National Science Foundation

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

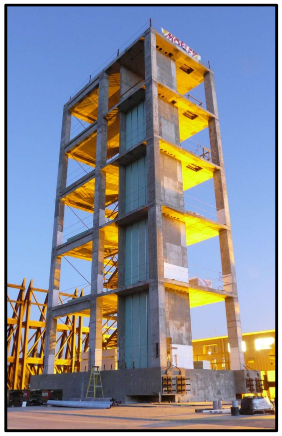
An Introduction to the NHERI SimCenter

Laura Lowes, SimCenter co-PI

University of Washington

Joint Researcher Workshop
UC San Diego, Lehigh & SimCenter

December 16-17, 2019
University of California, San Diego



LEHIGH NHERI
Real-Time Multi-Directional Testing Facility

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

SIMCENTER
COMPUTATIONAL MODELING AND SIMULATION CENTER

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

Goals

To produce Extensible Software that Researchers in Natural Hazards Engineering can use in their research

- Develop a **computational framework** that supports decision-making to enhance community resilience to natural hazards in the face of uncertainty;
- **Design the framework** to be sufficiently **flexible, extensible, and scalable** so that any component can be enhanced to improve the analysis and thereby meet the needs of a user group;
- **Seed the framework** with **connectivity to existing simulation tools** and **data** so it can be readily employed and improve as users identify new needs;
- **Release tools/applications built using this framework** that meet the computational needs of researchers in natural hazards engineering;
- **Provide an ecosystem that fosters collaboration** between scientists, engineers, urban planners, public officials, and others who seek to improve community resilience to natural hazards.

Performance-Based Engineering Framework

Simulation of Earthquake

Generate Site-Specific Ground

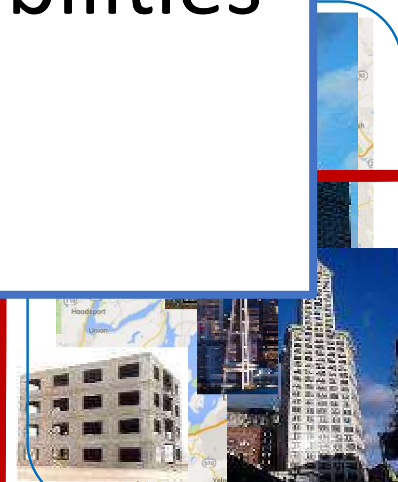
Simulate Structural

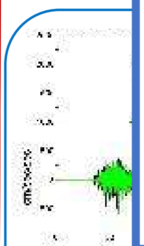
Estimate Loss and Assess

lete

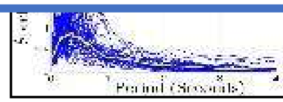
ft

ent





rock motions at various locations within the region



site-specific ground motions representing site hazard

PLUS

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

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

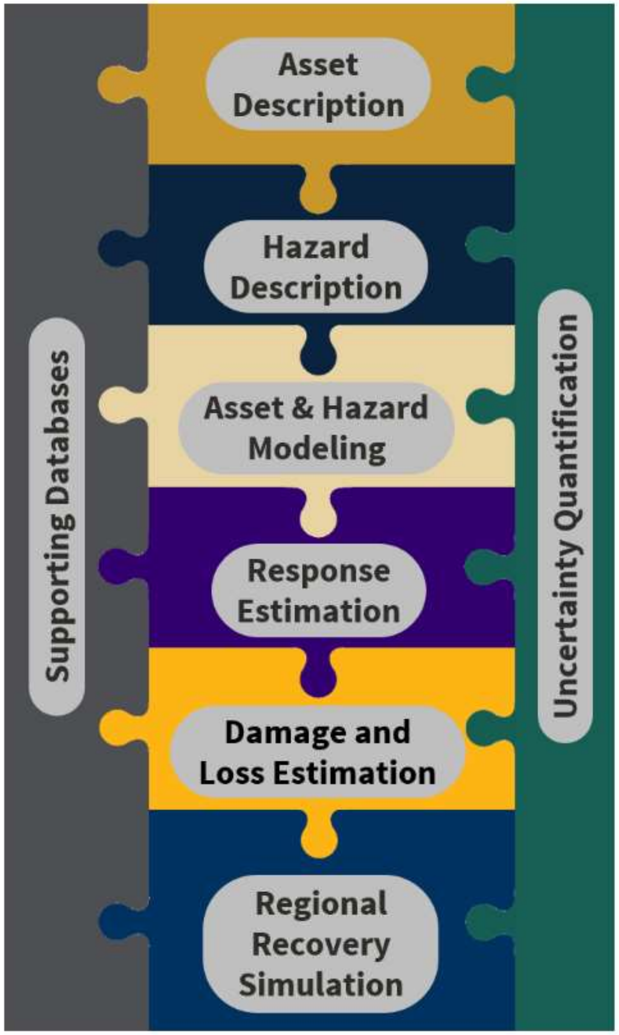
Strategy

Current software is often good, but:

- Regular software updating needed,
- Unable to scale to HPC,
- Difficult to interact with and move data from one app to another,
- Uncertainty quantification and propagation not considered.

- Move to cloud-based HPC environment,
- Provide integrated "plug and play" capability to link multiple software apps together into workflows,
- Include support for uncertainty quantification and propagation

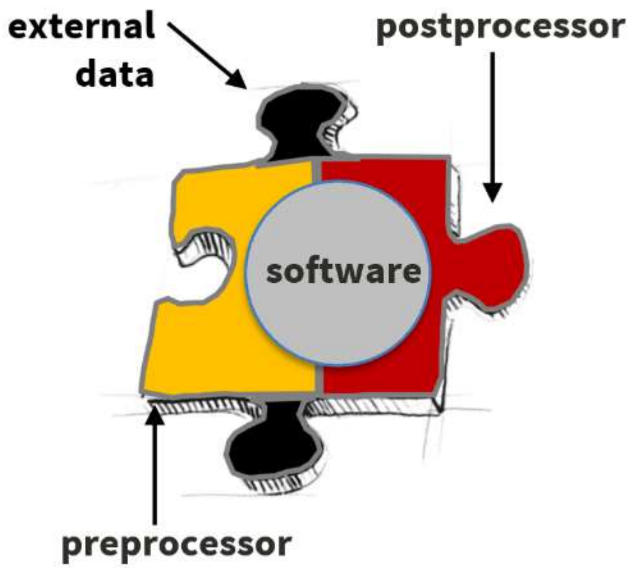
Application Framework



Application Framework:

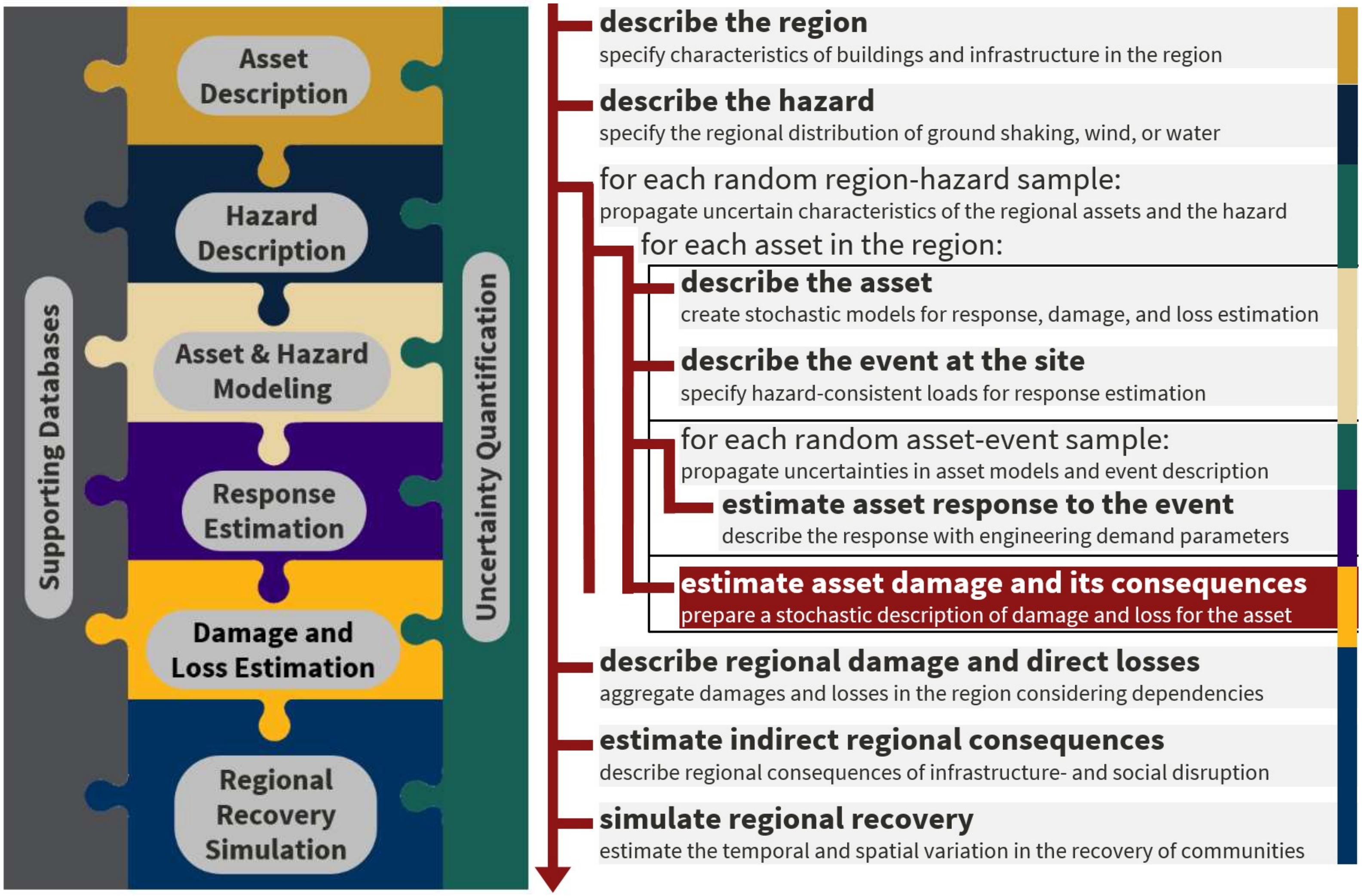
a collection of software connected by standardized interfaces

