
# An Introduction to the NHERI **SimCenter**

**Laura Lowes**
Co-PI
University of Washington

NSF award: CMMI 1612843

# Leadership Group

**Sanjay Govindjee**
UC Berkeley

**Ahsan Kareem**
Notre Dame

**Laura Lowes**
U Washington

**Greg Deierlein**
Stanford

**Satish Rao**
UC Berkeley

**Frank McKenna**
UC Berkeley

**Matt Schoettler**
UC Berkeley

# Software Development Team

**Peter (UW), Michael, Adam (Stanford), Frank, Charles, Wael, Pedro (UW)**

**Qian**

**Ziad**

**Jiawai (ND)**

# Domain Experts

**Additional experts in engineering, urban planning, social science, and computer and information science**


Iris Tien


George Deodatis


Patrick Lynette


Alex Taflanidis


Jack Baker


Ann-Margret Esnard


Joel Conte


Vesna Terzic


Jonathan Bray


Tracy Kijewski-Correa


Michael Motley


Paul Waddell


Camille Crittenden


Filip Filippou


Ewa Deelman


Kincho Law


Ertugrul Taciroglu


Stella Yu


Eduardo Miranda


Andrew Kennedy

# Mission

"Transforming the nation's ability to understand and mitigate adverse effects of natural hazards on the built environment through advanced computational simulation"

**Grounded in the present**

**Five year focus**

**Twenty year vision**

# What is Needed to Accomplish the Mission?


1) Applications that generate UQ in Response Quantities
2) Applications to perform Performance-Based Engineering
3) Applications for Community Resiliency
4) Educational Applications

# Performance-Based Engineering Framework

Simulation of Earthquake

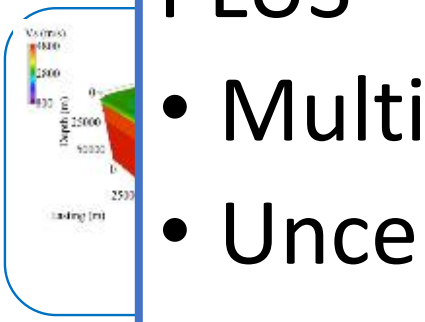
Generate Site-Specific Ground

Simulate Structural

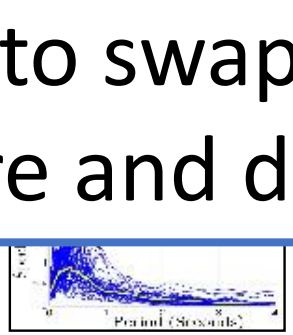
Estimate Loss and Assess

PLUS

- Multiple natural hazards
- Uncertainty quantification
- Option to leverage HPC capabilities
- Option to swap in/out new software and datasets



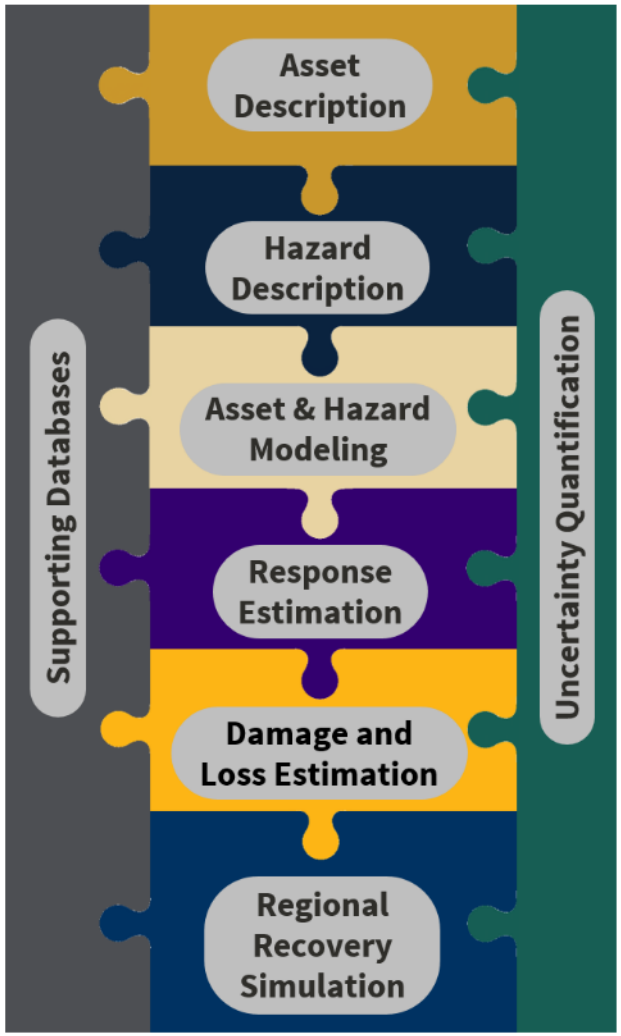
rock motions at various locations within the region



site-specific ground motions representing site hazard

Earth Scientists Str/Geo Engineers Loss & System Modelers Social Scientists

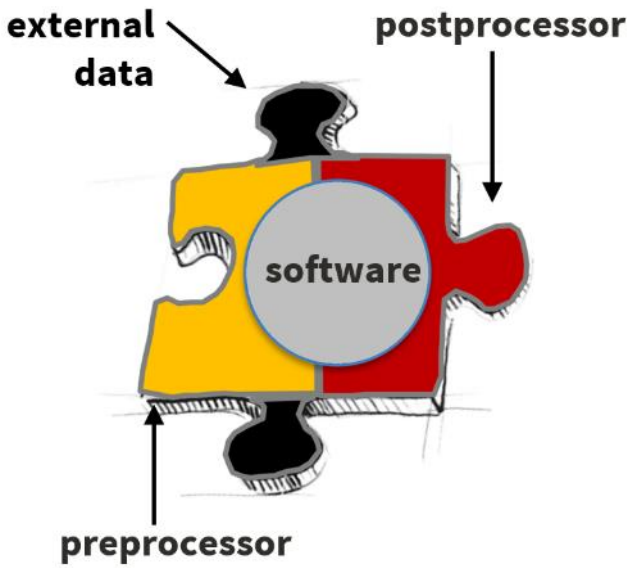
# Application Framework




Application Framework:

a collection of software connected by standardized interfaces

SimCenter efforts focus on framework to connect existing simulation software




HPC resources & data storage at

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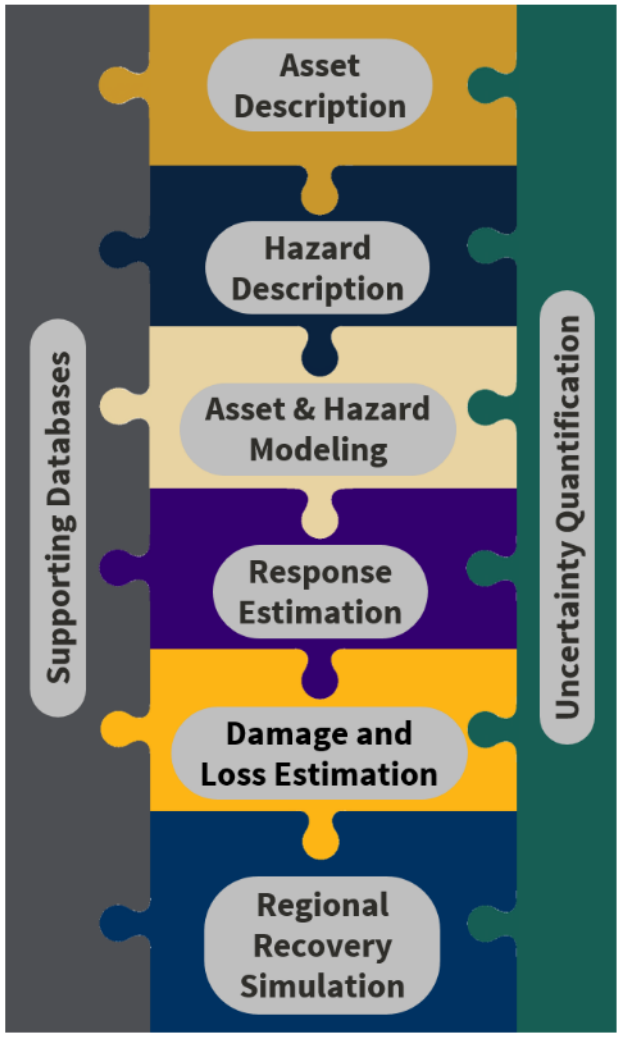
# Application Framework & Research Apps




**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

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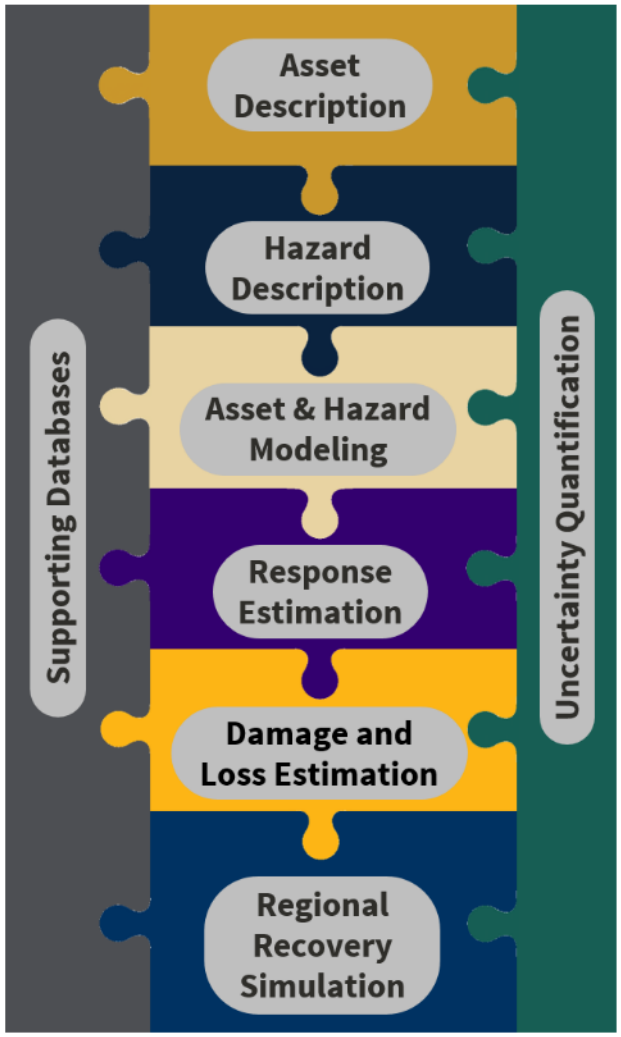


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CWE
WE
EE
FEM
PBE

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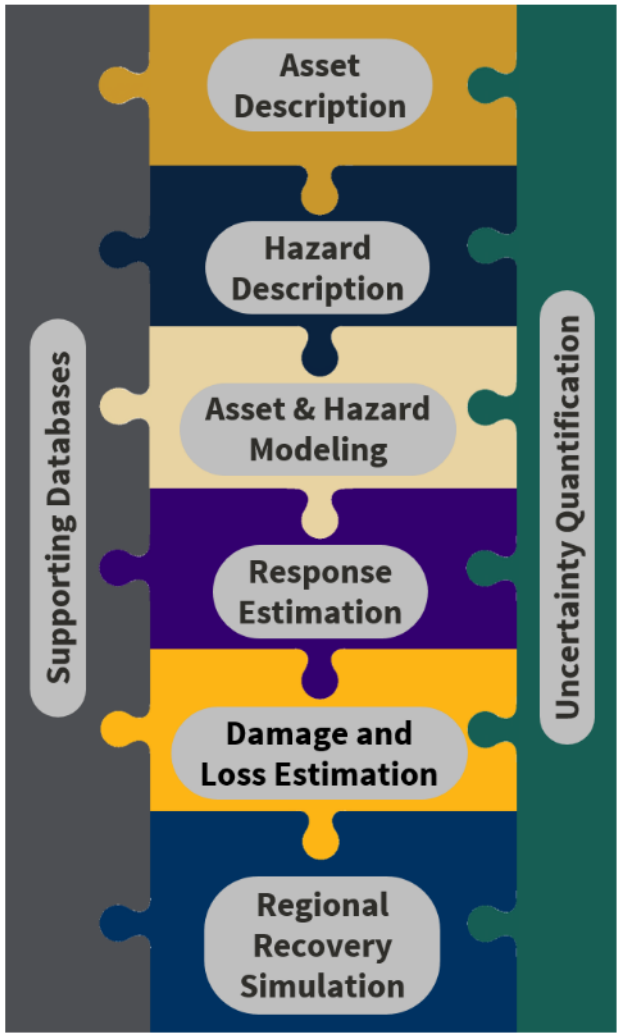


