
Oso landslide with in situ visualization

In situ visualization is a broad approach to processing simulation data in real-time - that is, wall-clock time, as the simulation is running. Generally, the approach is to provide data extracts, which are condensed representations of the data chosen for the explicit purpose of visualization and computed without writing data to external storage. Since these extracts (often images) are vastly smaller than the raw simulation itself, it becomes possible to save them at a far higher temporal frequency than is practical for the raw data, resulting in substantial gains in both efficiency and accuracy. In situ visualization allows simulations to export complete datasets only at the temporal frequency necessary for economic check- point/restart.

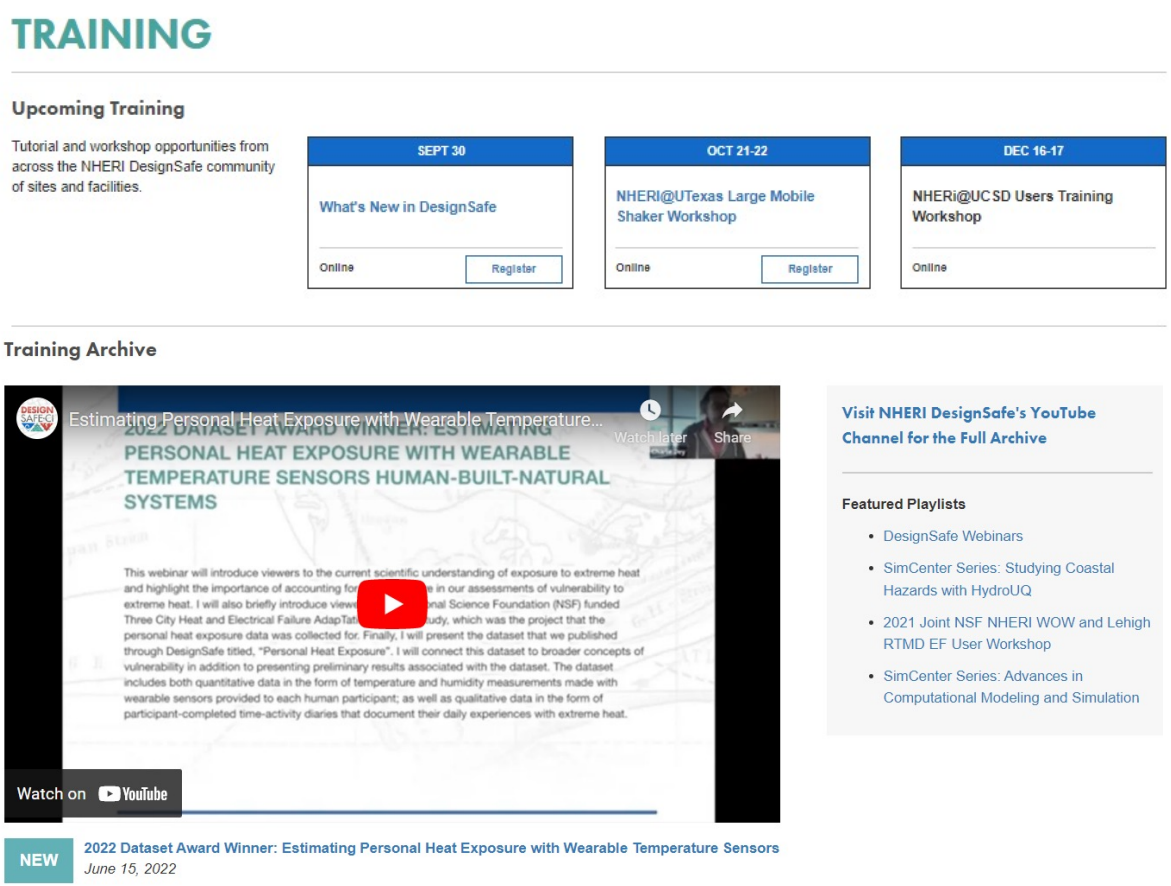
We leverage in situ viz with MPM using TACC Galaxy.