SimCenter efforts focus on framework to connect existing simulation software

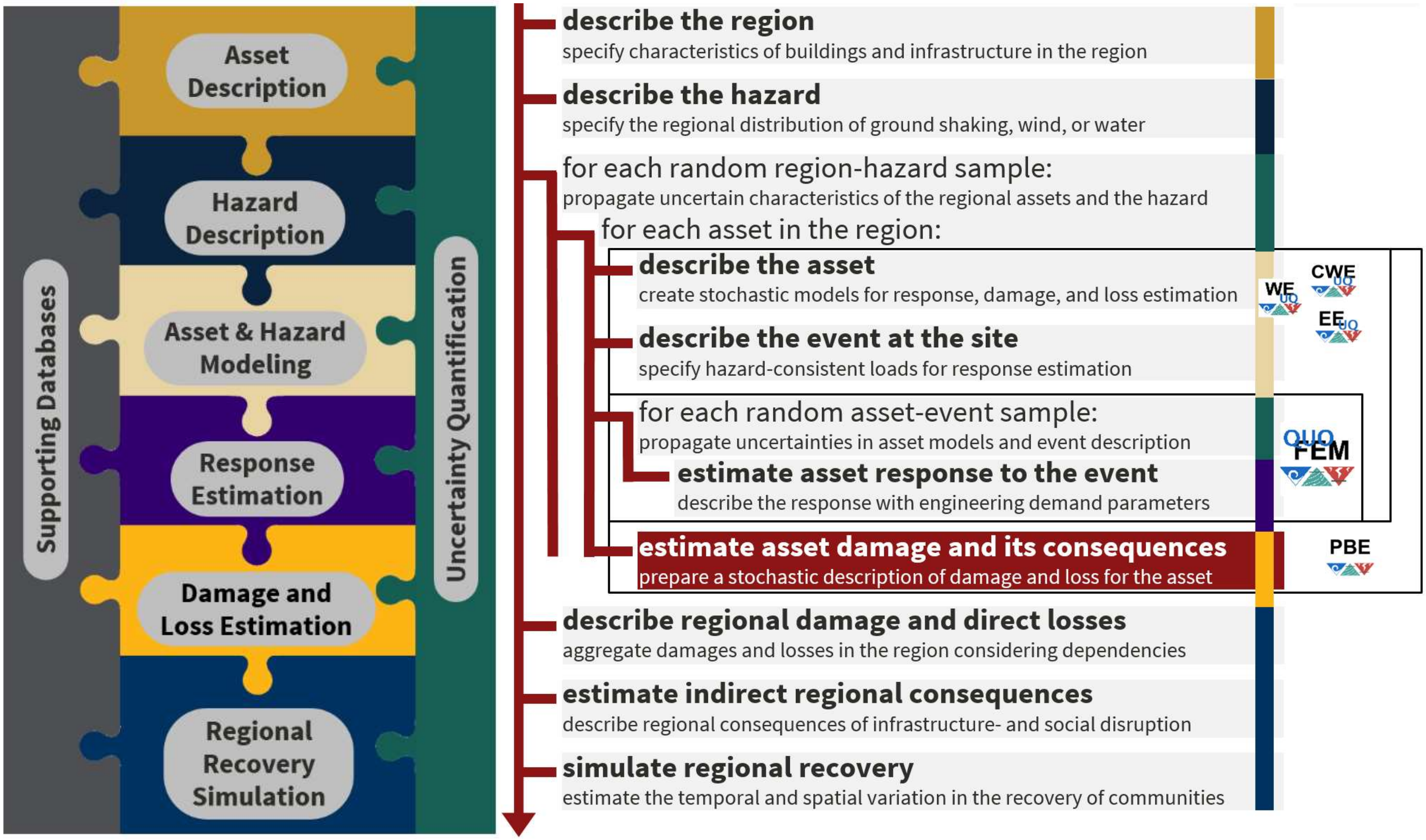


HPC resources & data storage at DESIGN SAFE-CI

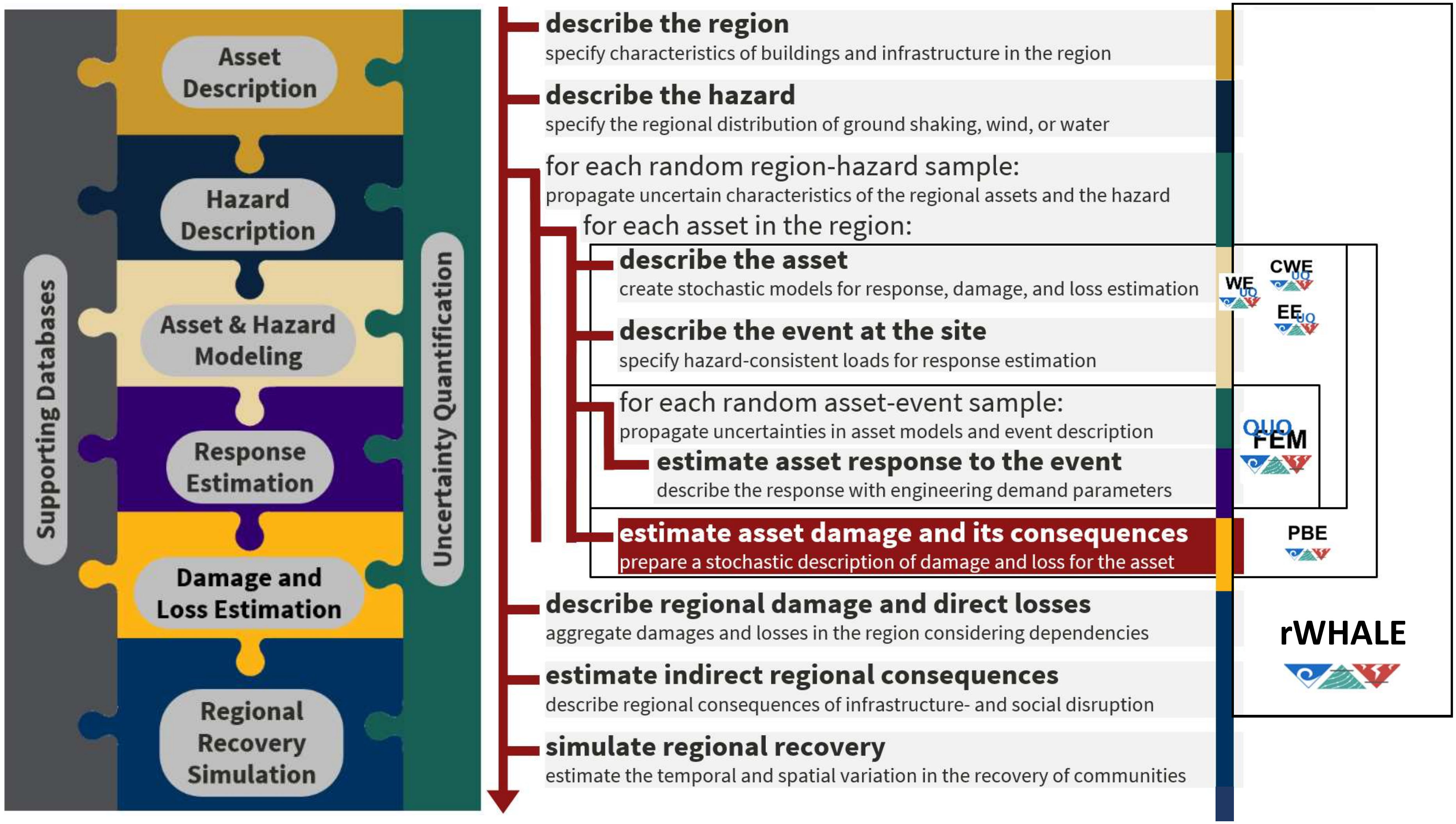
Application Framework & Research Apps



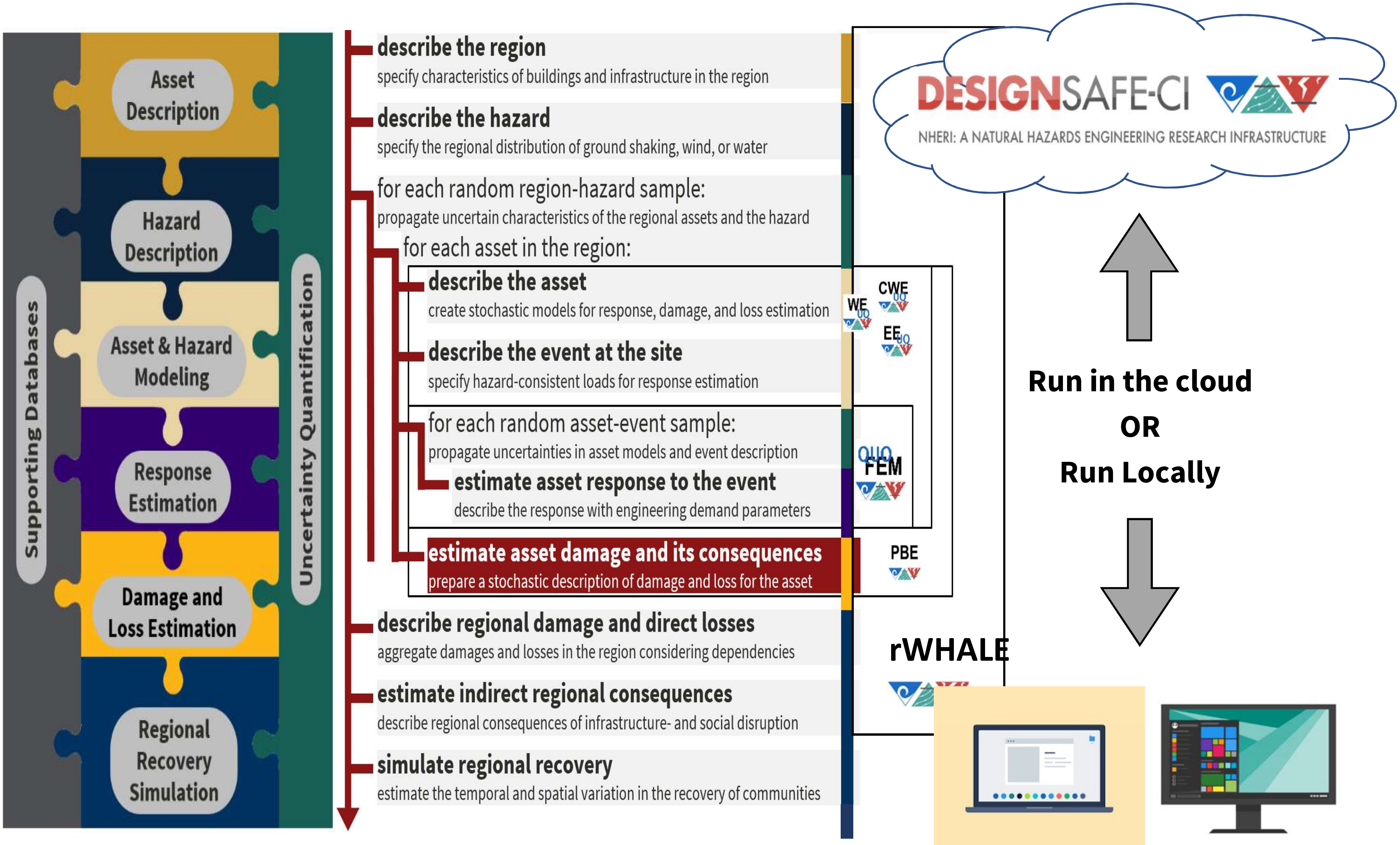
Application Framework & Research Apps



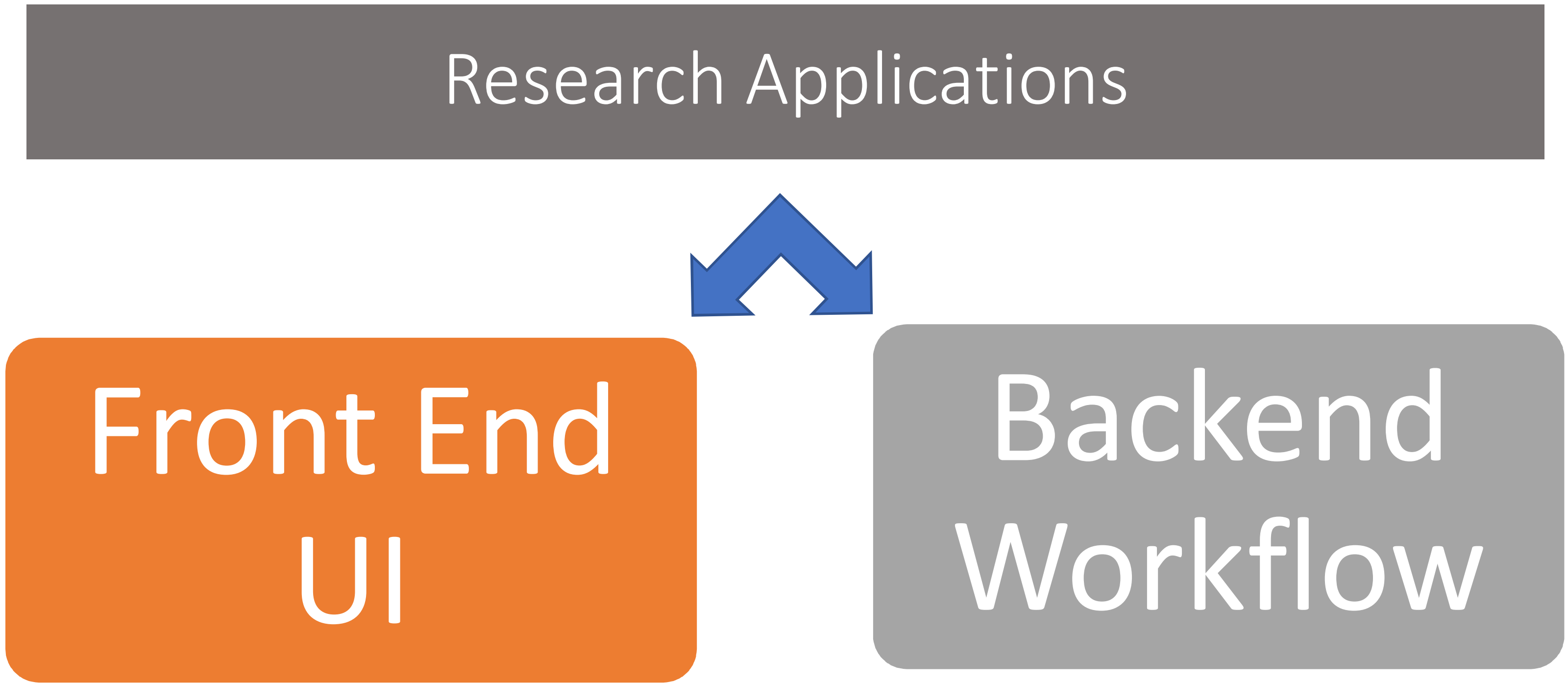
Application Framework & Research Apps



Application Framework & Research Apps

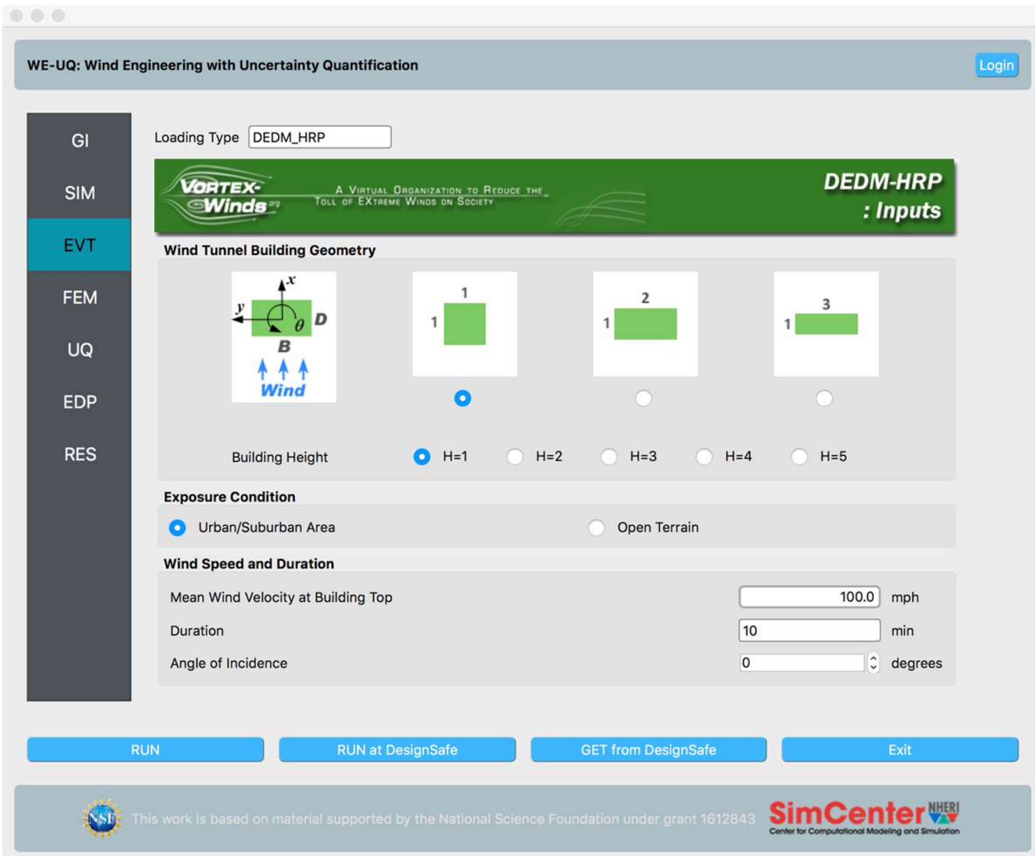