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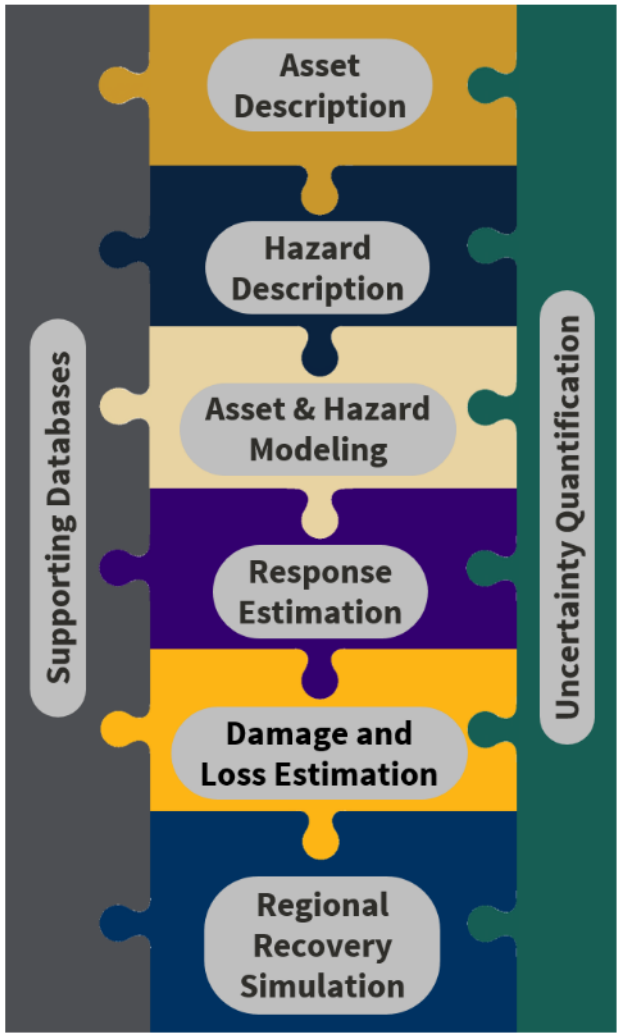


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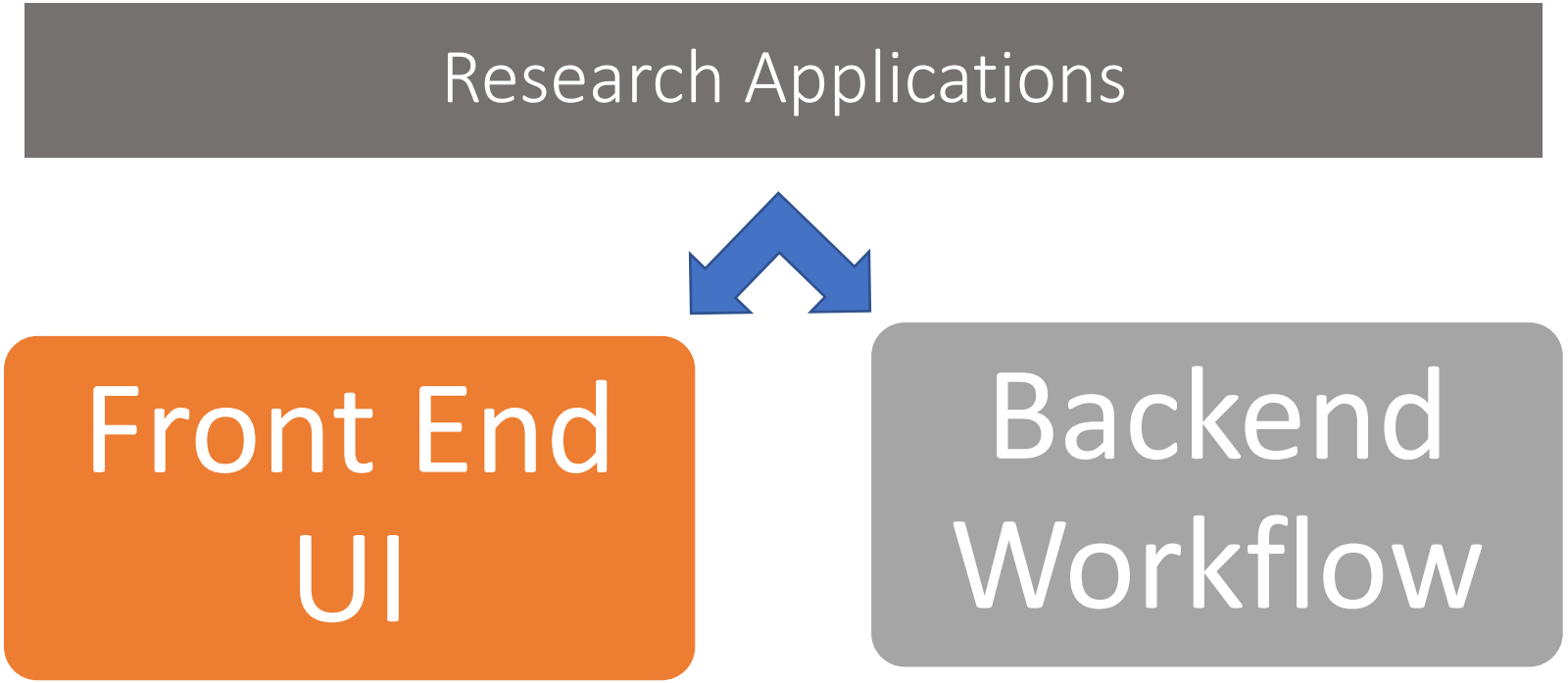
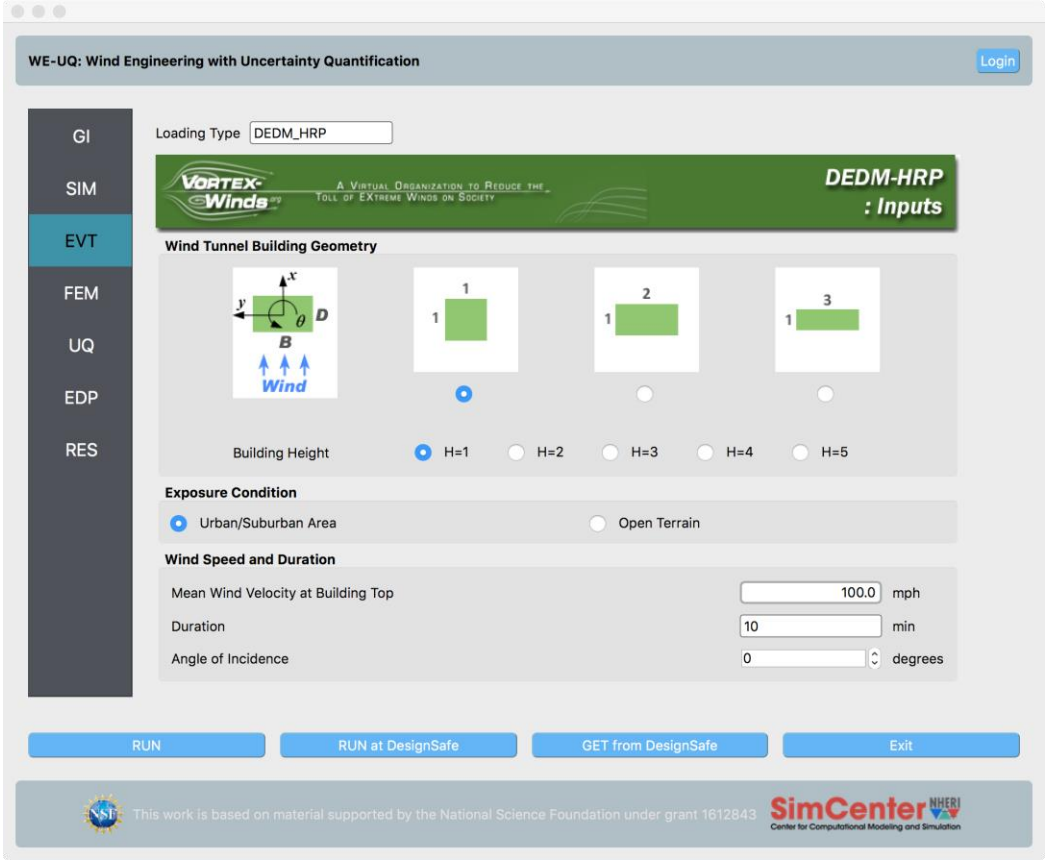
# Research Applications




- Front end is an application runs on your desktop
- Backend is a python “workflow” comprising one or more applications that run on either your desktop or on HPC resources provided by DeisgnSafe via the Texas Advanced Computing Center (TACC)

# Frontend - UI

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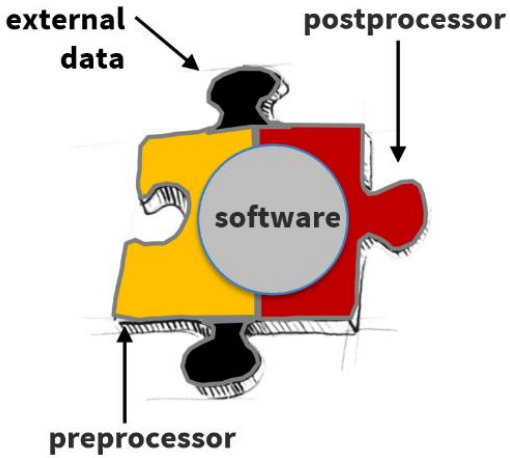
# Backend – A Scientific Workflow Application

**Scientific Workflow Application**: A scientific workflow is the **automation** of a process in which information is passed from **one application to the next.**




OR

# Input file for Backend Workflow is a **JSON** file

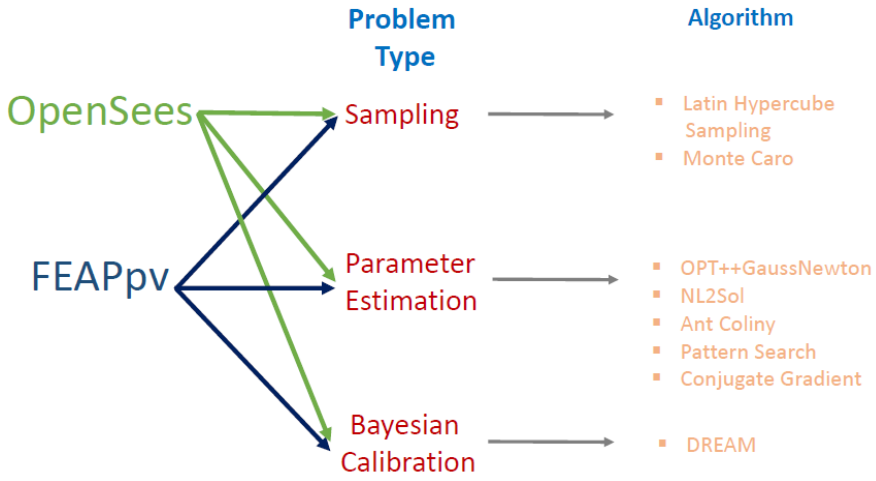
dakota.json

```
{
    "Applications": {
        "EDP": {
            "Application": "StandardWindEDP",
            "ApplicationData": {
            }
        },
        "Events": [
            {
                "Application": "StochasticWindInput-WittigSinha1975",
                "ApplicationData": {
                },
                "EventClassification": "Wind"
            }
        ],
        "Modeling": {
            "Application": "MDOF_BuildingModel",
            "ApplicationData": {
            }
        },
        "Simulation": {
            "Application": "OpenSees-Simulation",
            "ApplicationData": {
```

dakota.json

# uqFEM Application

- Integrates Simulation Applications with UQ Engine(s)