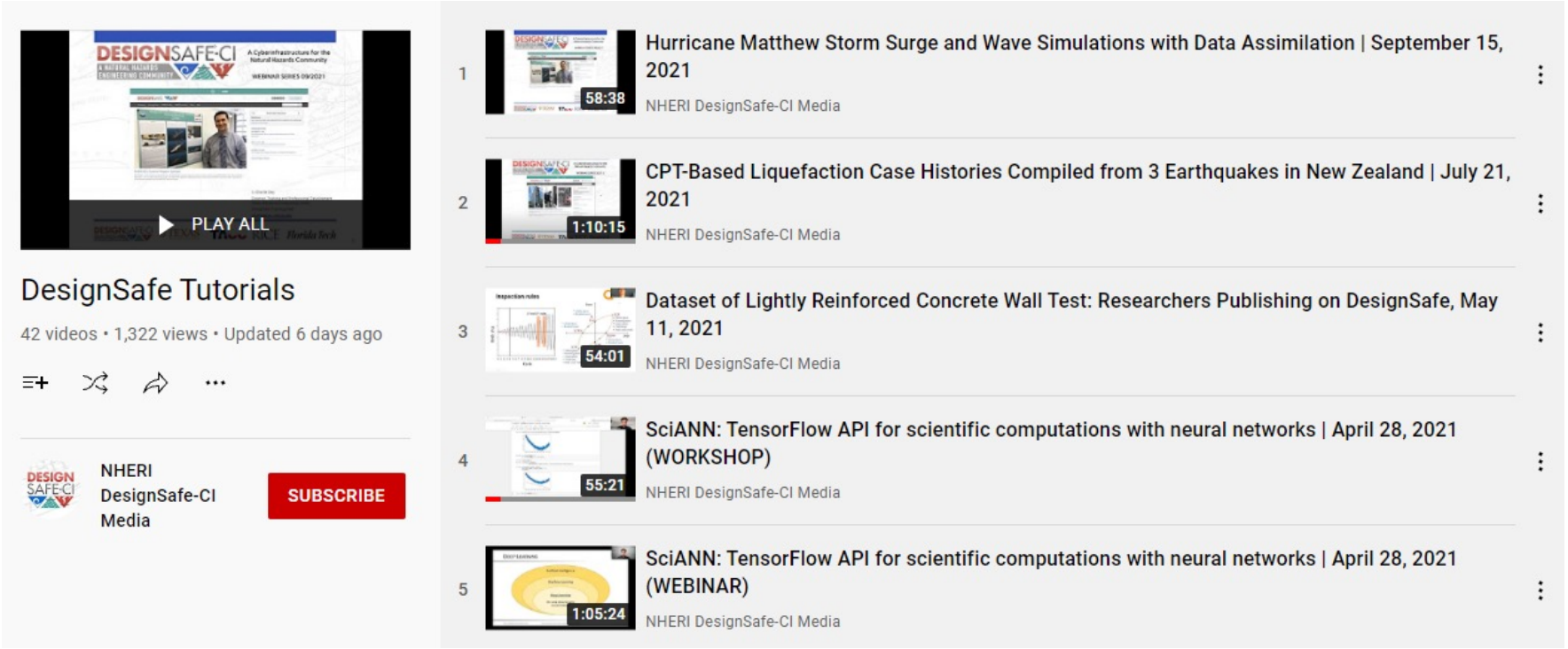
Learning Center



Webinars and Workshops



Learning Center: NHERI YouTube Channel

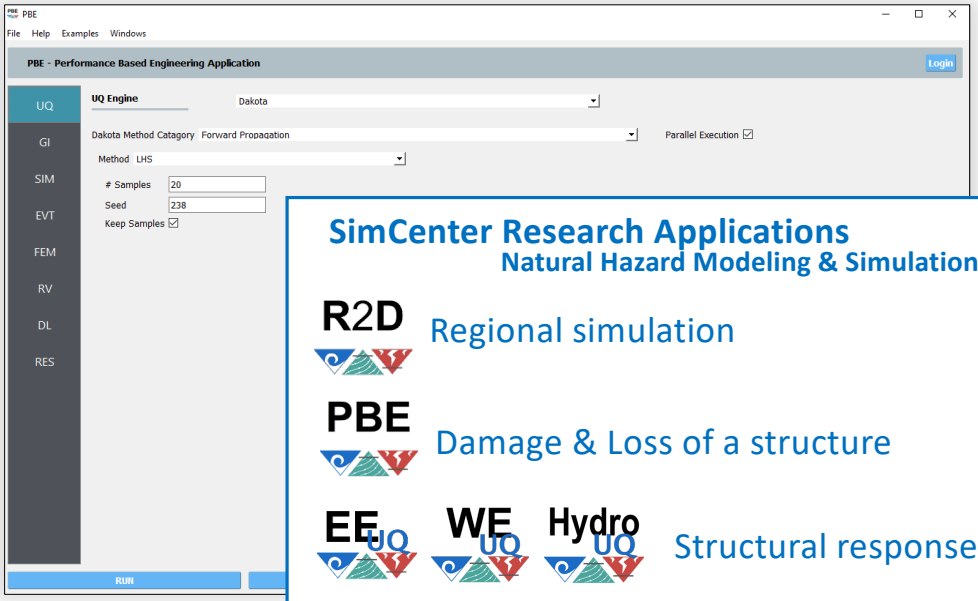


What is NHERI SimCenter?

Center for Computational Modeling & Simulation

Center that provides **software applications** for researchers in **Natural hazard engineering**

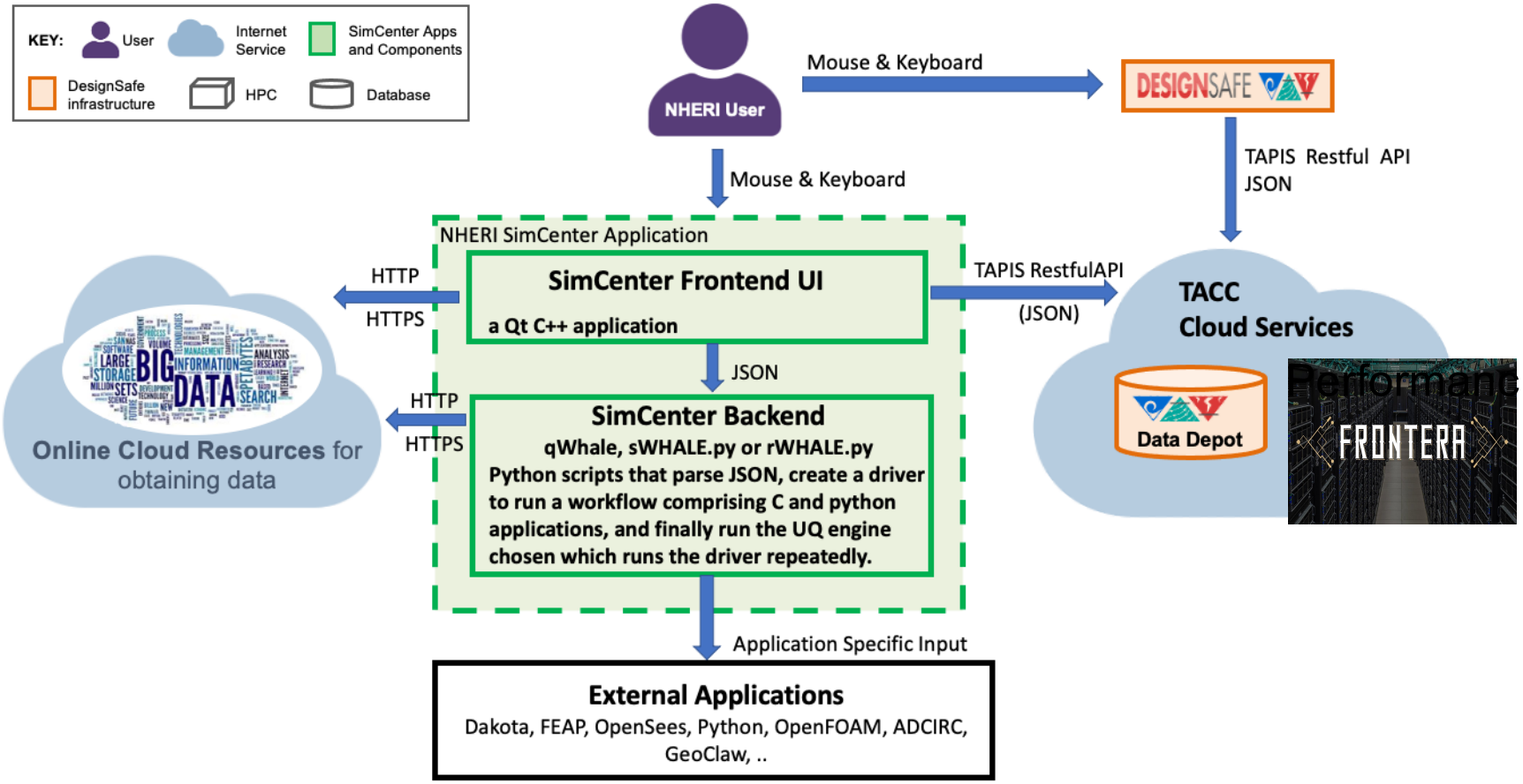
Researchers
Industry
Government Agencies



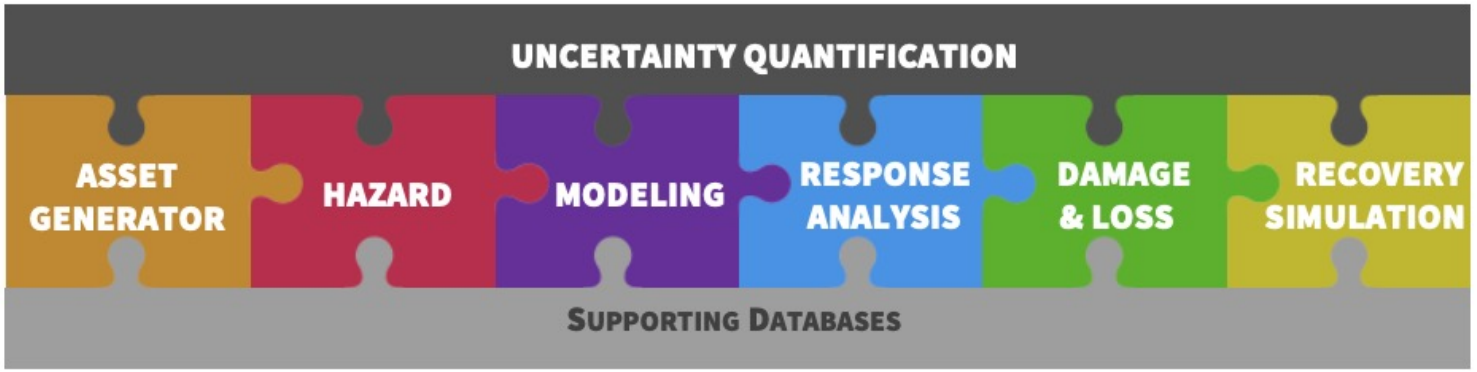
SimCenter Research Applications
Natural Hazard Modeling & Simulation