Research Applications



- 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

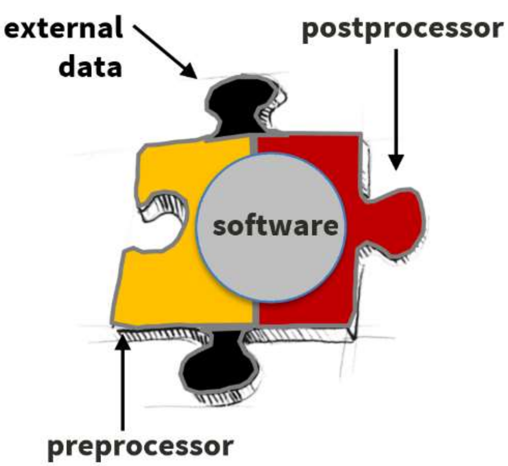


- Front end is an application runs on your desktop
- Backend is a python "workflow" comprising one or more applications that run on either your desktop or on HPC resources provided by DeisgnSafe via the Texas Advanced Computing Center (TACC)

SimCenter NHERI

Backend – A Scientific Workflow Application

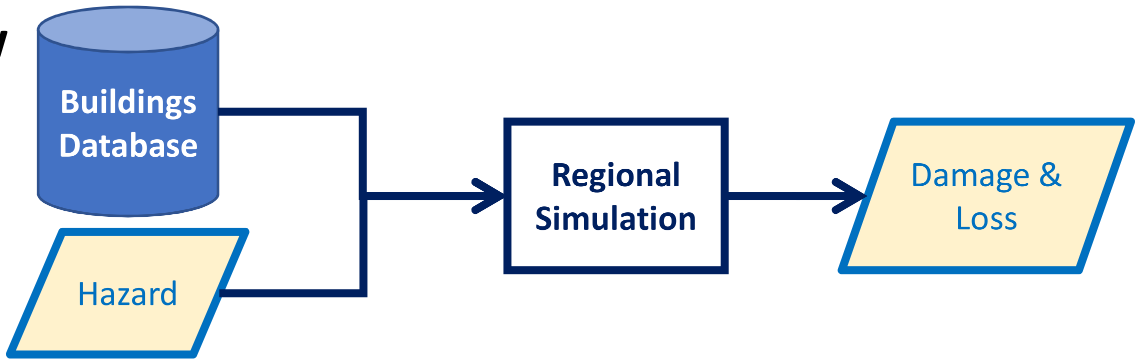