**Application:**

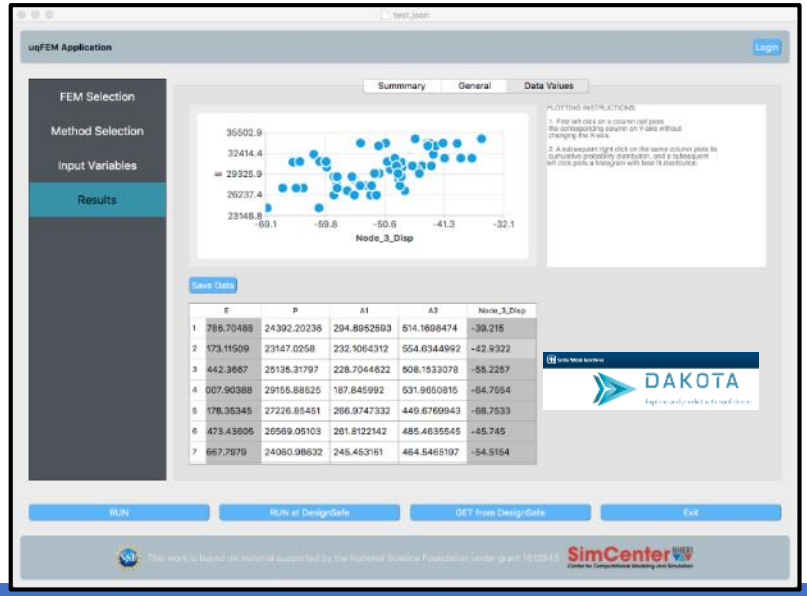
- **Inputs:** FEM model, input uncertainty specification, UQ method & post-processing script
- **Outputs:** Depends on problem type and post-processing (e.g. Uncertainty measures of outputs)

**Release Dates:**

- **V1.0 (June 2018)** Connecting UQ engine DAKOTA with OpenSees and FEAP
- **V2.0 (2019)** – UQ Engines other than DAKOTA (e.g. UQpy)

**Research Opportunities:**

- Surrogate Modeling
- Model Calibration



# uqFEM Application

- Integrates Simulation Applications with UQ Engine(s)

**Application:**

- **Inputs:** FEM mod
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  processing script
- **Outputs:** Depend
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  measures of outp

**Release Dates:**

- **V1.0 (June 2018)** Co
  DAKOTA with Open
- **V2.0 (2019)** – UQ Er
  (e.g. UQpy)

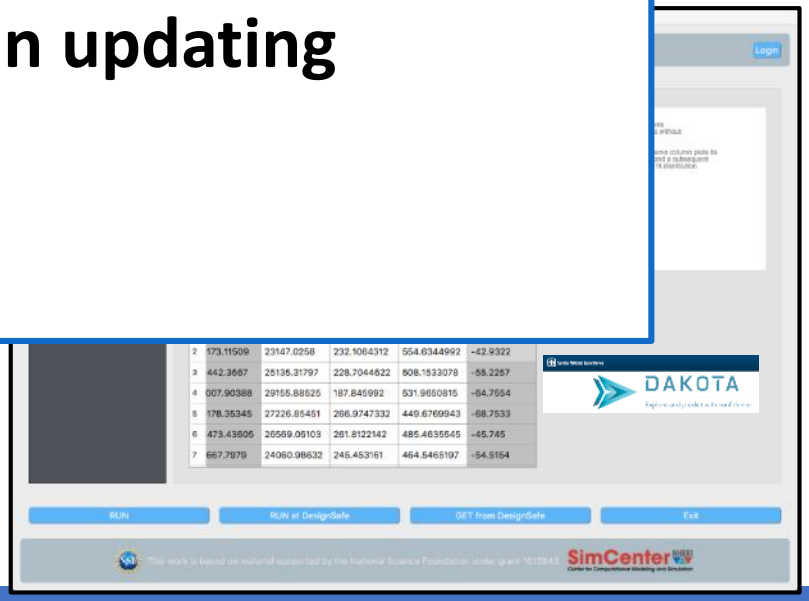
**Fall 2019 rename to quoFEM to emphasize inclusion of optimization in parameter estimation and Bayseian updating**

**Algorithm**

Latin Hypercube
Sampling
Monte Caro

OPT++GaussNewton
NL2Sol
Ant Coliny
Pattern Search
Conjugate Gradient

DREAM

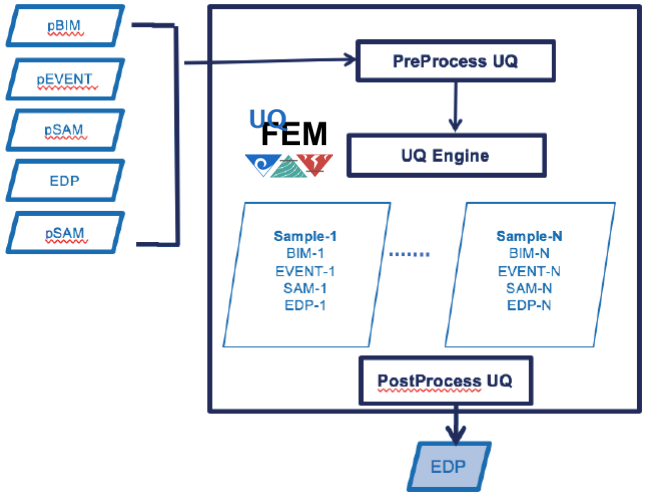



**Research Opportunities:**

- Surrogate Modeling
- Model Calibration

# EE-UQ Application

- Quantifies uncertainty in building response when subjected to an earthquake

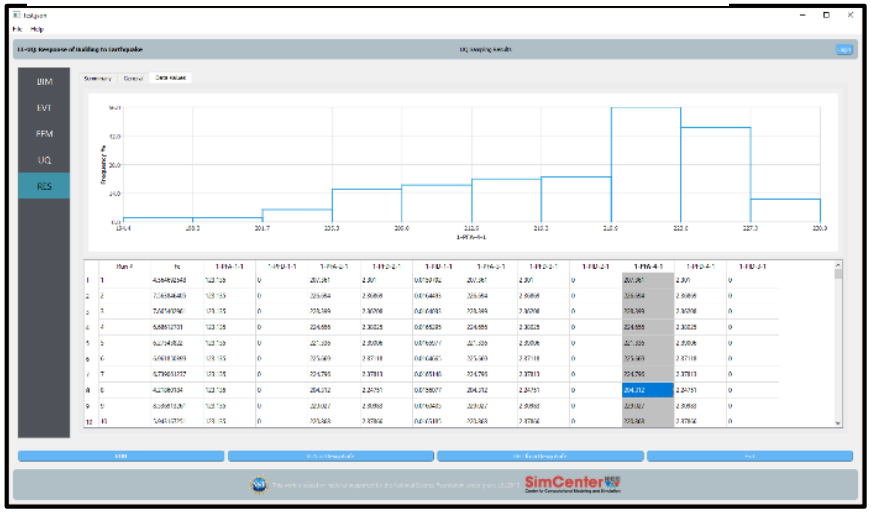



**Application:**

- **Inputs:** Building information, earthquake event & uncertainty specification
- **Outputs:** Uncertainty measures of building response

**Release Dates:**

- **V1.0 (2018)** Uniform Excitation
- **V2.0 (2019)** Rock Outcrop motions + Expert System
- **V3.0 (2020)** Soil Box around Building + Machine Learning

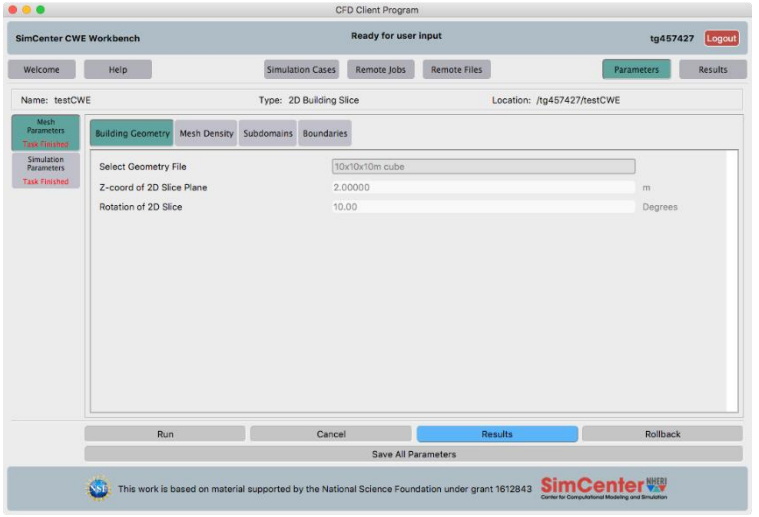


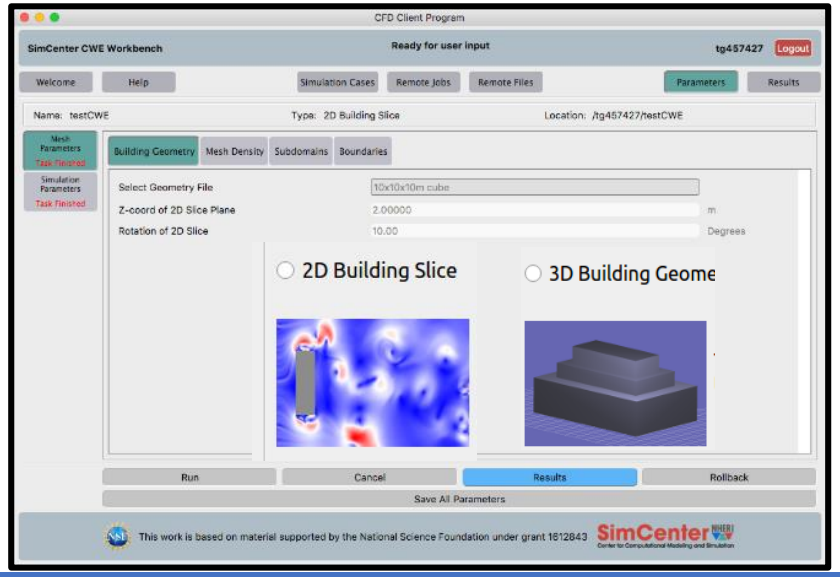
**Research Opportunities:**

- Finite element modeling
- Hazard characterization
- UQ including surrogate model generation
- Datasets for model calibration

# Computational Wind Engineering

- Interface to OpenFOAM (CFD)
- User Inputs Building Information
- User Selects from different loading options & Inputs Parameters
- User Specifies RV distributions
- The tool generates the analysis model, obtains wind forces in building, run a set of deterministic simulations on DesignSafe.
- User selects run & views different output results.




- Version 1.0 (June 2018): Wind Flow around Bluff Bodies
- Version 2.0 (2019): Wind Forces on Building
- Version 3.0 (2020): Multi-fidelity Modeling & UQ

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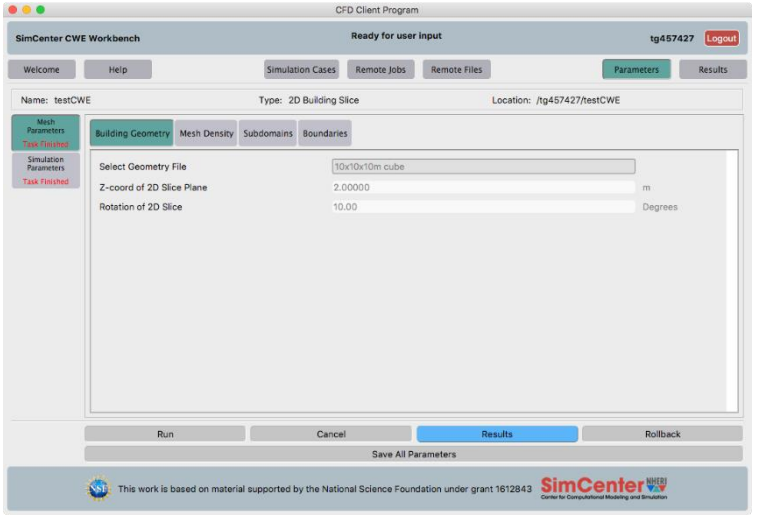