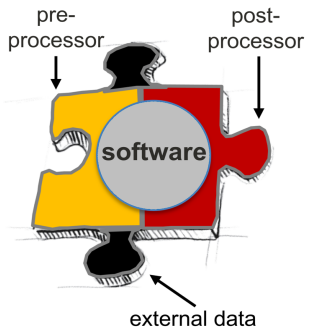
- R2D — Regional simulation
- PBE — Damage & Loss of a structure
- EE-UQ, WE-UQ, Hydro-UQ — Structural response
- QUOFEM — General UQ analysis

UI Launches Scientific Workflows



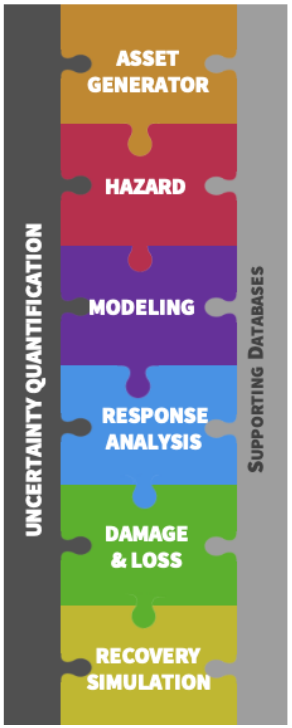
Computational Framework for Building Workflows