Scientific Workflow Application: A scientific workflow is the **automation** of a process in which information is passed from **one application to the next.**



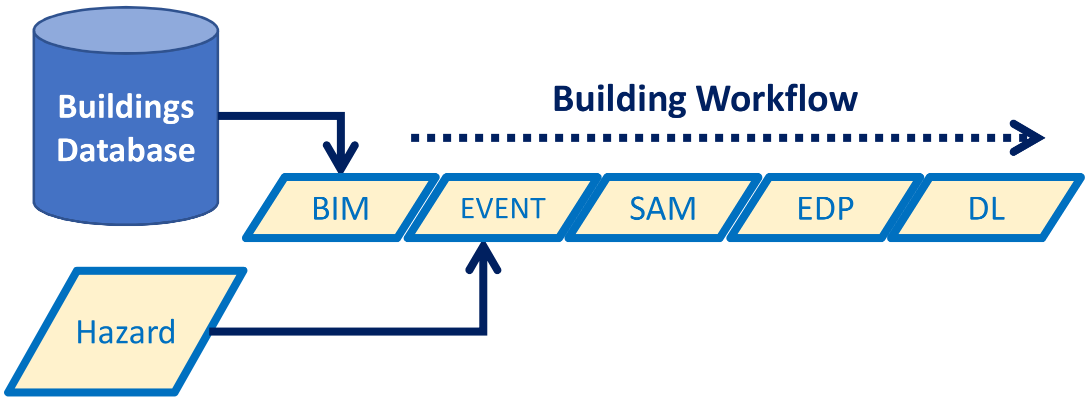
OR

Computational Workflow

- **Regional workflow**



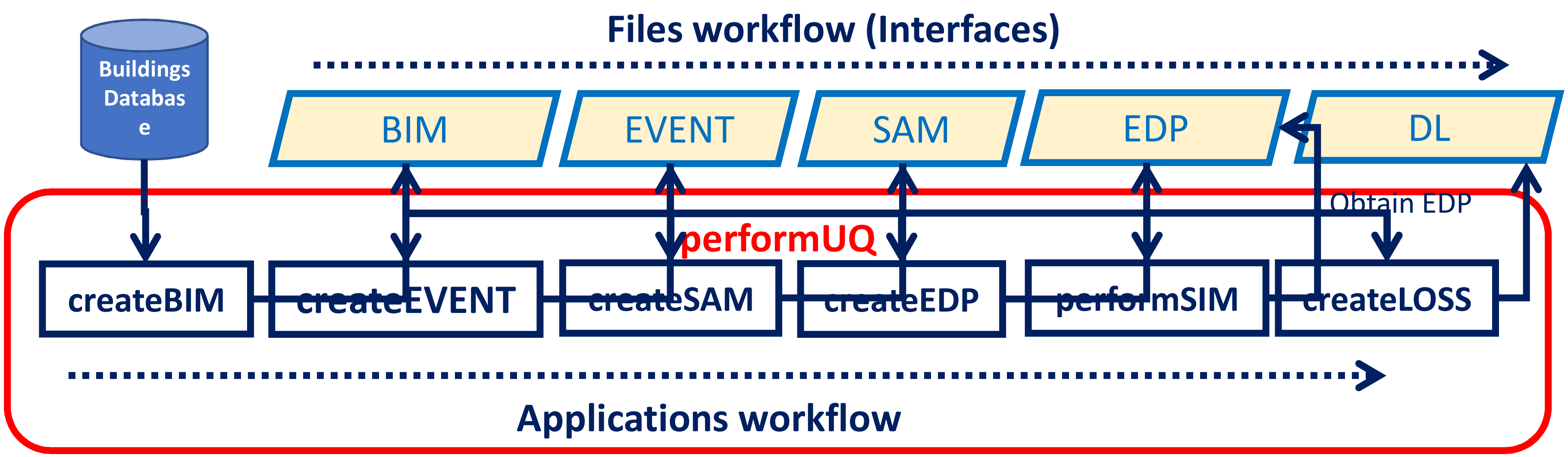
- **Single building workflow**



BIM: **B**uilding **I**nformation **M**odel
SAM: **S**tructural **A**nalysis **M**odel
EDP: **E**ngineering **D**emand **P**arameters
DL: **D**amage & **L**oss