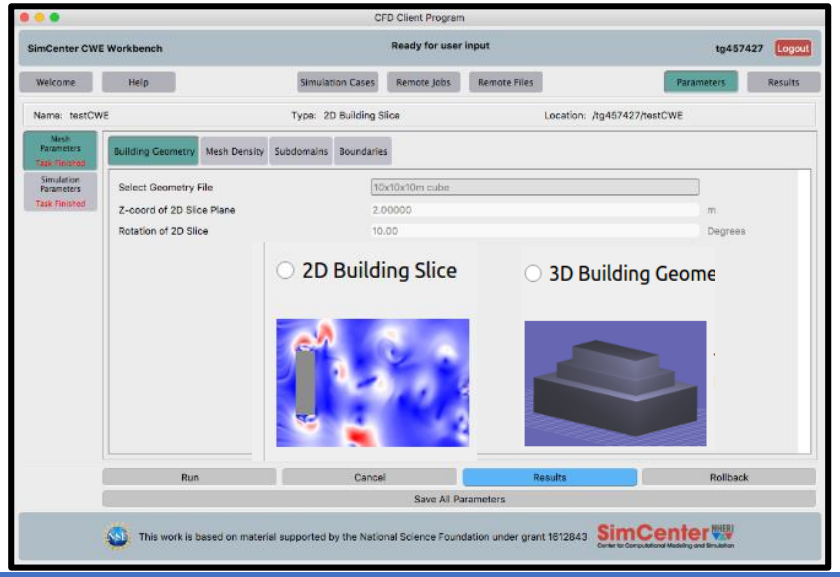


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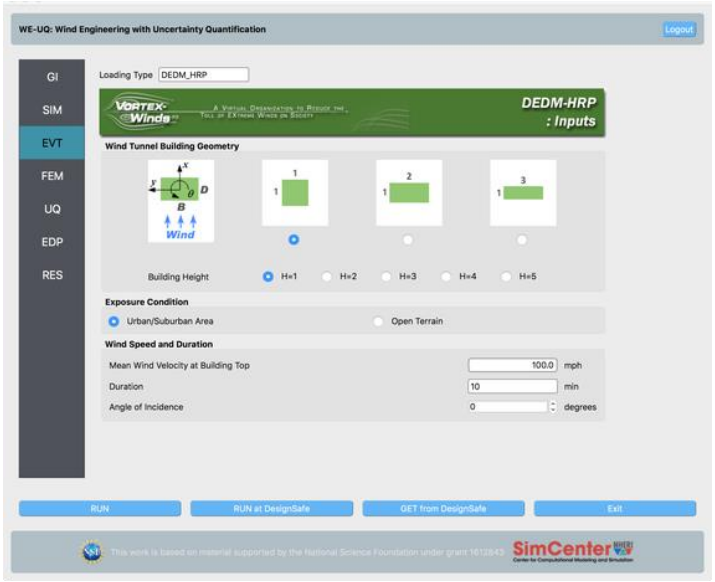
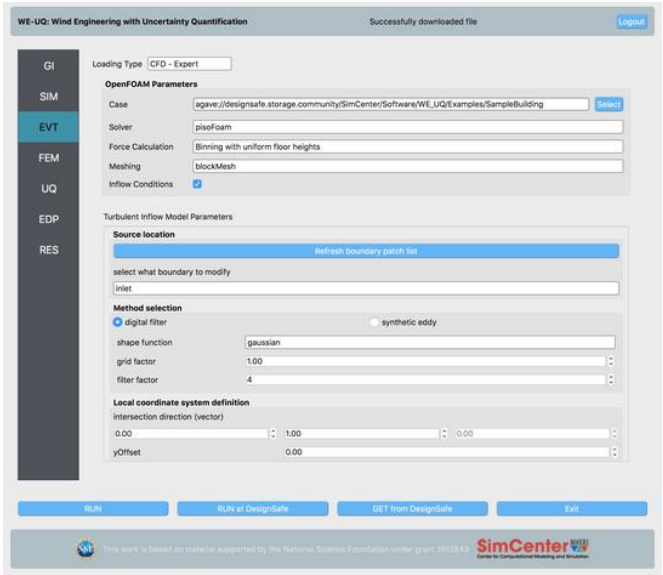
# Wind Engineering

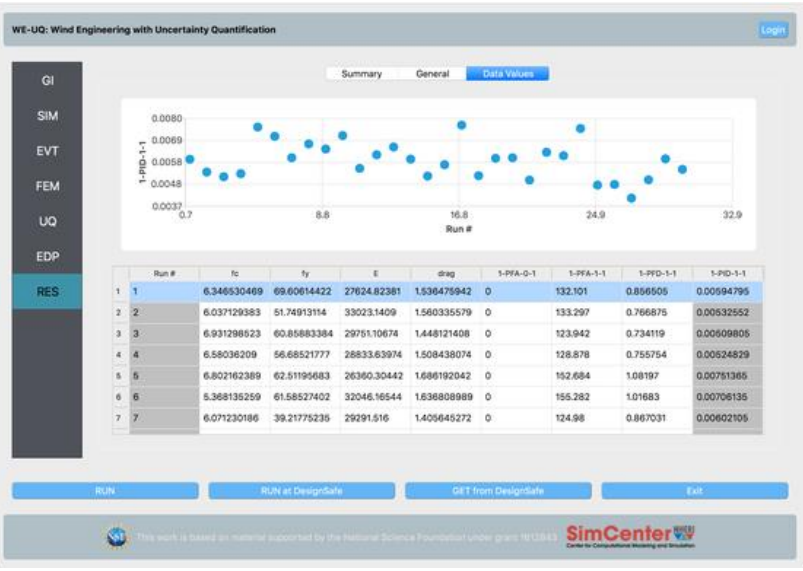
- Assess the building performance to wind loading. The application is focused
- Quantifying uncertainties in predicted response due to uncertainty in building properties, wind load, and simplification incorporated in simulation software.
- Option to perform simulations on the Stampede2,

- Version 1.0 (July 2019)



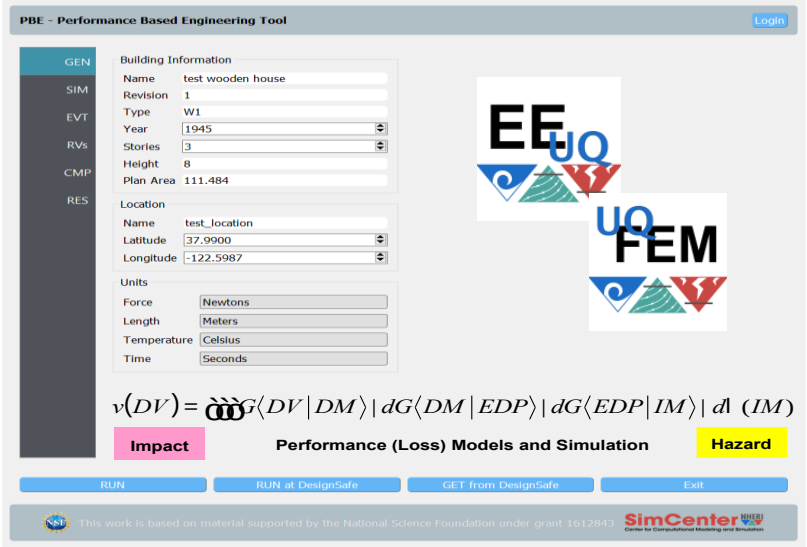



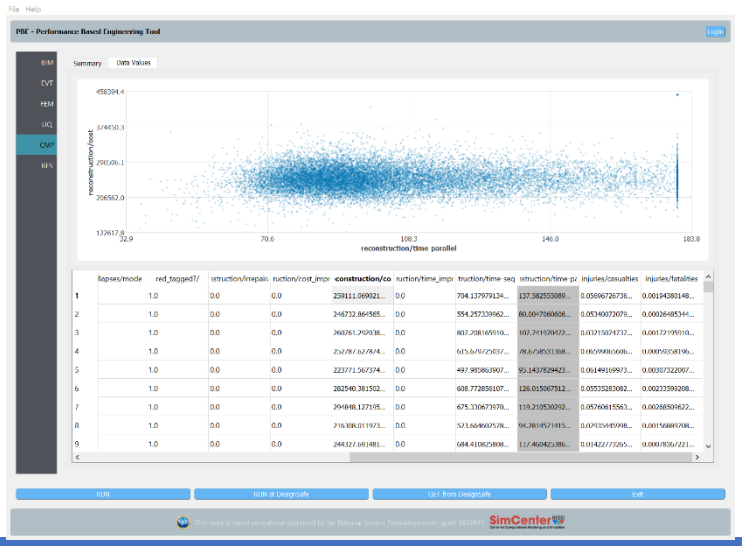




# PBE Application

- Probabilistic damage & loss calculations of a building subjected to a natural hazard




## Application:

- **Inputs:**
  Building & structural information,
  Hazard characterization,
  Contents,
  Damage & loss functions, e.g. **P58, HAZUS, Pelicun,** or user-defined.
- **Outputs:** Damage, loss, and consequences

## Release Dates:

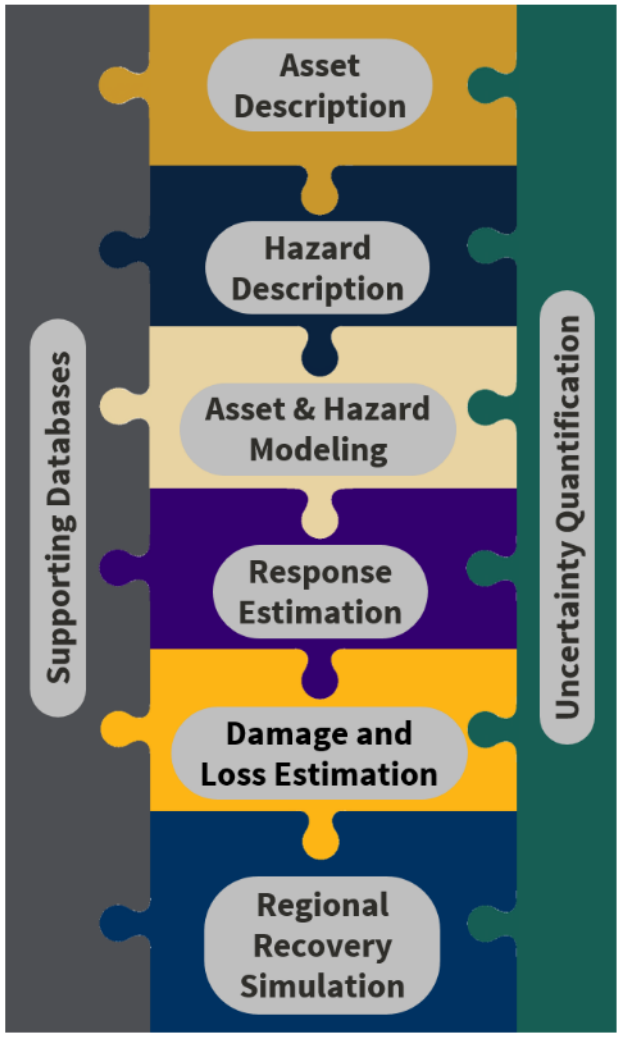
- **V1.0 (Oct 2018)** Earthquake
- **V2.0 (2020)** Other Hazards

## Research Opportunities:

- Damage & loss calculations
- Validation of fragility and consequence functions

# COMING in 2020: Resiliency Decision Tool

RDT

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RDT

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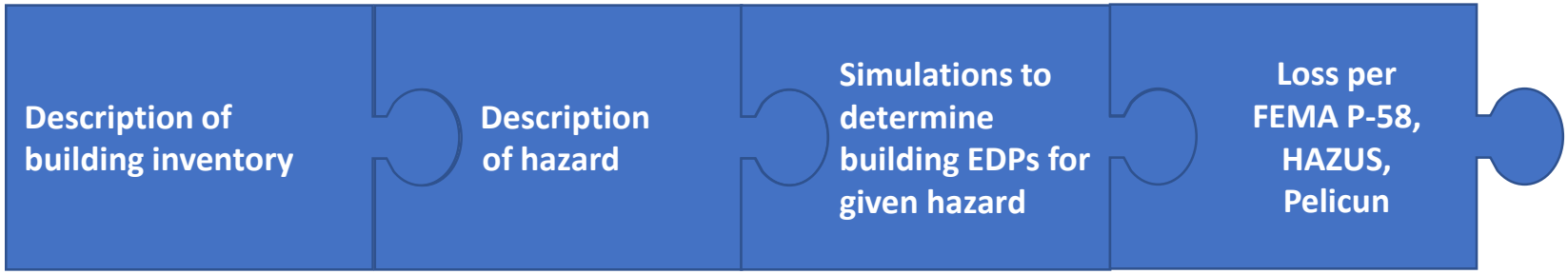
# RDT Creates and executes a regional loss workflow

- Backend application for regional hazard and loss simulations includes multiple individual applications.