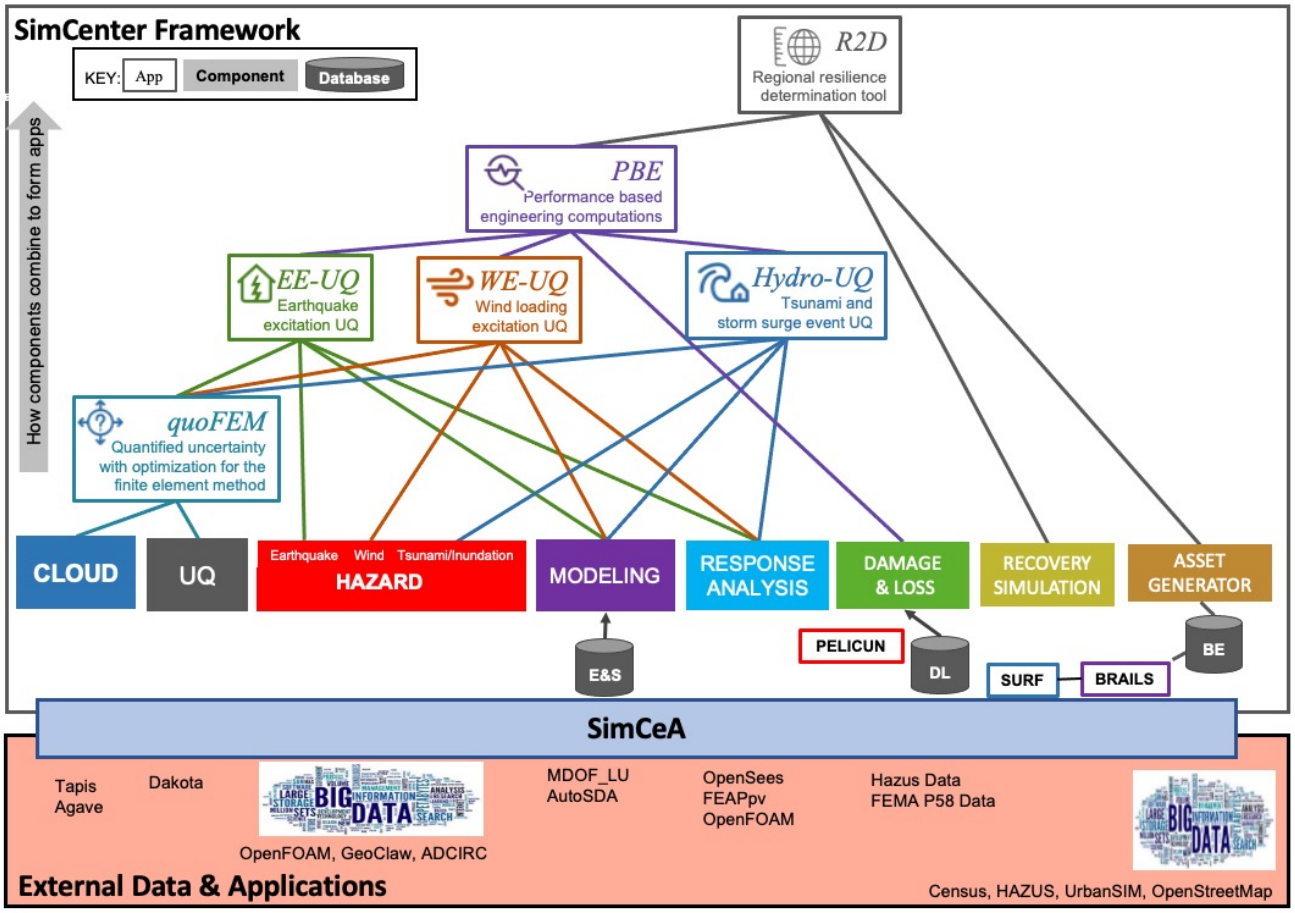




OpenSource :: Multi-Fidelity :: Multi-Hazard

SimCenter Applications Built with Framework





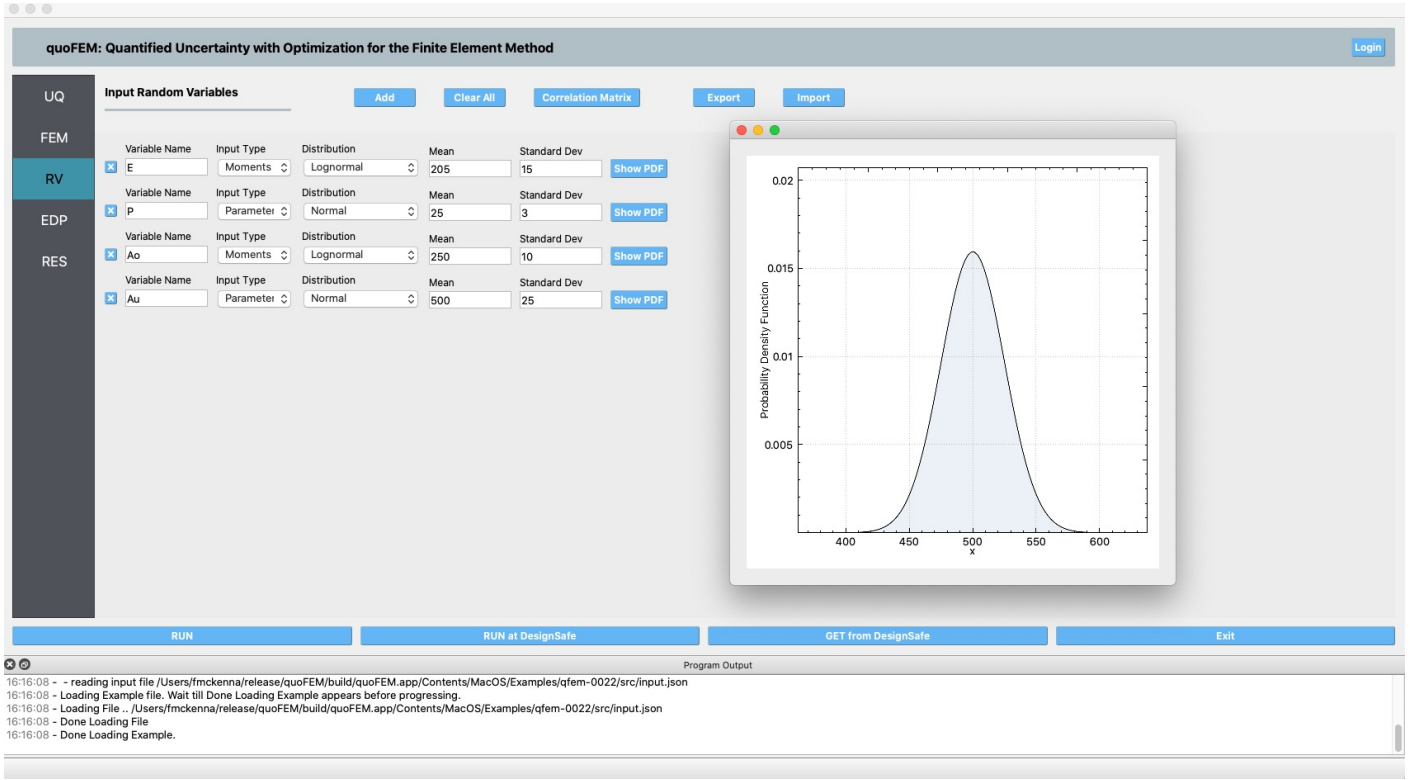
Workflow Application

quoFEM (v3.0)

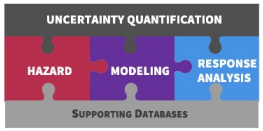
Integrates Simulation Applications with UQ Applications

UQ Problem Types:

- Sampling
- Sensitivity
- Reliability
- Calibration
- Bayesian Calibration
- Surrogate Modeling



Workflow Application



EE-UQ V3.0

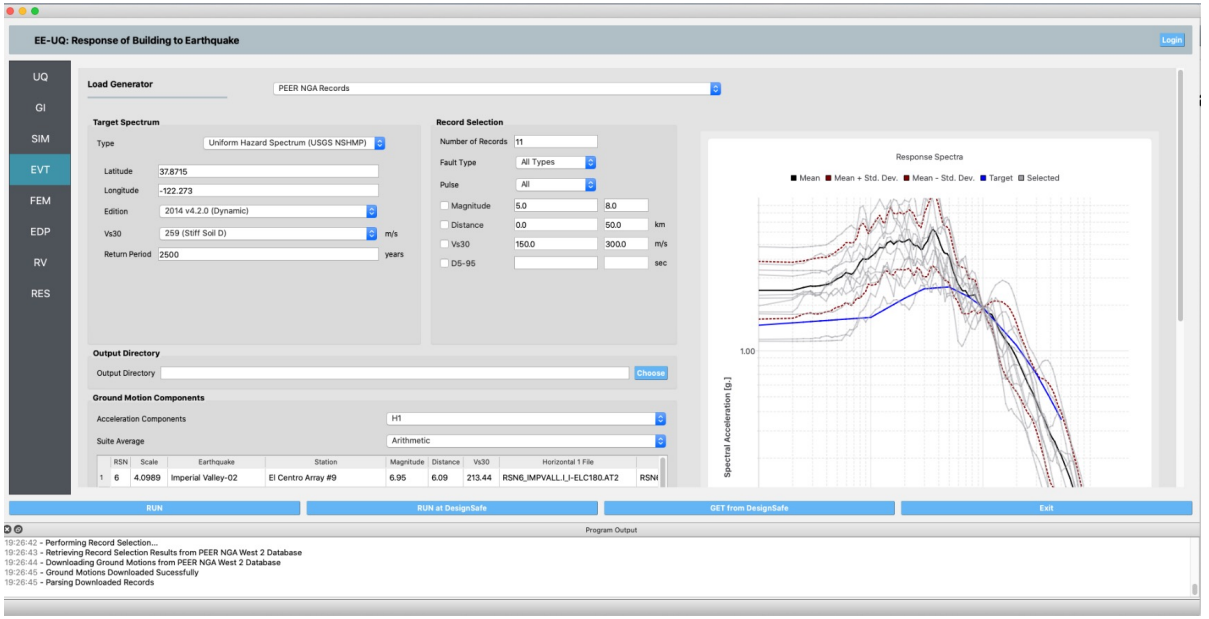
Integrates UQ applications of quoFEM , Earthquake Loading Applications, Building Model Generators with analysis application to determining response of building to earthquake loading

Hazard (Earthquake):

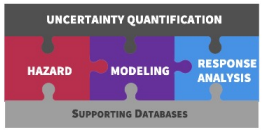
Stochastic Motions
PEER NGA Search with target spectrum
Site Response with Random Fields

Modeling (Building):

OpenSees
Nonlinear Shear Spring (MDOF)
Steel Building Design & Build (AutoSDA)
Concrete Building Design & Build



Workflow Application



WE-UQ V2.2.0

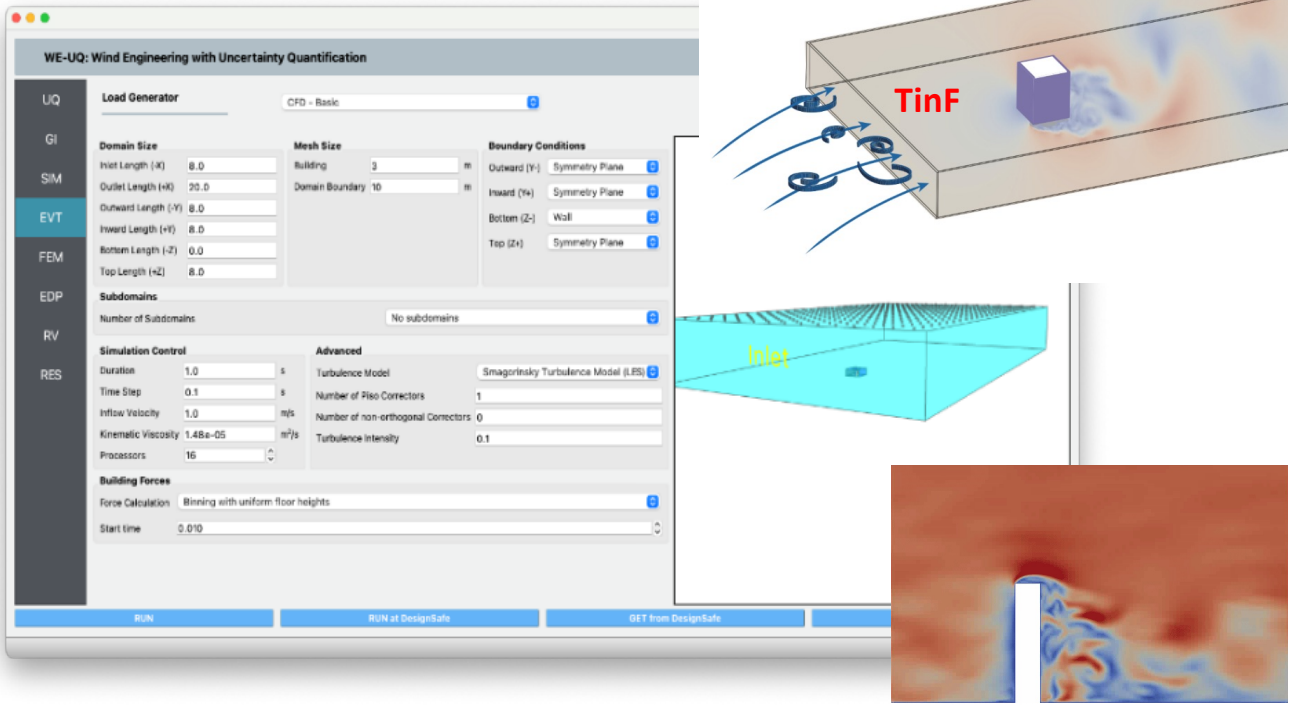
Integrates quoFEM UQ applications, Wind Loading Applications and Building Model Generators with analysis engine to determine response of building subjected to wind loading.