Workflow Overview

- **Applications & Interfaces**

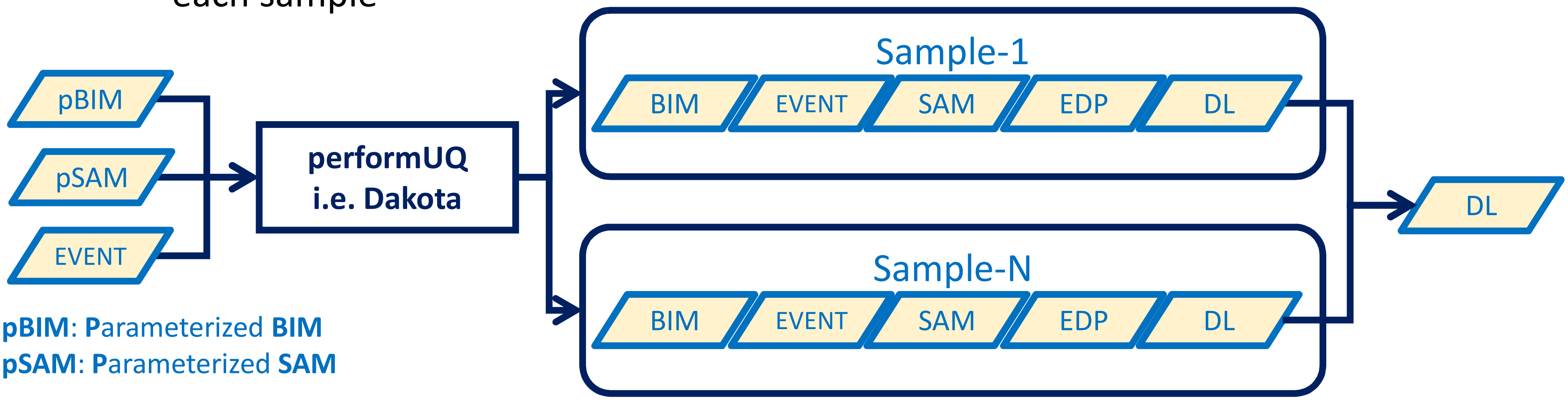


BIM: **B**uilding **I**nformation **M**odel
SAM: **S**tructural **A**nalysis **M**odel
EDP: **E**ngineering **D**emand **P**arameters
DL: **D**amage & **L**oss

lighter text are Inputs/Outputs
darker text are applications

Forward Uncertainty Propagation

- Uncertainties are handled using Dakota
- Each workflow application is called initially to define random variables
- Dakota samples the random variables and runs the workflow applications for each sample



pBIM: **P**arameterized **BIM**
pSAM: **P**arameterized **SAM**

Adams, B.M., Bauman, L.E., Bohnhoff, W.J., Dalbey, K.R., Ebeida, M.S., Eddy, J.P., Eldred, M.S., Hough, P.D., Hu, K.T., Jakeman, J.D., Stephens, J.A., Swiler, L.P., Vigil, D.M., and Wildey, T.M., "Dakota, A Multilevel Parallel Object-Oriented Framework for Design Optimization, Parameter Estimation, Uncertainty Quantification, and Sensitivity Analysis: Version 6.8 Theory Manual," Sandia Technical Report SAND2014-4253, May 2018.

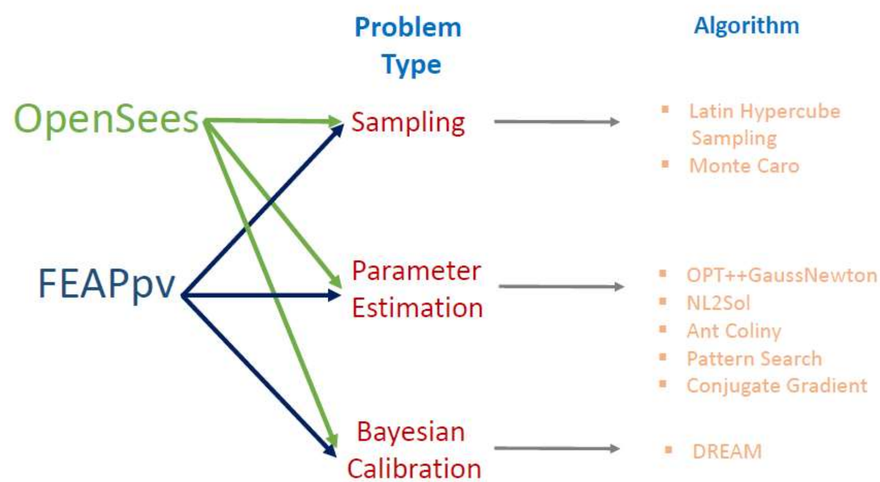
Input file for Backend Workflow is a **JSON** file