**Current Release V1.1 (Feb 2019)**

- Regional **earthquake** workflow
- Various hazard representations

**Future Release V2.0 (Sept 2019)**

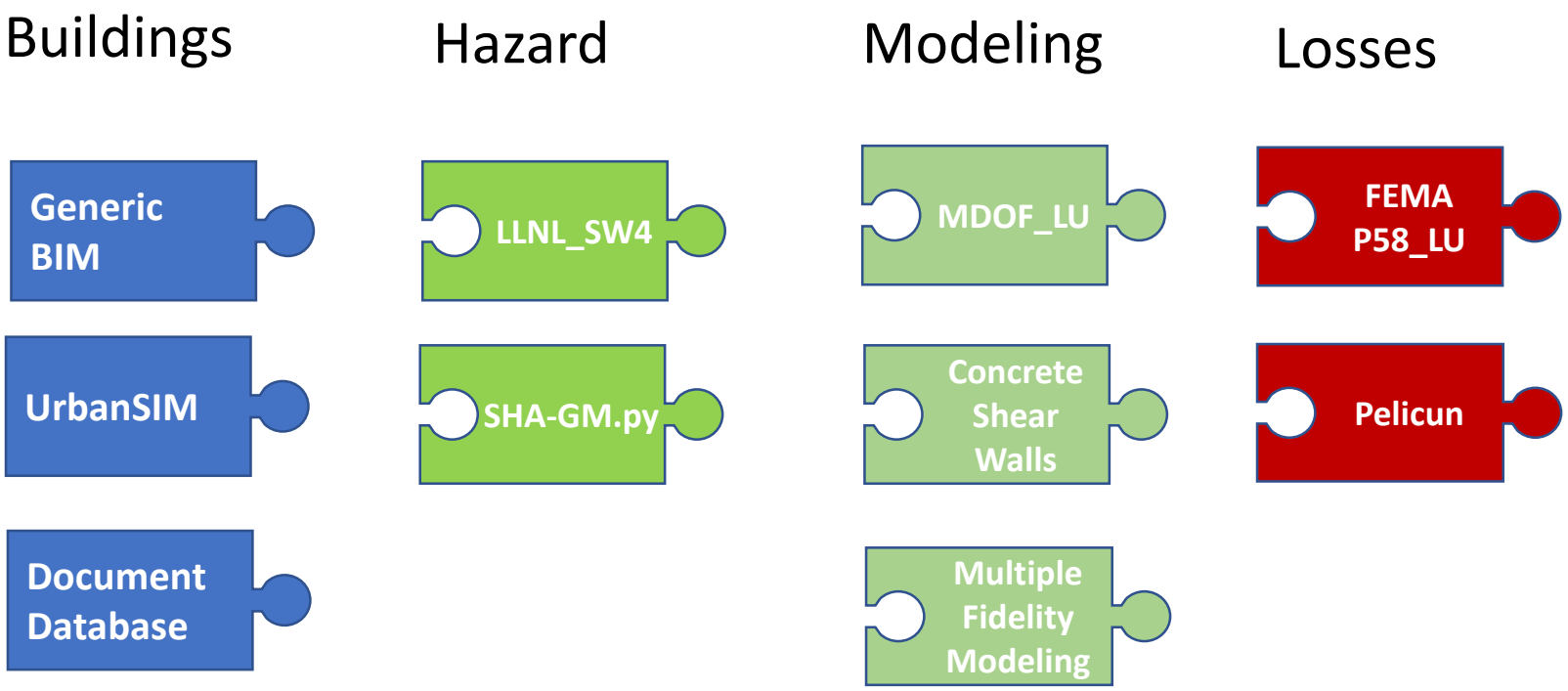
- Regional **Hurricane** workflow
- Initial version to consider ASCE7 wind loading and HAZUS type damage and loss

**Development team:** Deierlein (lead), Kareem, Conte, Deelman, Deodatis, Kijewski-Correa, Taflanidis, Tien, Frank McKenna, Wael Elhaddad (software development)

# Workflow for Regional (EQ) Loss Simulation

## Applications

The Application Framework provides applications with standard interfaces

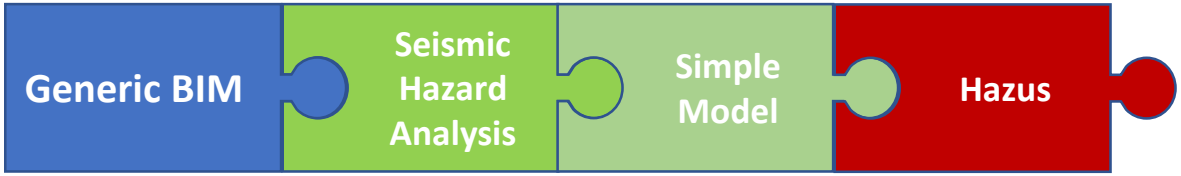


# Workflow for Regional (EQ) Loss Simulation

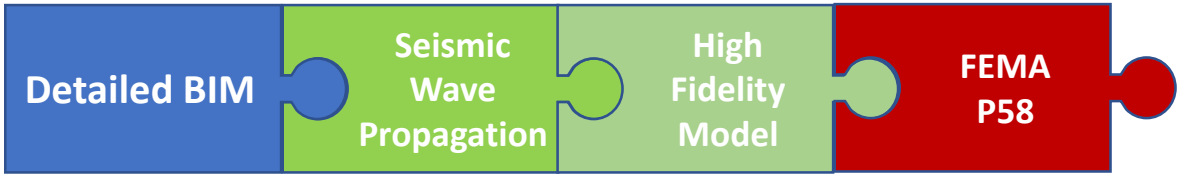
## Configuration

Chain a set of applications into a building workflow

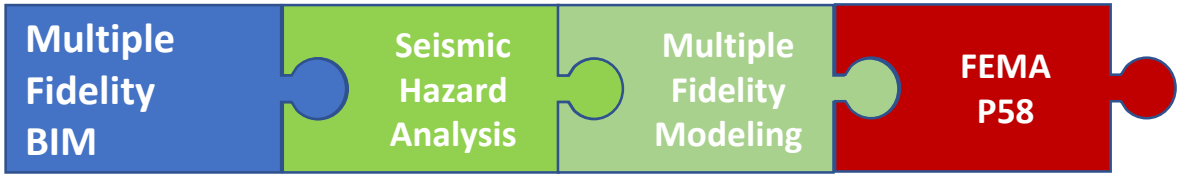
Low Fidelity Configuration




High Fidelity Configuration




Multiple Fidelity Configuration



# RDT creates a JASON script

Untitled — Edited

Workflow — emacs Workflow1.json — 137×55

```
{
   "Name": "Workflow 1",
   "Author": "fmk",
   "WorkflowType": "Regional Simulation",
   "buildingFile":"buildings.json",
   "Applications": {
      "Buildings": {
         "BuildingApplication": "UrbanSimDatabase",
         "ApplicationData": {
            "Min": "1",
            "Max":"1856000",
            "parcelsFile":"/Users/fmckenna/NHERI/parcels.csv",
            "buildingsFile":"/Users/fmckenna/NHERI/buildings2010.csv"
         }
      },
      "Events": [
         {
            "EventClassification": "Earthquake",
            "EventApplication": "LLNL-SW4",
            "ApplicationData": {
               "pathSW4results": "/Users/fmckenna/NHERI/Hayward7.0/",
               "filenameHFmeta":"/Users/fmckenna/NHERI/Workflow1.1/createEVENT/HFmeta"
            }
         }
      ],
      "Modeling": {
            "ModelingApplication": "MDOF-LU",
            "ApplicationData": {
               "hazusData":"/Users/fmckenna/NHERI/Workflow1.1/createSAM/data/HazusData.txt"
            }
      },
      "EDP": {
            "EDPApplication": "StandardEarthquakeEDP",
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      },
      "Simulation": {
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      },
      "UQ-Simulation": {
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      },
      "Damage&Loss": {
         "Damage&LossApplication": "FemaP58-LU",
         "ApplicationData": {
            "filenameSettings":"/Users/fmckenna/NHERI/Workflow1.1/createLOSS/data/settings.ini",
            "pathCurves":"/Users/fmckenna/NHERI/Workflow1.1/createLOSS/data/ATCCurves/",
            "pathNormative":"/Users/fmckenna/NHERI/Workflow1.1/createLOSS/data/normative/"
         }
      }
   }
}
-uu-:**-F1  Workflow1.json   Top L11    (Fundamental)----------
Auto-saving...done
```
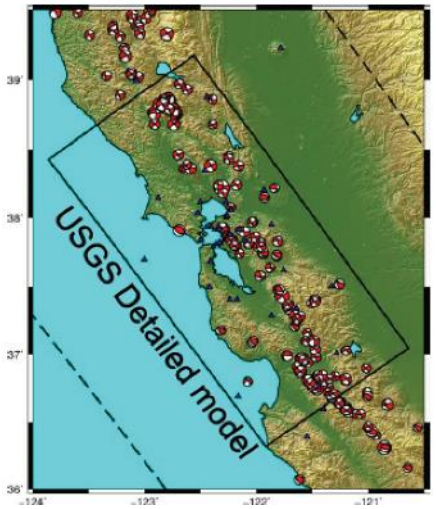
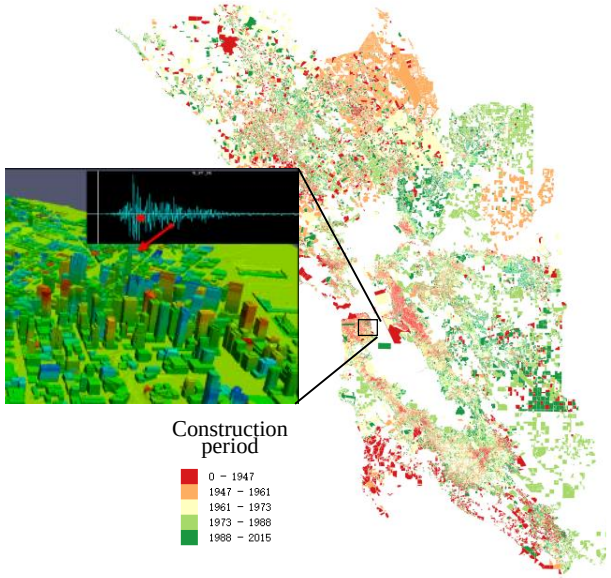
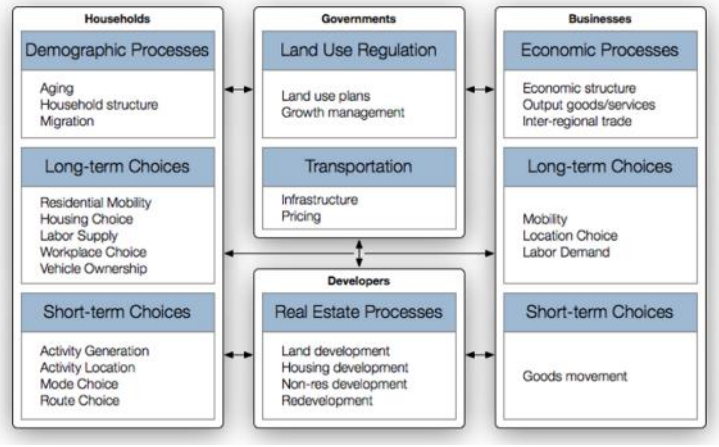

# Regional End-to-End Testbed (EQ)




M7.0 Hayward Fault




1.8 million buildings in SF Bay Area



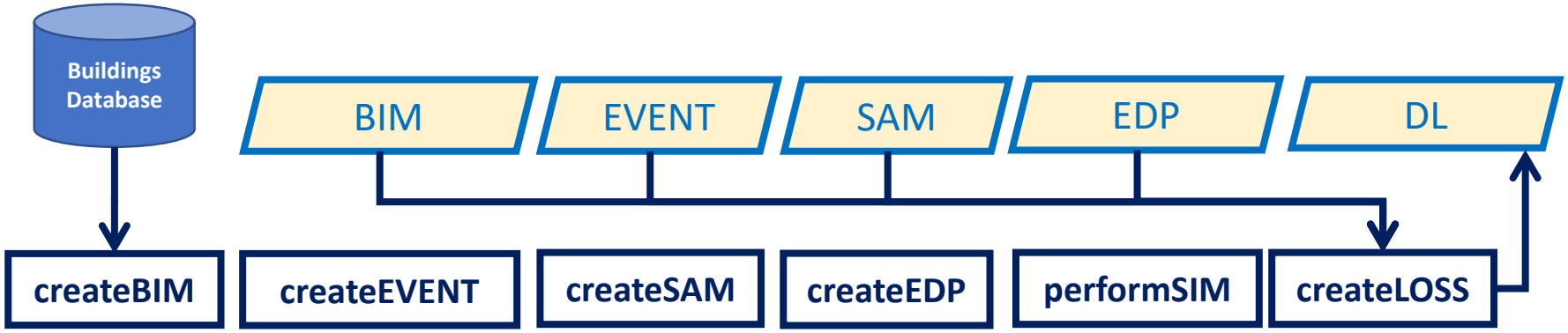

Policy/Planning: *building losses & downtime in 2010 and 2040*

***Objective:*** *develop/exercise a computational workflow for a significant simulation that can engage broad NEHRI community*