Hazard (Wind):

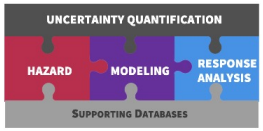
Stochastic Wind
Database-enabled utilizing Vortex-Winds TPU's low-rise wind tunnel datasets
User-provided wind tunnel test data
Uncoupled or **coupled** CFD simulations using OpenFOAM & incorporating TinF options for expert users

Modeling (Building)

OpenSees
Nonlinear Shear Spring (MDOF)



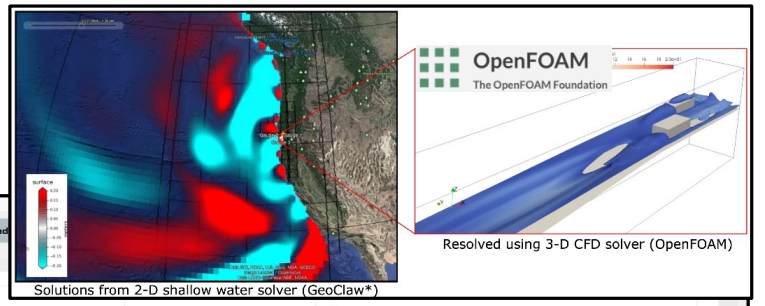
Hydro UQ Workflow Application



Hydro-UQ V1.0.0 –
Integrates UQ applications, Tsunami & Storm Surge Loading Applications and Building Model Generators with Analysis engine to determine response of structure.

Hazard (Tsunami and storm surge):

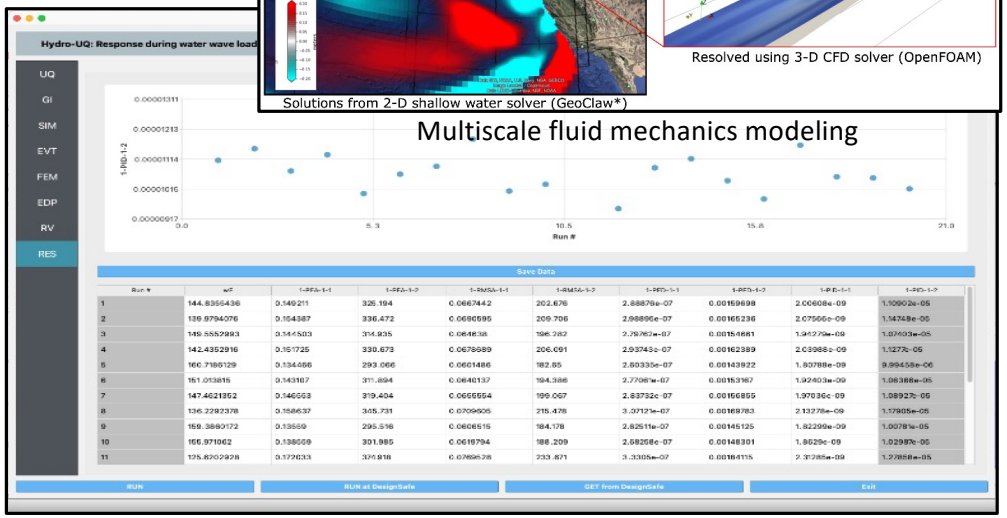
2D Shallow-water → 3D CFD
OSU wave flume digital twin
Easy to use turbulence models for studying broken & unbroken wave behavior



Multiscale fluid mechanics modeling

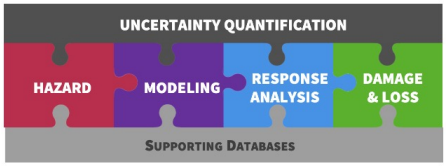
Modeling (Building)

OpenSees
Nonlinear Shear Spring (MDOF)



Probabilistic structural response

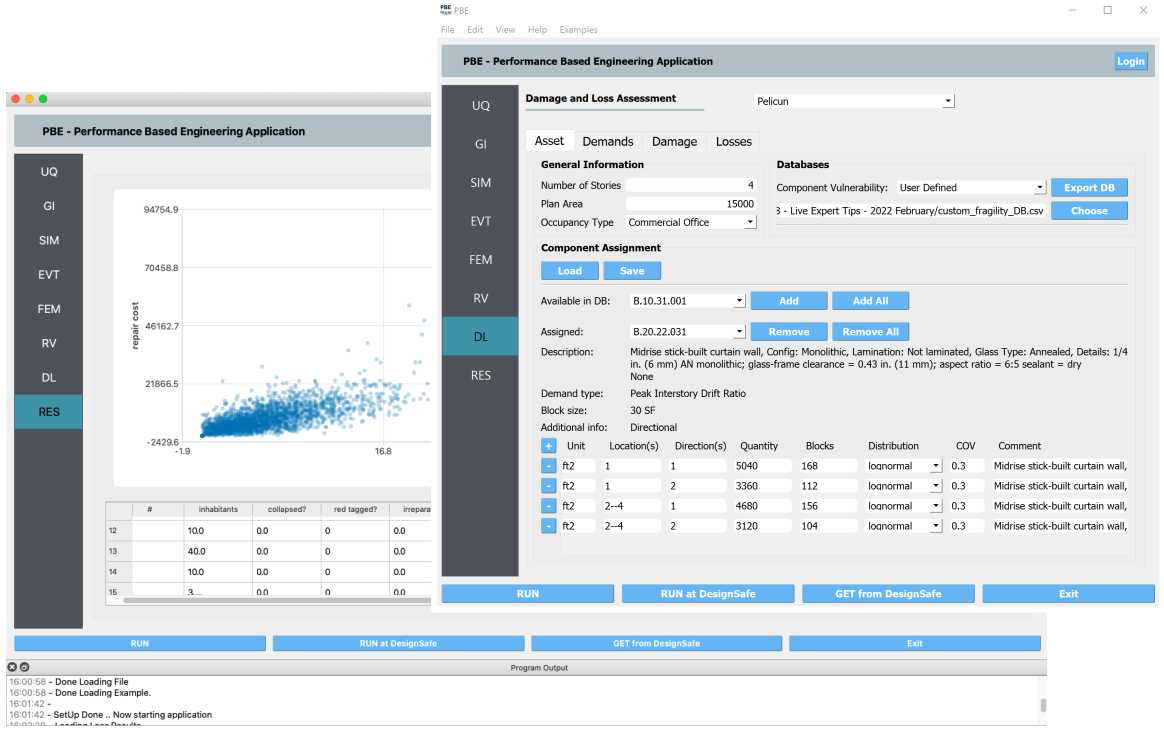
PBE Workflow Application



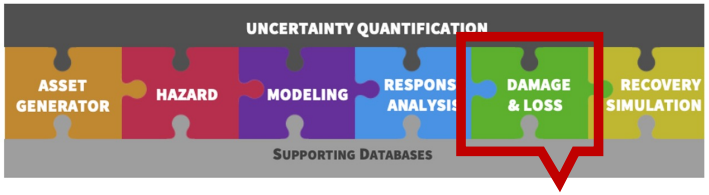
PBE v2.0 (3.0 coming this month!)–
Integrates UQ applications of quoFEM, Building Model Generators, Earthquake Loading, analysis engine and our PELICUN tool for damage and loss assessment.