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
```

quoFEM Application

- Integrates Simulation Applications with UQ Engine(s)



Application:

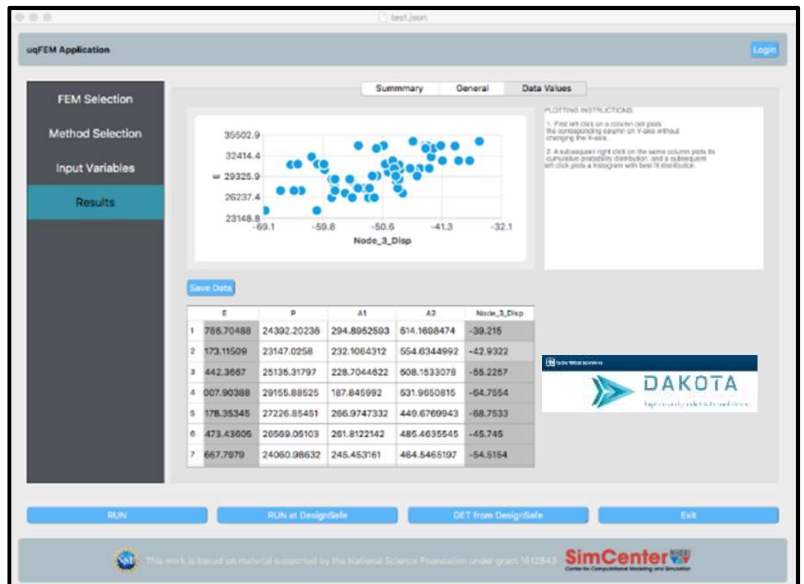
- **Inputs:** FEM model, input uncertainty specification, UQ method & post-processing script
- **Outputs:** Depends on problem type and post-processing (e.g. Uncertainty measures of outputs)

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)

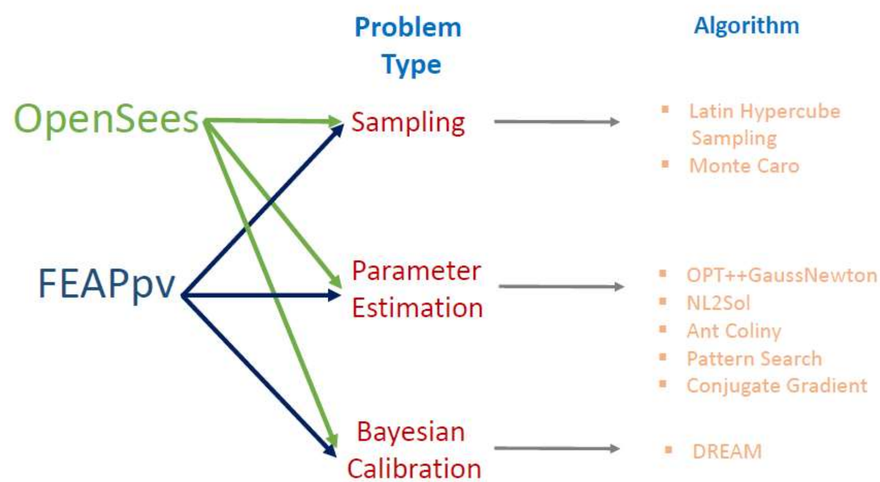
Research Opportunities:

- Surrogate Modeling
- Model Calibration



quoFEM Application

- Integrates Simulation Applications with UQ Engine(s)



Application:

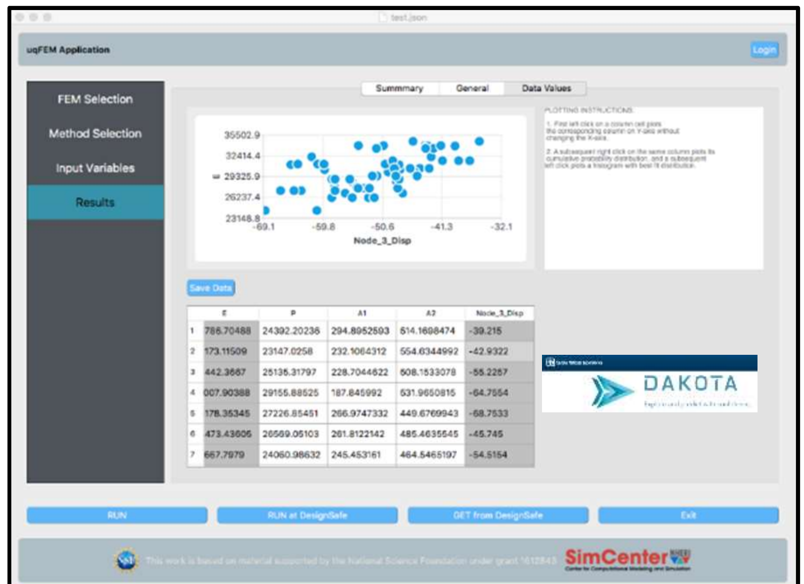
- **Inputs:** FEM model, input uncertainty specification, UQ method & post-processing script
- **Outputs:** Depends on problem type and post-processing (e.g. Uncertainty measures of outputs)

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

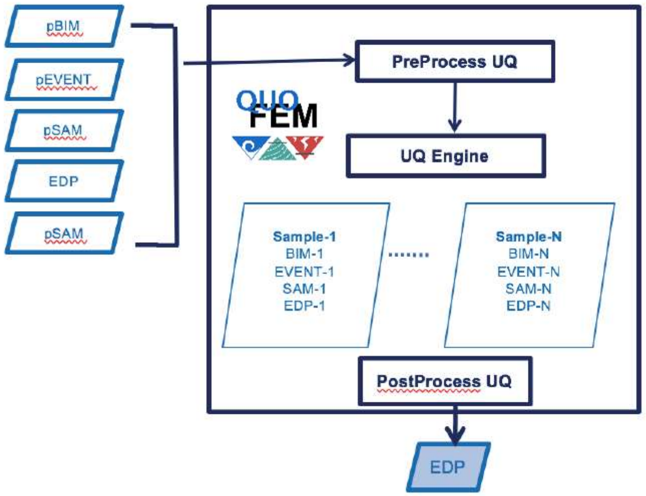


EE-UQ Application

- Quantifies uncertainty in building response when subjected to an earthquake

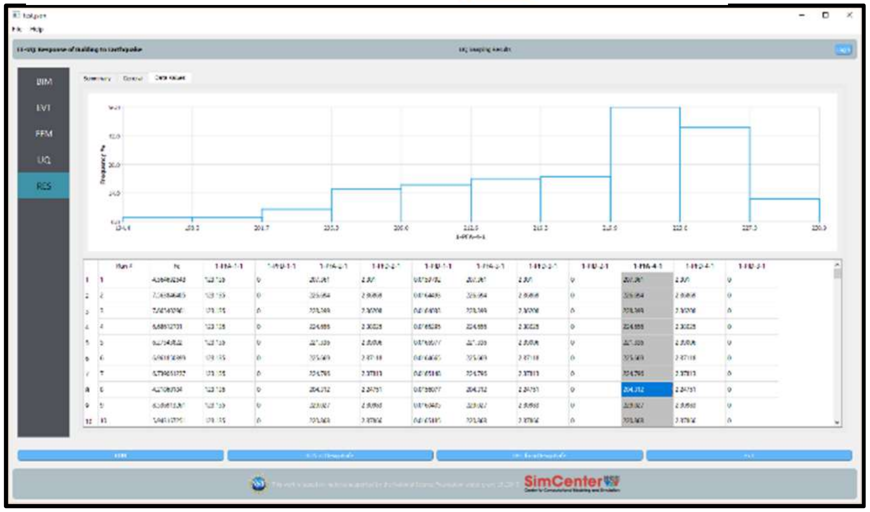