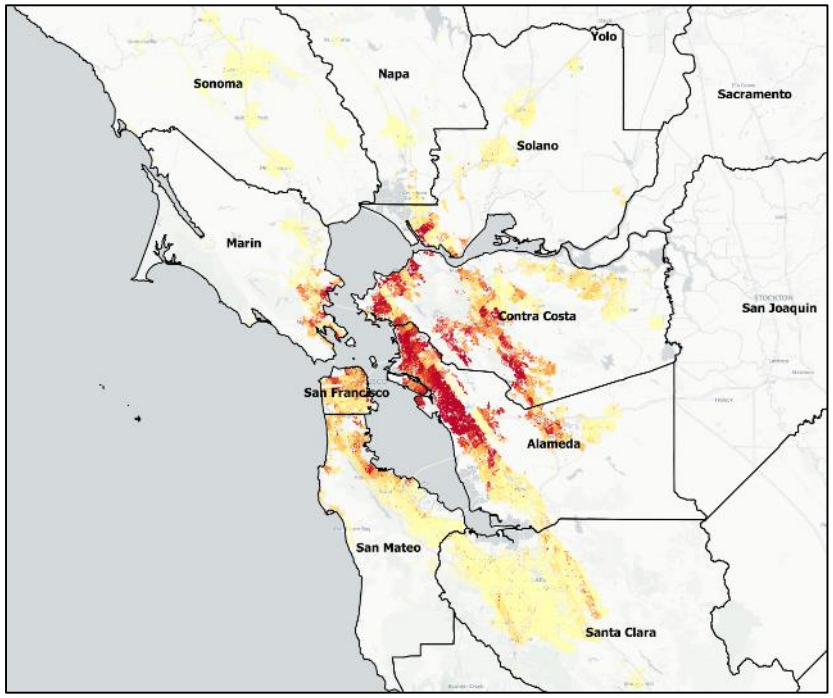
**Ground Motions:** 3D simulation, GM's at 2km grid (Rodgers, Pitarka & Petersson)
**Building Inventory:** UrbanSim and DataSF Portal; geometry, age, occupancy
**Building Analyses:** OpenSees, simplified NL MDOF, FEMA P58 (w/Cheng & Lu, Tsinghua)
**Visualization:** Q-GIS, UrbanSim
**Interpretation:** UrbanSim - urban growth, damage/loss, displaced occupants/population

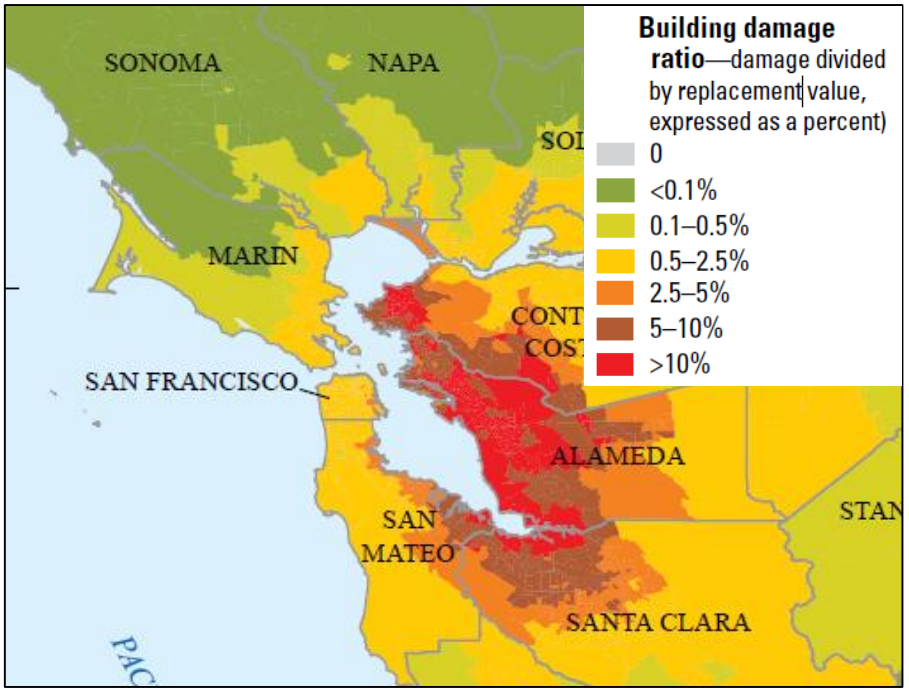
# Registered Workflow Applications

| Type | Name | Description |
|---|---|---|
| **createBIM** | GenericBimDatabase | Creates a simple BIM from a building flat file (csv) |
| | UrbanSimDatabase | Creates a simple BIM from UrbanSim simulation outputs |
| **createEVENT** | LLNL_SW4 | Gets Event input from SW4 outputs |
| | SHA-GM | Computes event input using SHA and record selection/scaling |
| **createSAM** | MDOF_LU | Creates a MDOF shear building model |
| **createEDP** | StandardEarthquakeEDP | Defines the standard EDPs used for a seismic event |
| **performSIM** | OpenSeesSimulation | Performs simulation using OpenSees and calculates the EDPs |
| **createLOSS** | FEMAP58_LU | Calculates damage and loss estimates using FEMA P58 procedure |
| **performUQ** | DakotaFEM | Propagates uncertainty in all applications using Dakota |



# Comparison of Building Damage




## SimCenter Workflow

- *Red-tagged buildings 141,400*
- *Net buildings damage ratio 5.6%*

## USGS Haywired

- *Red-tagged buildings 101,000*
- *Net buildings damage ratio 2.9%*

# Comparison To HayWired Scenario

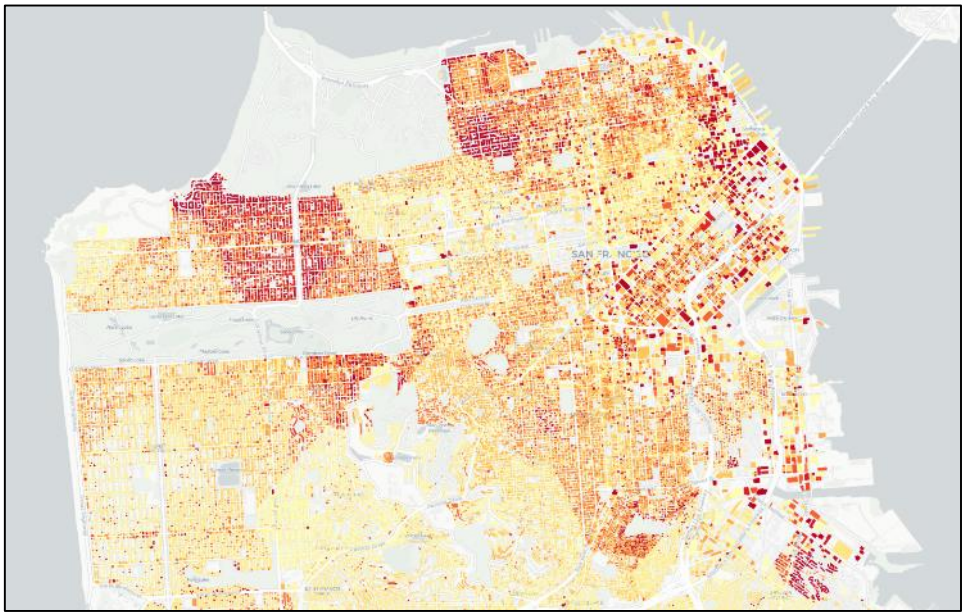
- **HayWired Scenario:** A study lead by USGS, involving approximately 60 partners, to simulate the effects and consequences of a hypothetical, yet scientifically realistic, magnitude M7.0 earthquake on the Hayward fault.

| | HayWired Scenario | SimCenter Testbed |
|---|---|---|
| **Number of Buildings** | 3 Million | 1.84 Million |
| **Red Tagged Buildings** | 101,000 | 141,459 |
| **Building Damage** | $30.3 Billion | $84.1 Billion |
| **Net Damage Ratio** | 2.91% | 5.6% |
| **Total Buildings Cost** | $1.04 Trillion | $1.5 Trillion |

Detweiler, S.T., and Wein, A.M., eds., 2018, The HayWired earthquake scenario—Engineering implications: U.S. Geological Survey Scientific Investigations Report 2017–5013–I–Q, 429 p., https://doi.org/10.3133/sir20175013v2.

# High Resolution Results

- **Parcel-level Data of Building Damage**

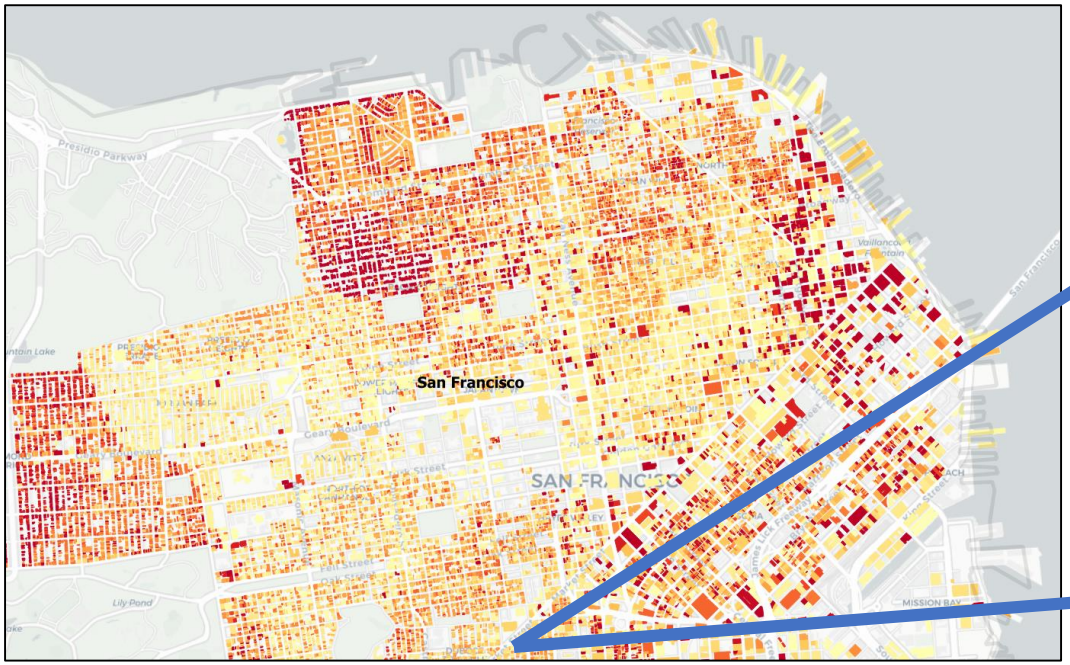


San Francisco

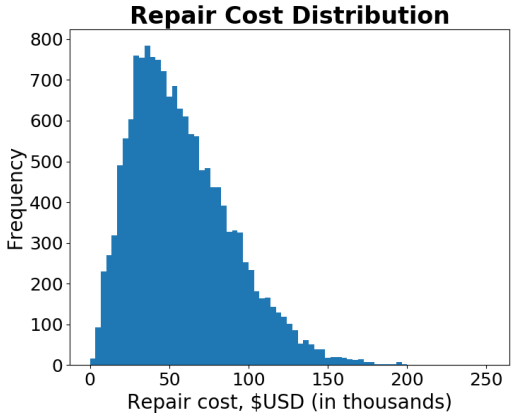
Oakland - Alameda

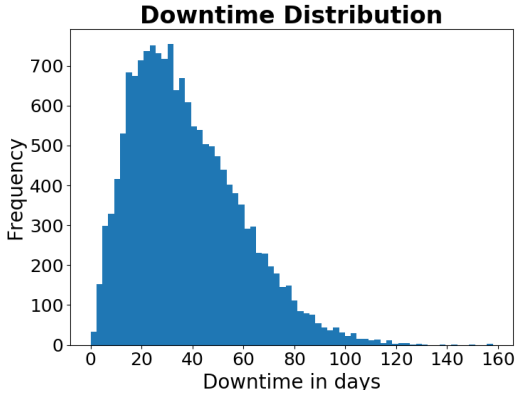
*Opportunities to evaluate planning and policy decisions (land use, retrofit, etc.)*