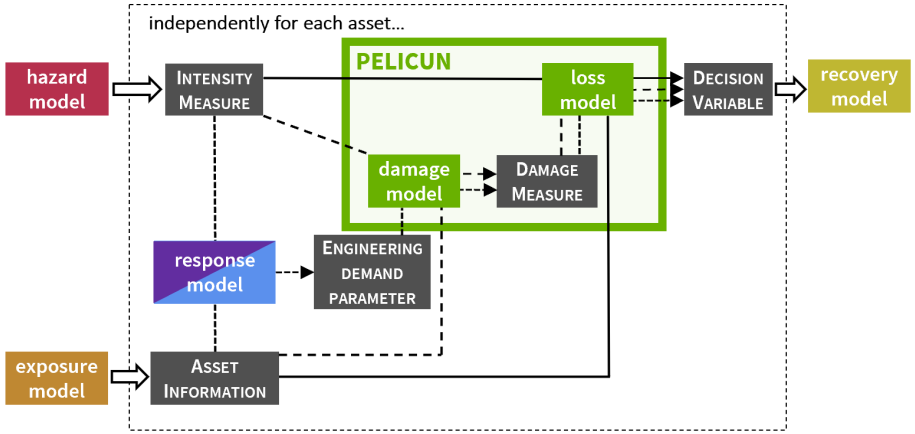
Damage & Loss (using PELICUN):

- Building-level assessment (e.g., HAZUS)
- Component-level assessment (e.g., FEMA P58)
- Supports external response estimation
- Customizable fragility & consequence functions



Pelicun: Performance Assessment

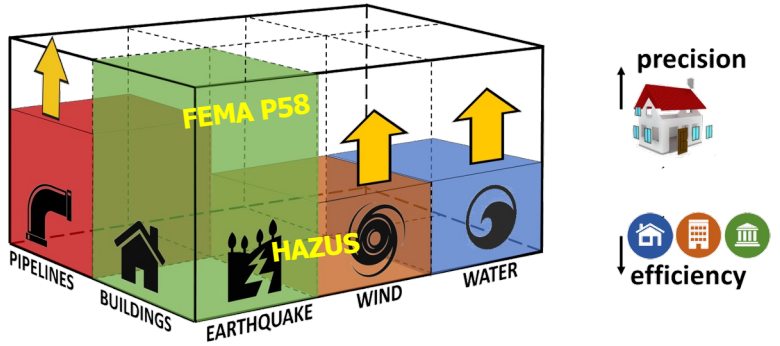




Multi-Fidelity Approach

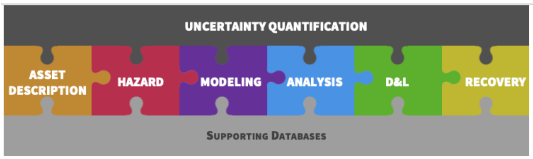
Newest Pelicun features:

- Standardized data schema that unifies performance model data across hazards, assets, and resolutions
- Cascading damages and damage processes
- Customizable damage – consequence mapping
- Portfolio and regional assessment
- Uncertainty in component assignments



Community-Driven Development of New Models & Data

R2D Workflow Application



R2D V2.1 –
Create complex workflows for regional hazard simulation to facilitate research in disaster risk management and recovery.