Application:

- **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



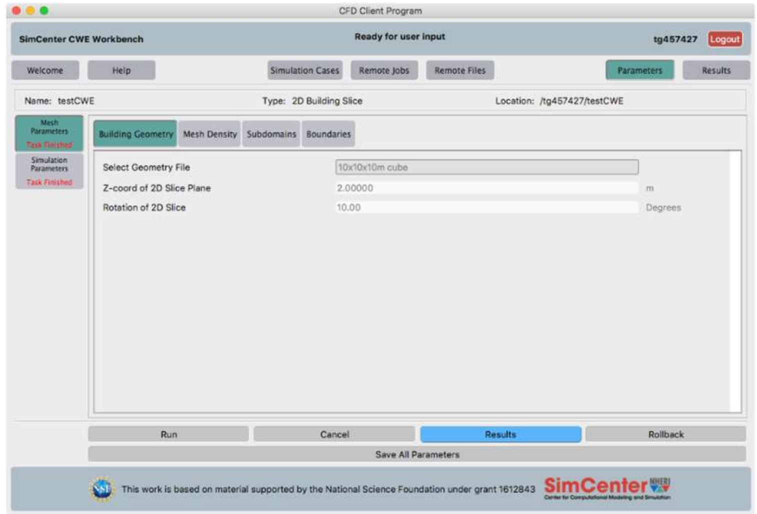
Research Opportunities:

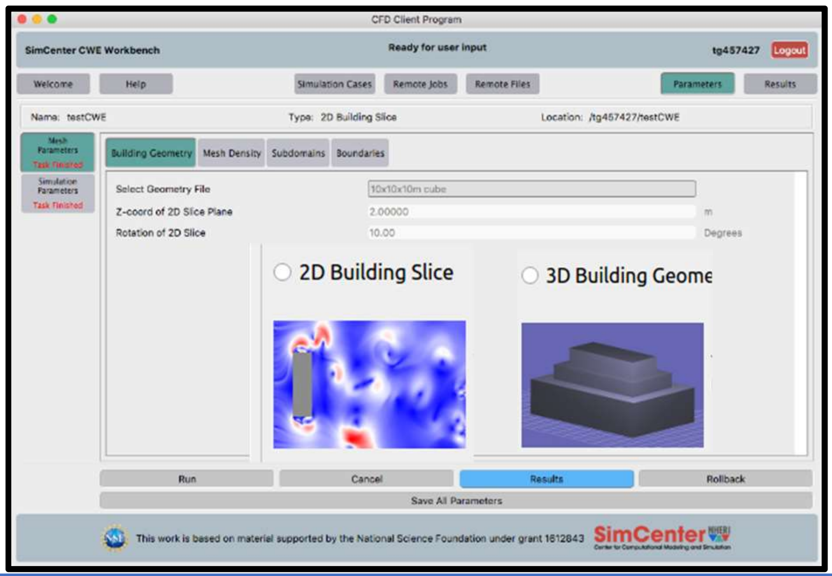
- Finite element modeling
- Hazard characterization
- UQ including surrogate model generation
- Datasets for model calibration

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.

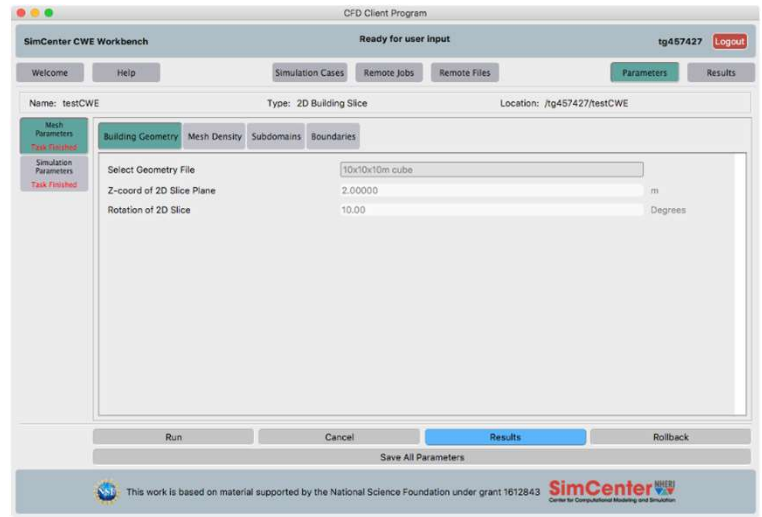
- Version 1.0 (June 2018): Wind Flow around Bluff Bodies
- Version 2.0 (2019): Wind Forces on Building
- Version 3.0 (2020): Multi-fidelity Modeling & UQ



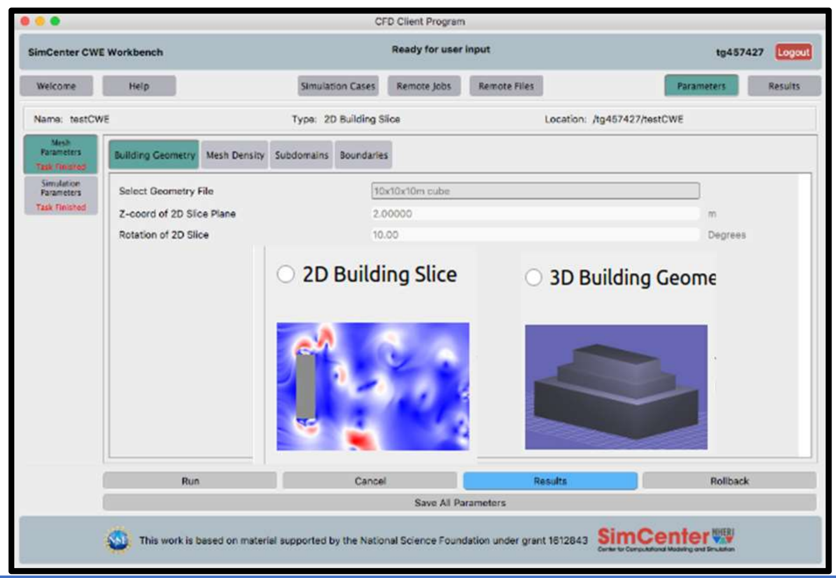


Computational Wind Engineering

- 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.

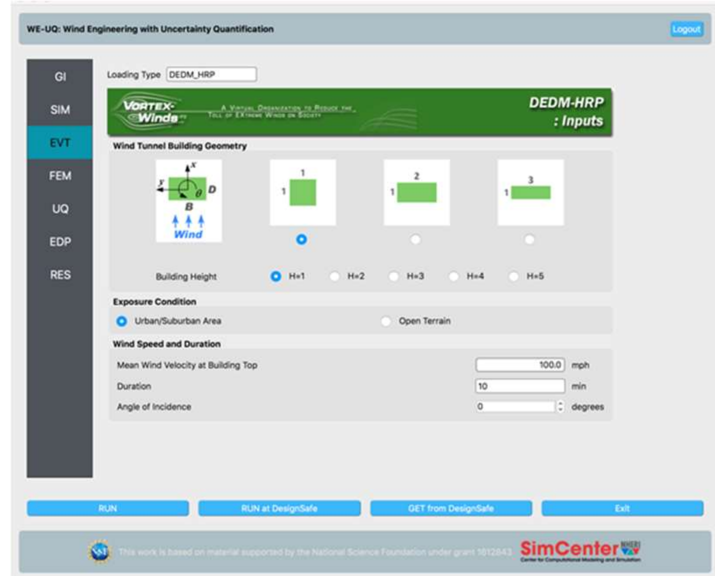


- Version 1.0 (June 2018): Wind Flow around Bluff Bodies
- Version 2.0 (2019): Wind Forces on Building
- Version 3.0 (2020): Multi-fidelity Modeling & UQ

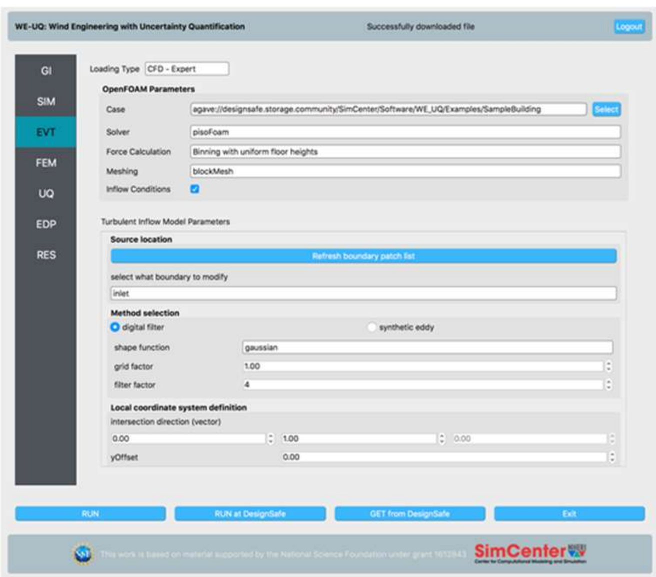


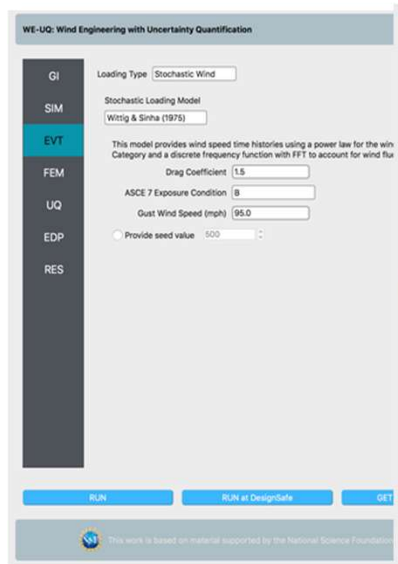
Wind Engineering

- 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)





SimCenter NHERI

PBE Application