# Parcel Level Results




Loss Ratios

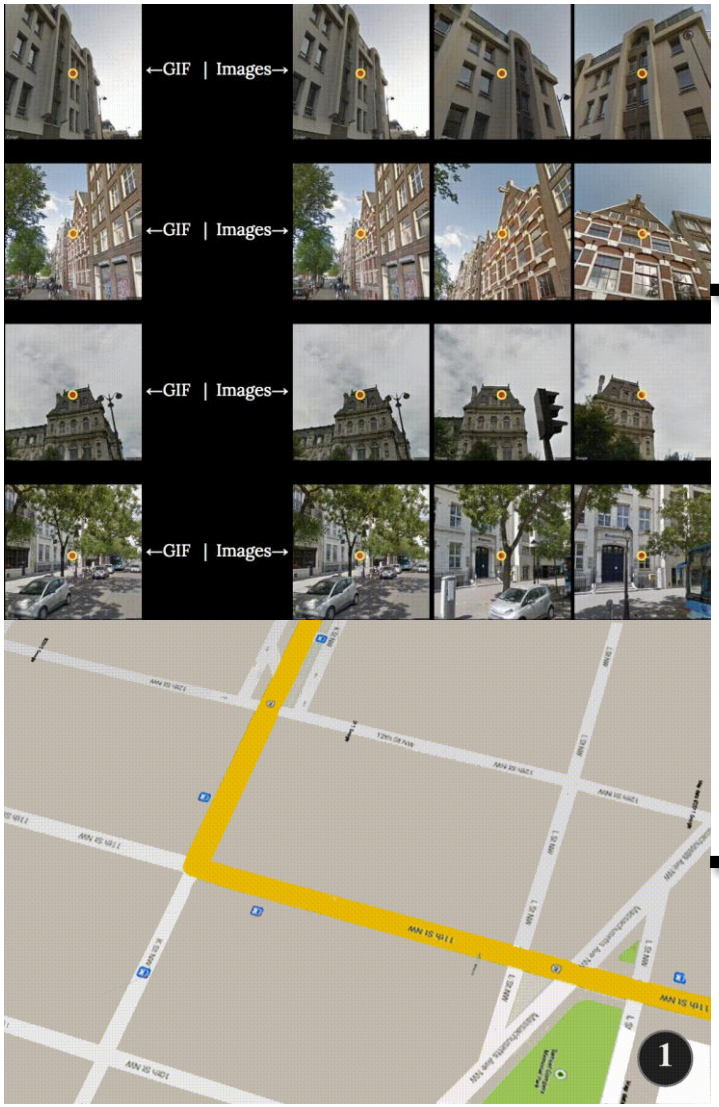


# Additional SimCenter Products

- rWHALE: Regional Workflow for Hazard and Loss Estimation
  - Library of all of the applications (used in uqFEM, EEuq, CWEuq …) that "wrap" existing software to enable workflows.
  - Developer: Zsarnóczay
- PELICUN: Probabilistic estimation of losses, injuries, and community resilience under natural disasters
  - Encompasses FEMA P-58 and HAZUS fragilities
  - Development team: Miranda, Terzic, Baker, Kijewski-Correa, Zsarnóczay
- SMELT: Stochastic, modular, and extensible library for time history generation
  - Developer: Michael Gardner
- S3hark Site Response
  - Development team: Deodatis, Bray, Arduino, Baker, Taciroglu, Wang
- AI Tools (in development)
  - Development team: Yu, Law, Taciroglu, Wang
- Educational Applications: MDOF EvW PGT BFM

# *SimCenter* product: AI for Data to BIM




**Future Virtual Engineer**

images

Machine Learning

- Height
- Construction type
- Number of stories
- ……

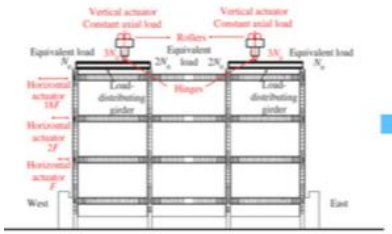
building properties

camera pose
3D models

- SF building footprints: 117023 buildings, height, GPS coordinates, …
- SF building permits: 1+ million records, #stories, construction types, GPS coordinates, …
- SF land use: 115,468 records, land use types, year built, GPS coordinates, …