Asset definition

csv files
GIS files

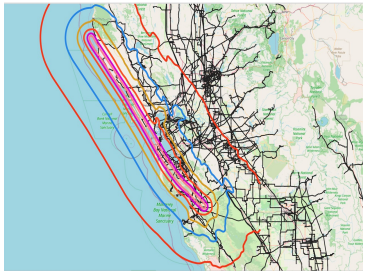
Hazard definition

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

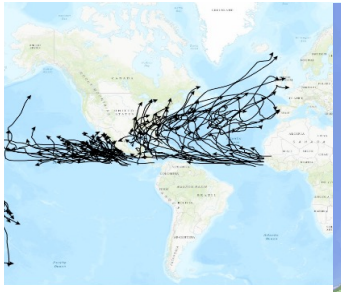
Damage and loss

HAZUS
User-provided fragility functions

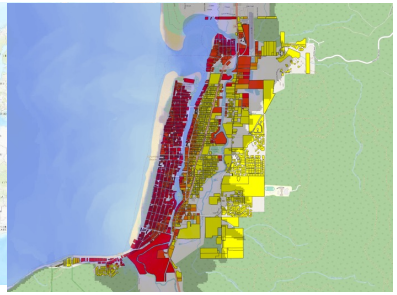
Multiple Hazards



Earthquakes

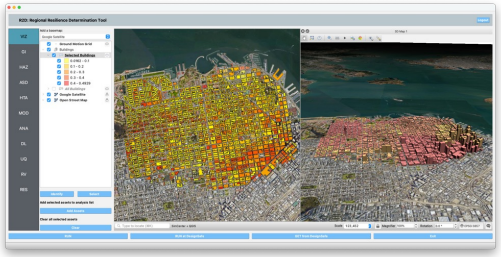


Hurricanes

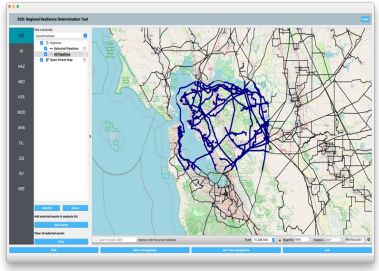


Tsunamis

Multiple Assets



Buildings

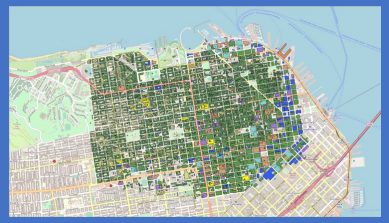


Lifelines

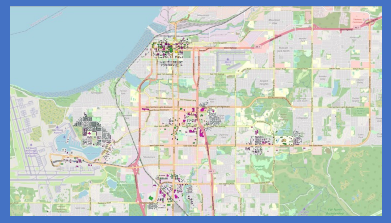
Regional Testbeds & Examples Available

Earthquake

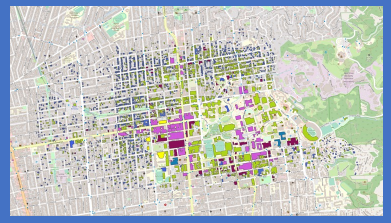
IM PGA



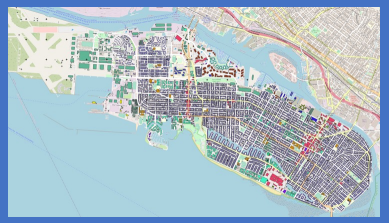
Recorded GMs



Physics-based GMs

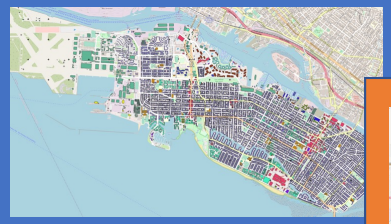


NGAWII GMs



Liquefaction

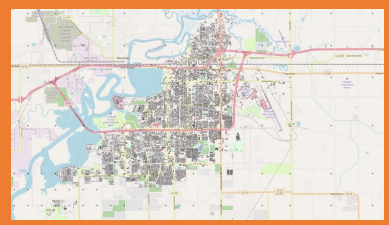
USGS ShakeMap



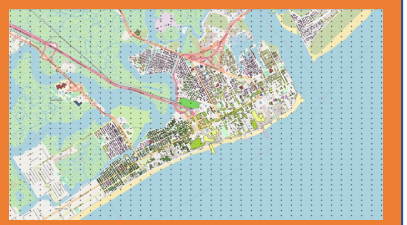
Site-response

Tsunami

Hurricane:



Wind



Wind/Water

Usage of AI/ML in SimCenter Workflows

1. Inventory Collection

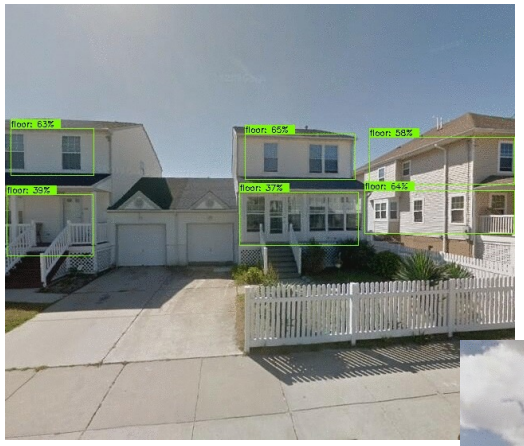
2. Reduction of Simulation Time

1. Inventory Generation

3 Categories of ML Methods Used:

1. **Image Classification:** to assign to an input image a single label from a fixed set of labels
2. **Image Segmentation**: to locate (detect) objects and object boundaries in an input image
3. **Image Processing**: using image segmentation combine object location with mathematics of pinhole cameras to determine information

BRAILS | Workflow: Inventory

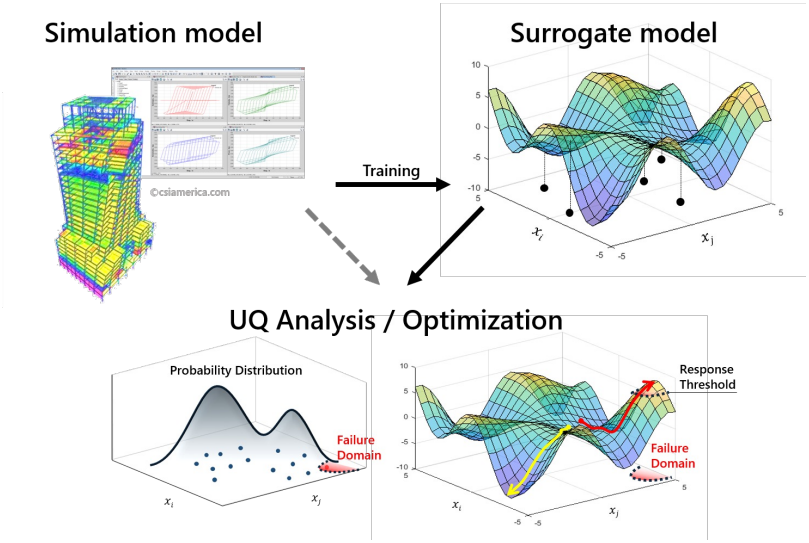


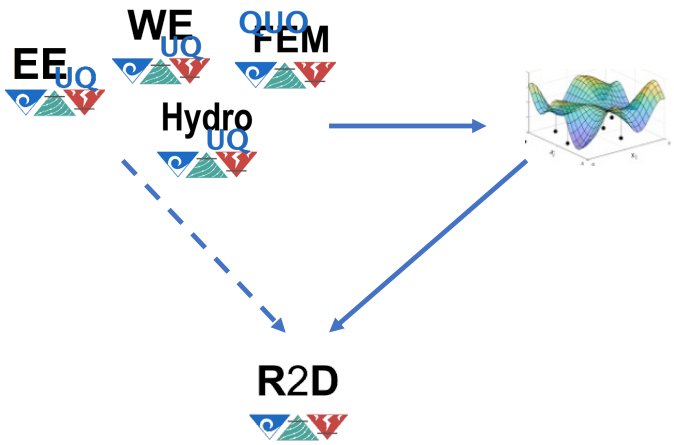
BRAILS creates regional-scale building inventories at building-level granularity using deep learning and computer vision techniques. BRAILS is capable of predicting:

• Roof shape • Roof cover type • Occupancy type • Era of construction	Classification
• Number of floors • Existence of chimneys • Existence of garages	Object Detection
• Building height • Roof eave height • Roof pitch angle • Window area • First floor height	Image Processing

2. Reduction of Simulation Time

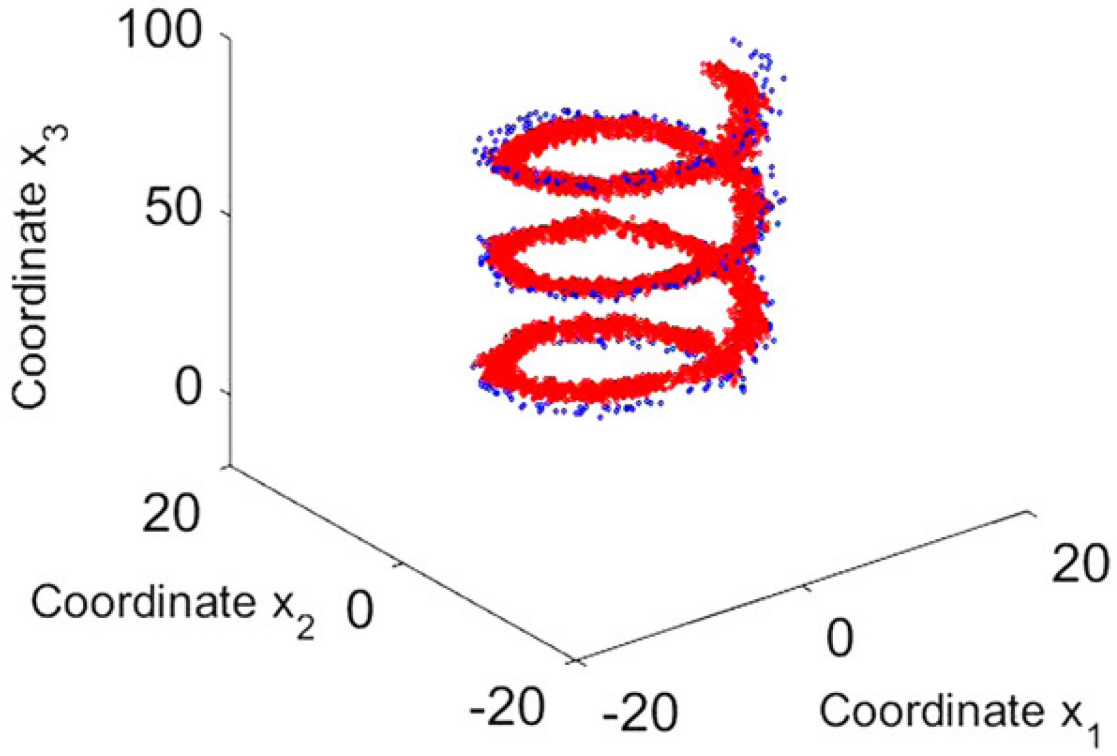
Use ML to generate Surrogates to replace Numerical Simulations in Workflow



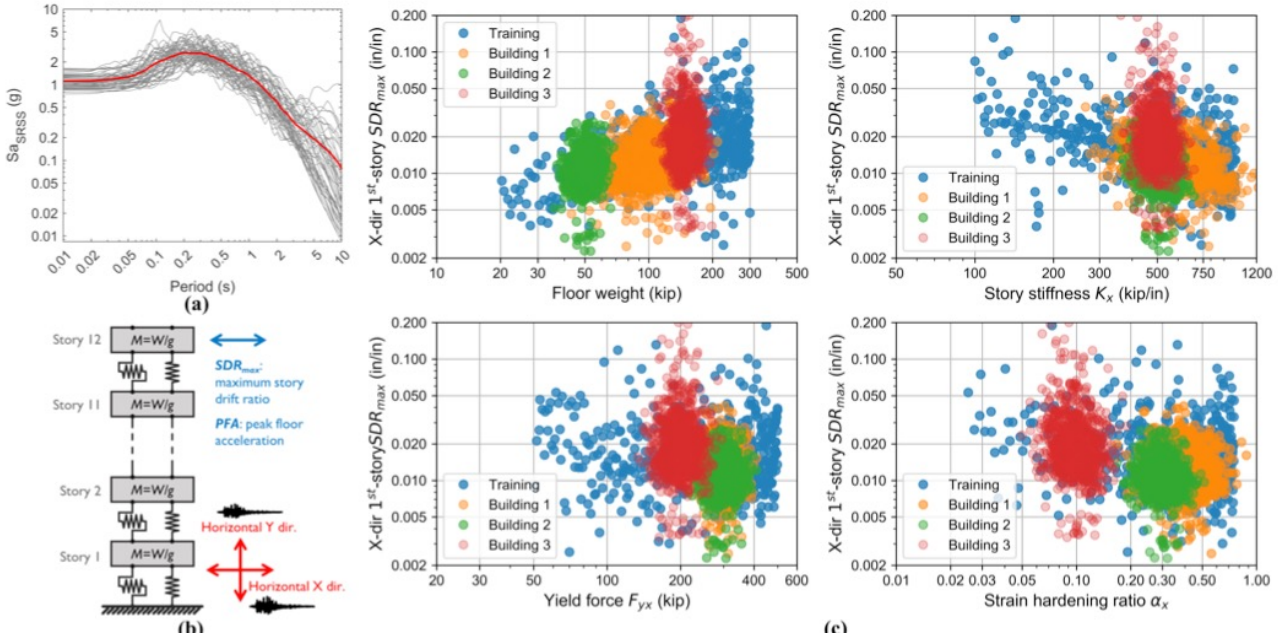


Advanced Manifold Learning Methods

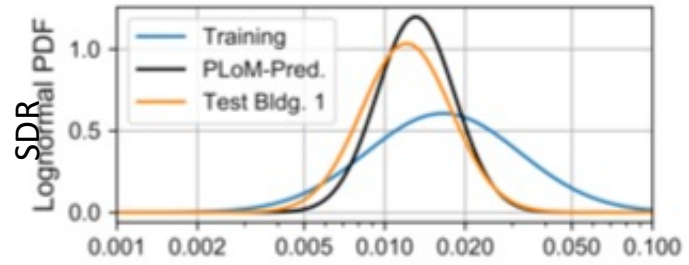
- Identification of non-linear response manifolds via **PLoM** method of Soize and Ghanem (2016,2020)
- Limited data
- High-dimensional stochastic problems

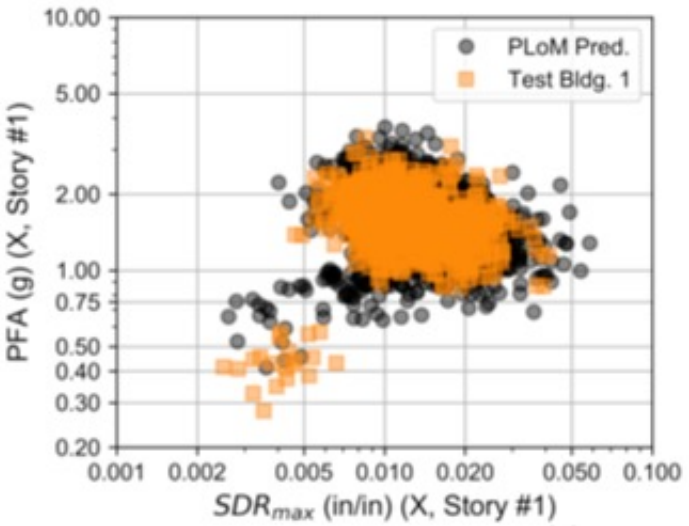


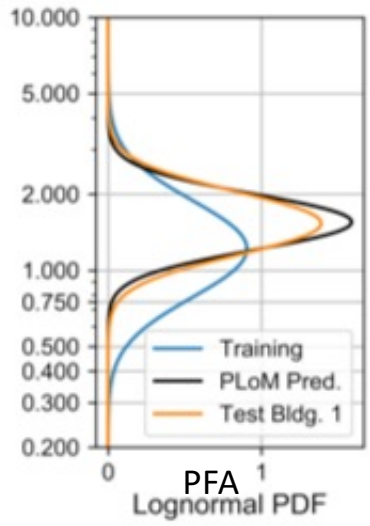
PLoM Example

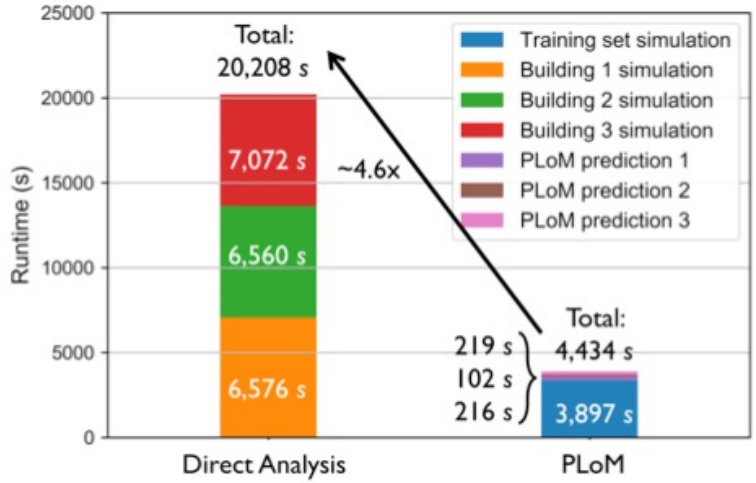


PLoM Example









Outline

- Welcome
- Introduction to NHERI
- ML in Earthquake Engineering: Opportunities and Challenges