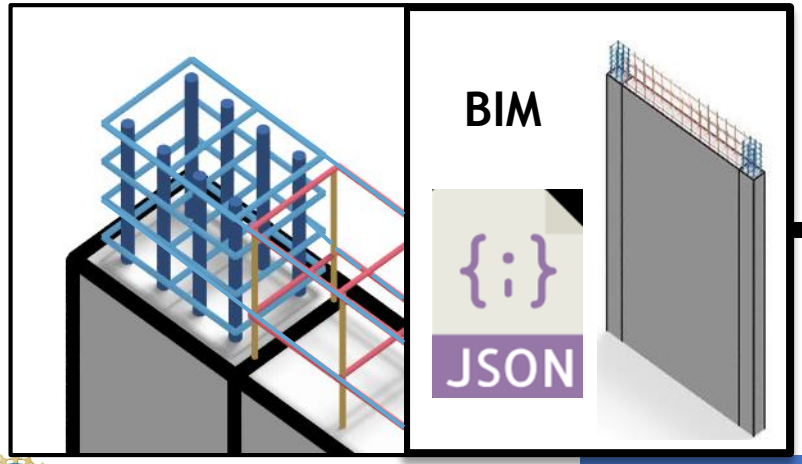
# AI Applications: BIM to SAM

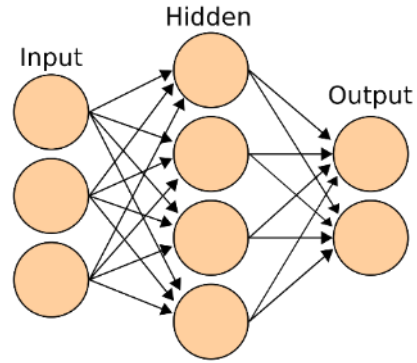
**Structural Engineers**

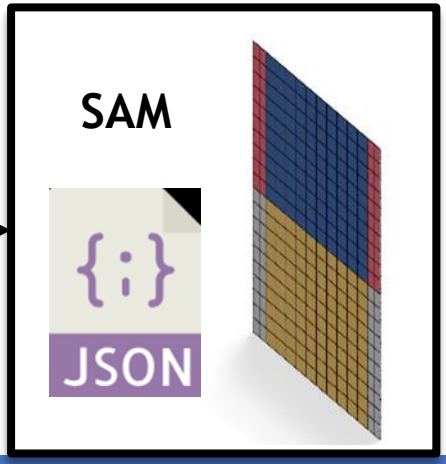


**Future Virtual Engineer**

Dataset: 87 walls
Training: 98% accurate
Testing: 93% accurate

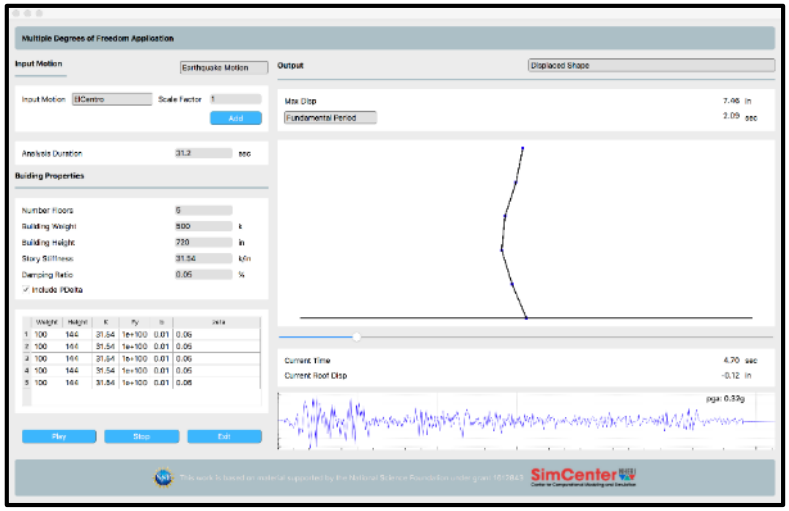


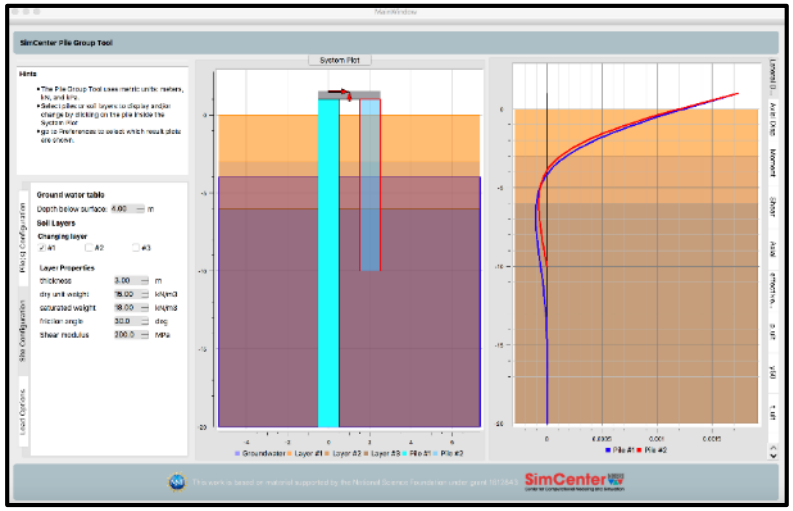



# Educational Applications

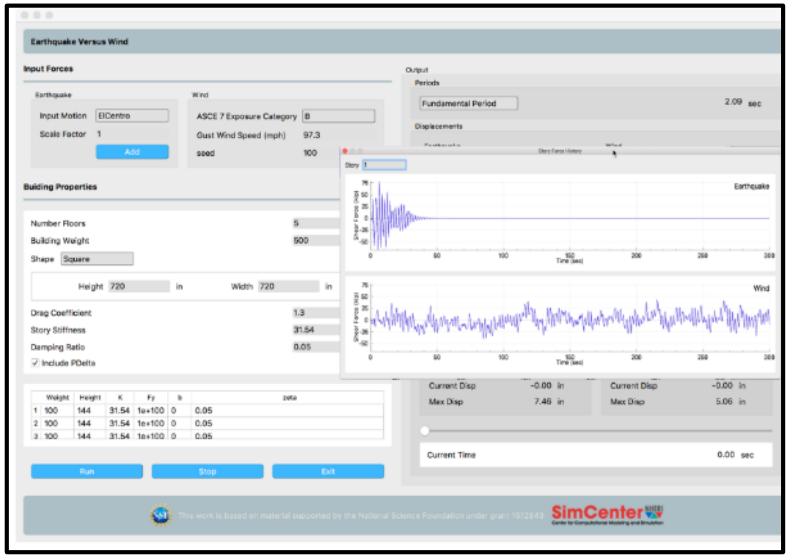
MDOF



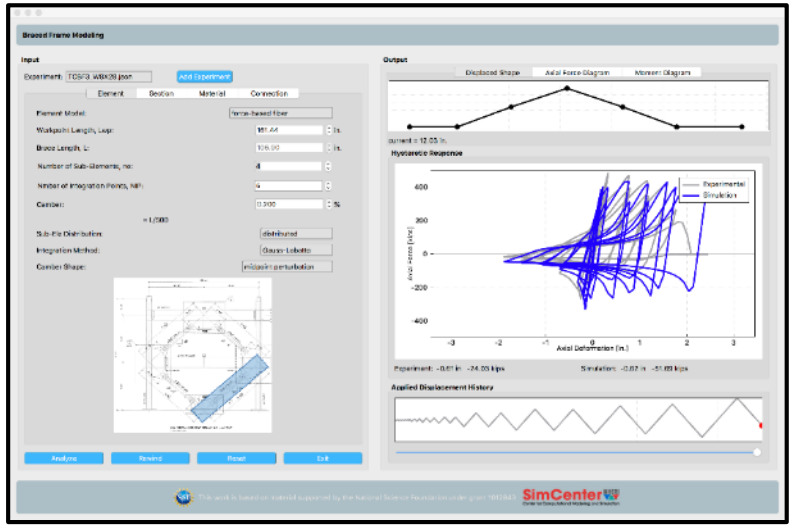

PGT



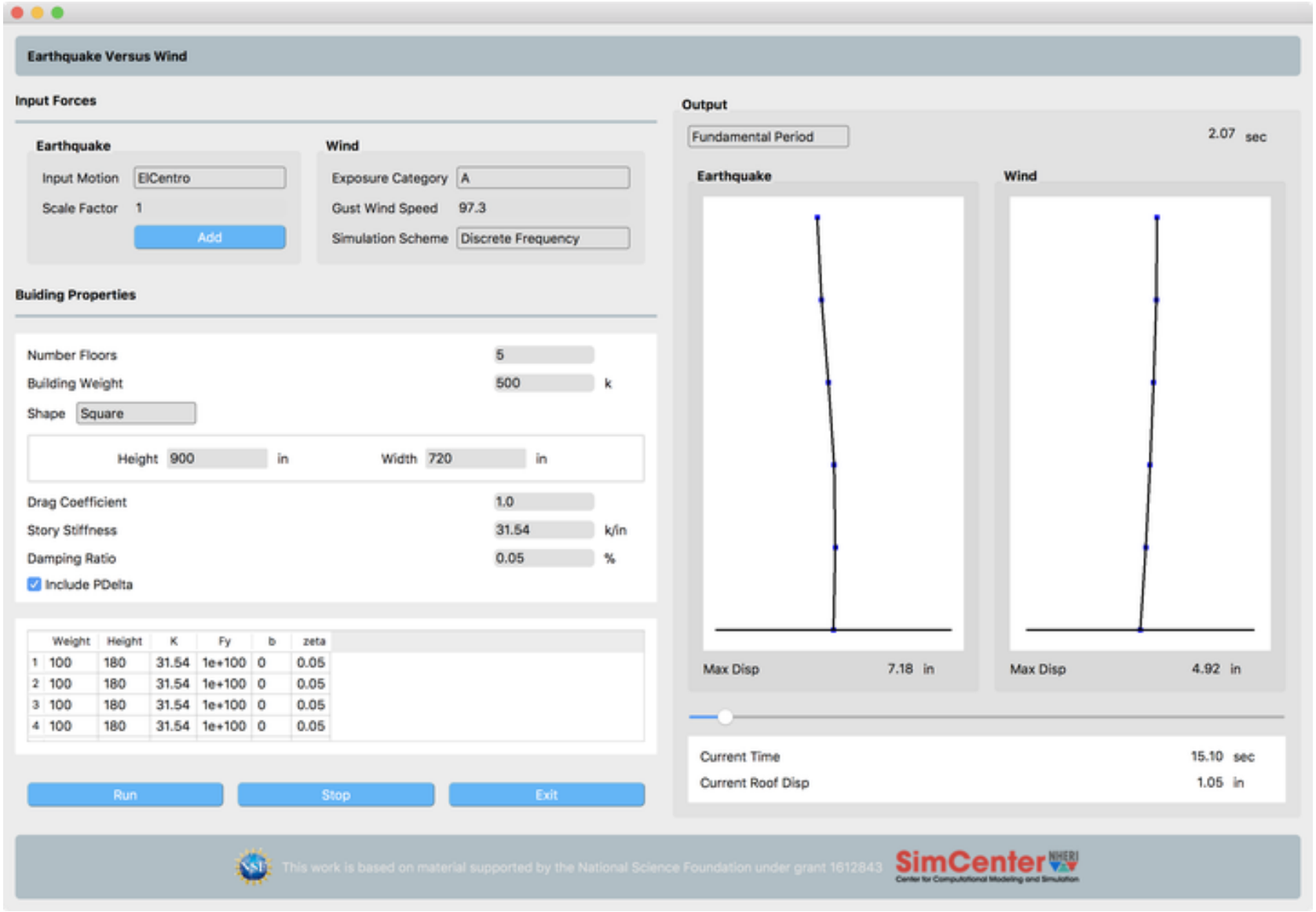

EvW



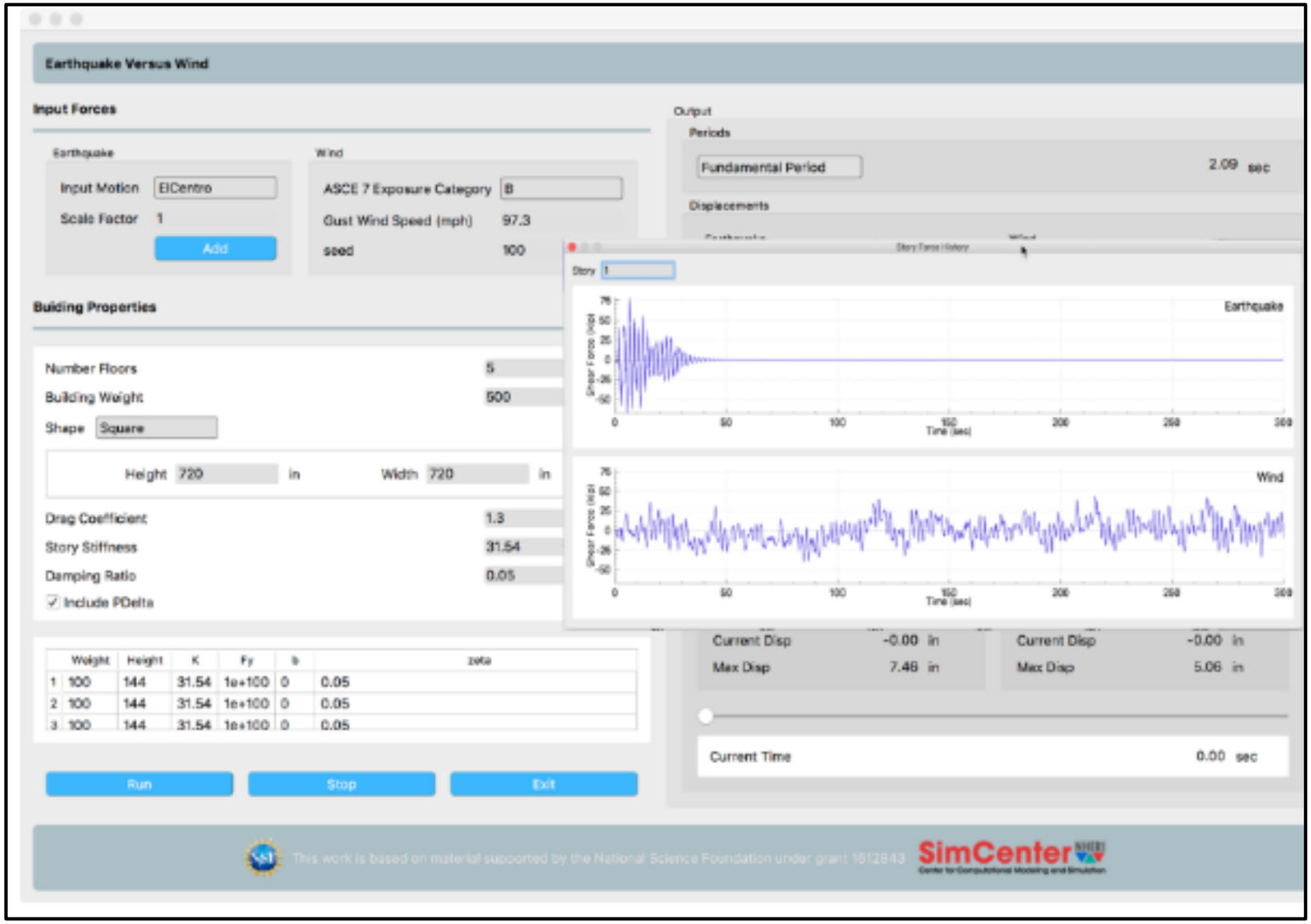

BFM



# Educational Applications

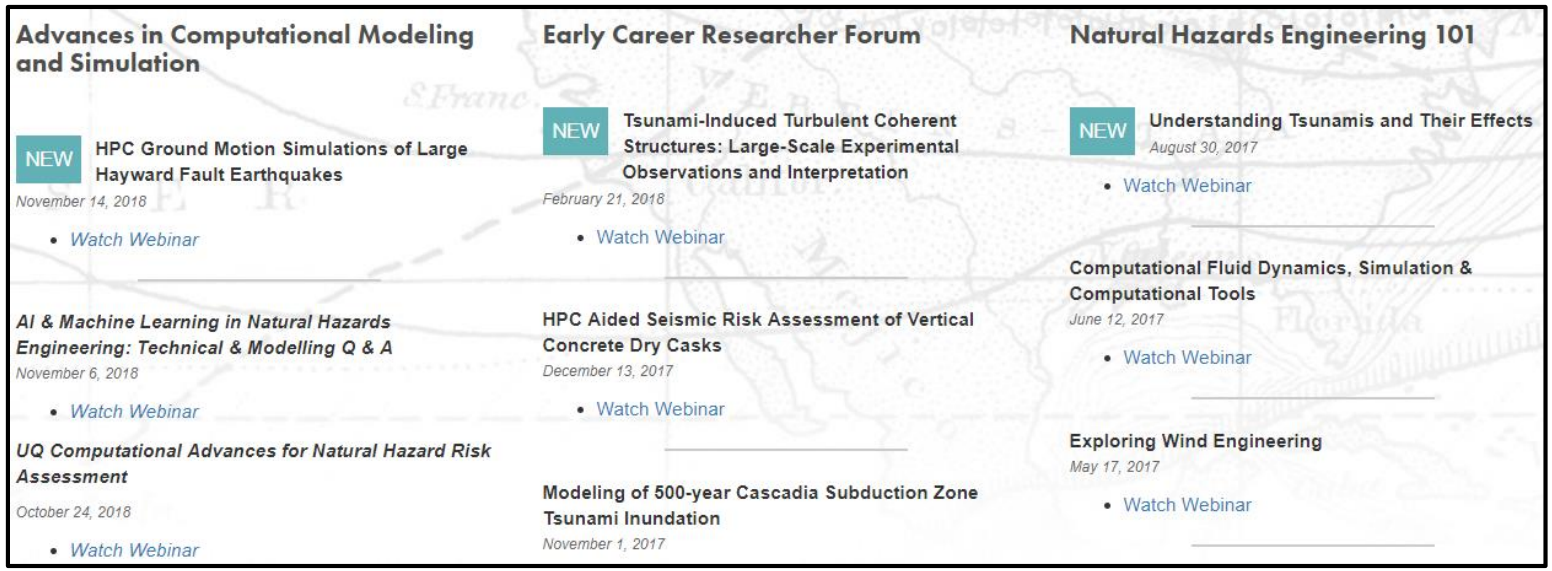


# Educational Applications



# Opportunities for Learning More

- SimCenter Online Webinars



**Advances in Computational Modeling and Simulation**

NEW **HPC Ground Motion Simulations of Large Hayward Fault Earthquakes**
*November 14, 2018*
- *Watch Webinar*

***AI & Machine Learning in Natural Hazards Engineering: Technical & Modelling Q & A***
*November 6, 2018*
- *Watch Webinar*

***UQ Computational Advances for Natural Hazard Risk Assessment***
*October 24, 2018*
- *Watch Webinar*

**Early Career Researcher Forum**

NEW **Tsunami-Induced Turbulent Coherent Structures: Large-Scale Experimental Observations and Interpretation**
*February 21, 2018*
- Watch Webinar

**HPC Aided Seismic Risk Assessment of Vertical Concrete Dry Casks**
*December 13, 2017*
- Watch Webinar

**Modeling of 500-year Cascadia Subduction Zone Tsunami Inundation**
*November 1, 2017*

**Natural Hazards Engineering 101**

NEW **Understanding Tsunamis and Their Effects**
*August 30, 2017*
- Watch Webinar

**Computational Fluid Dynamics, Simulation & Computational Tools**
*June 12, 2017*
- Watch Webinar

**Exploring Wind Engineering**
*May 17, 2017*
- Watch Webinar

# Educational Opportunities

- SimCenter Tool Training Workshop (expected Summer 2020)

- Summer Programming Bootcamp (expected Summer 2020)

- Summer REU Program

https://www.designsafe-ci.org/learning-center/reu/

# Engage and Collaborate with SimCenter

- Subscribe to SimCenter news and join Slack channels
  - https://simcenter.designsafe-ci.org/join-community/
- SimCenter Research Tools
  - https://simcenter.designsafe-ci.org/research-tools
- Software Source Codes and Contributions
  - https://github.com/NHERI-SimCenter
- Letters of support and collaboration questions
  - https://simcenter.designsafe-ci.org/about/collaborate/