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

Application:

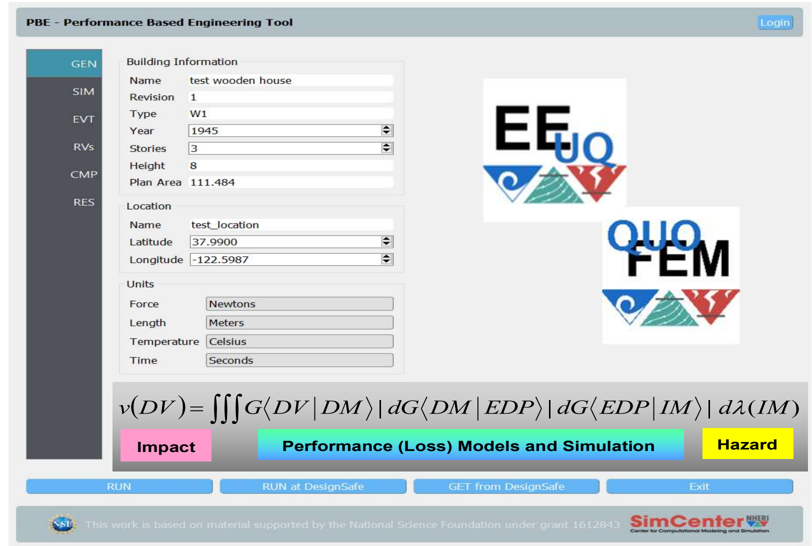
- **Inputs:**
  Building & structural information,
  Hazard characterization,
  Contents,
  Damage & loss functions, e.g. **P58, HAZUS, Pelicun,** or user-defined.
- **Outputs:** Damage, loss, and consequences

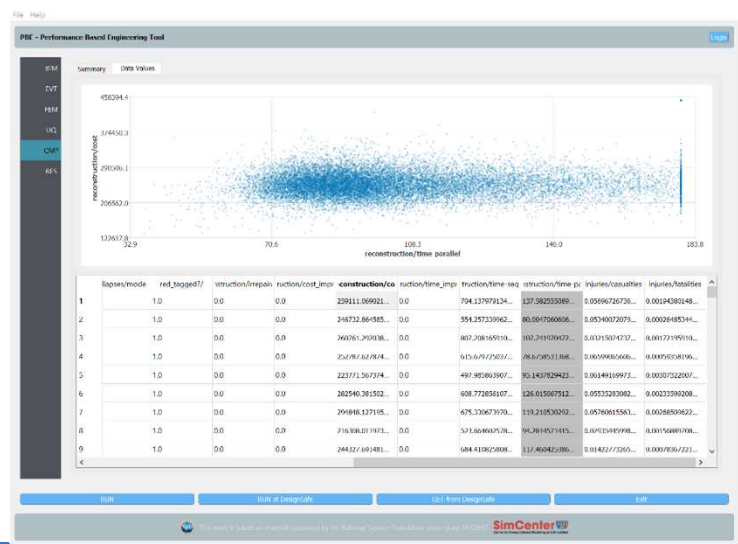
Release Dates:

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

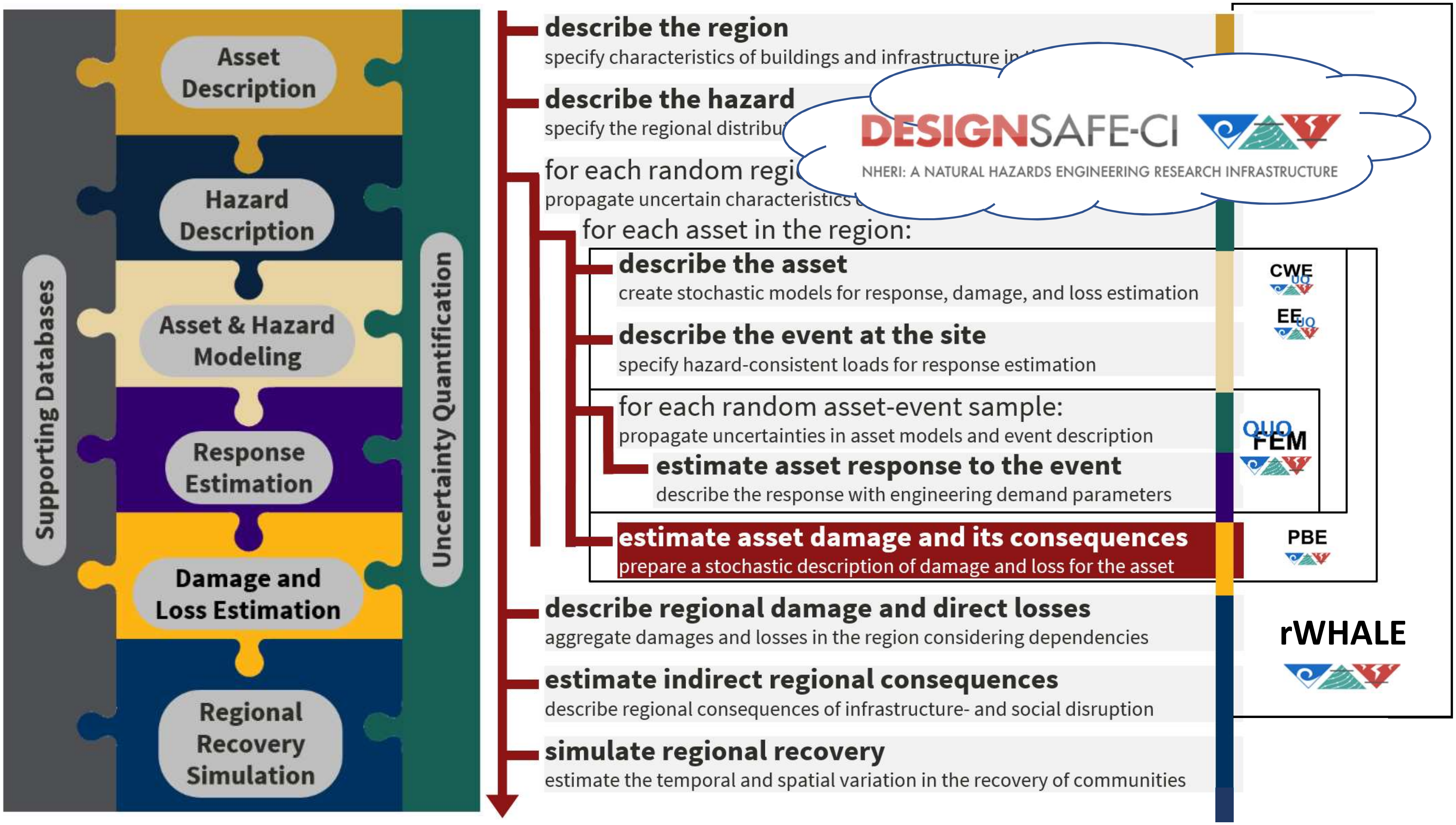
Research Opportunities:

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



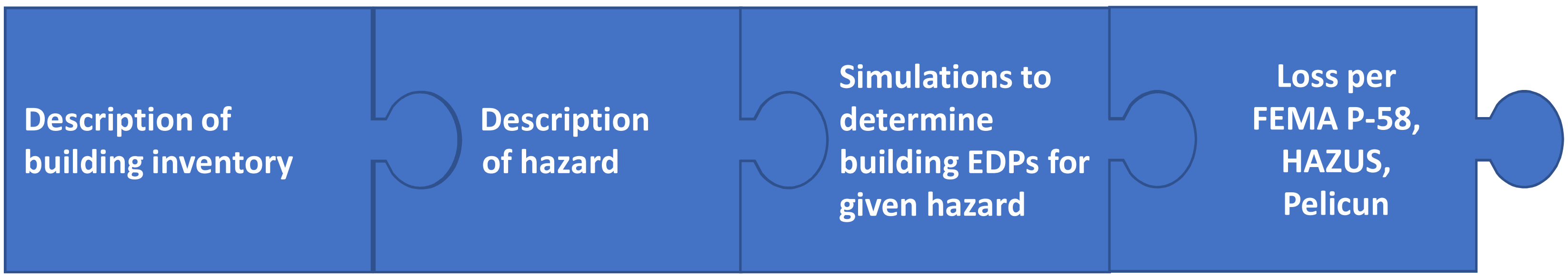


Regional Simulations and Loss Estimation Using rWHALE



Creates and executes a regional loss workflow

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



Initial Release V1.1 (Feb 2019)

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

Current Release V2.0 (Sept 2019)

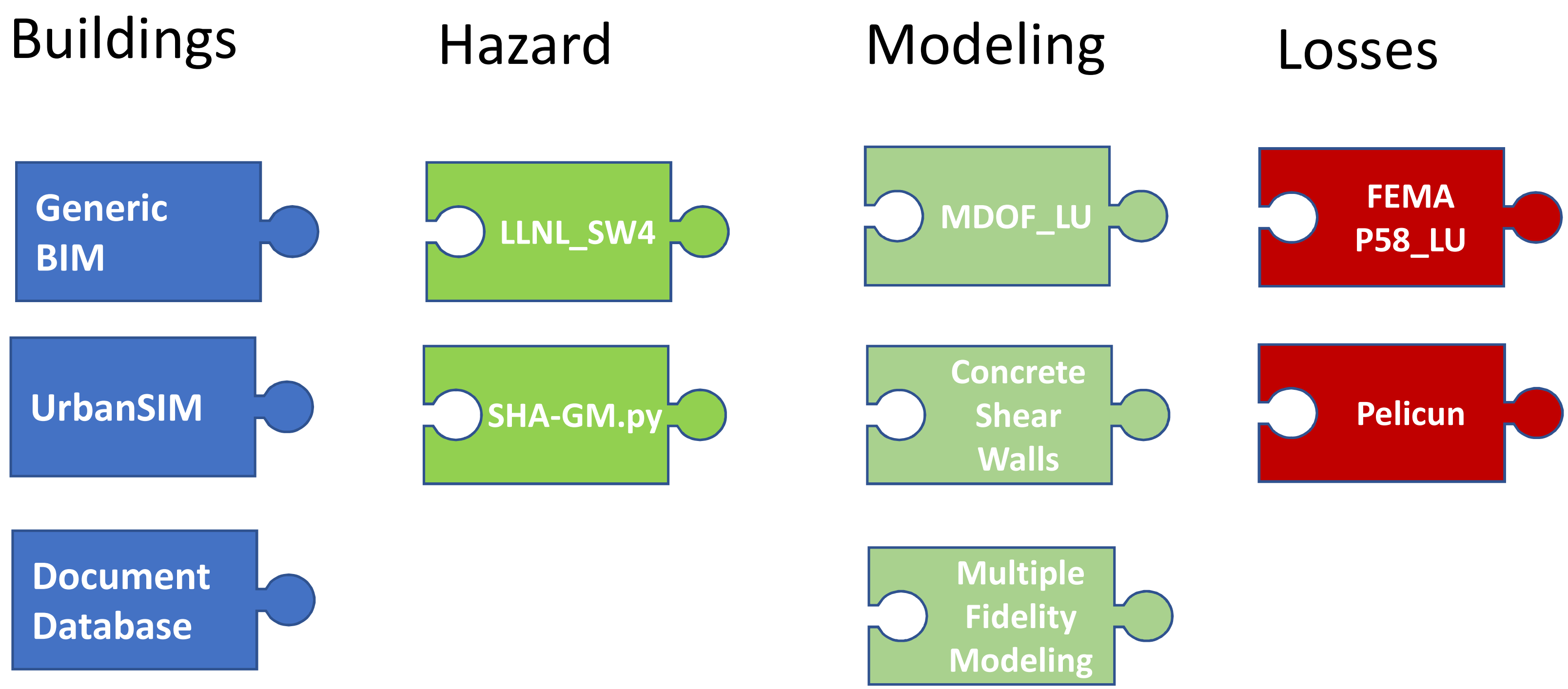
- Regional **Hurricane** workflow
- Initial version to consider ASCE7 wind loading and HAZUS type damage and loss

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

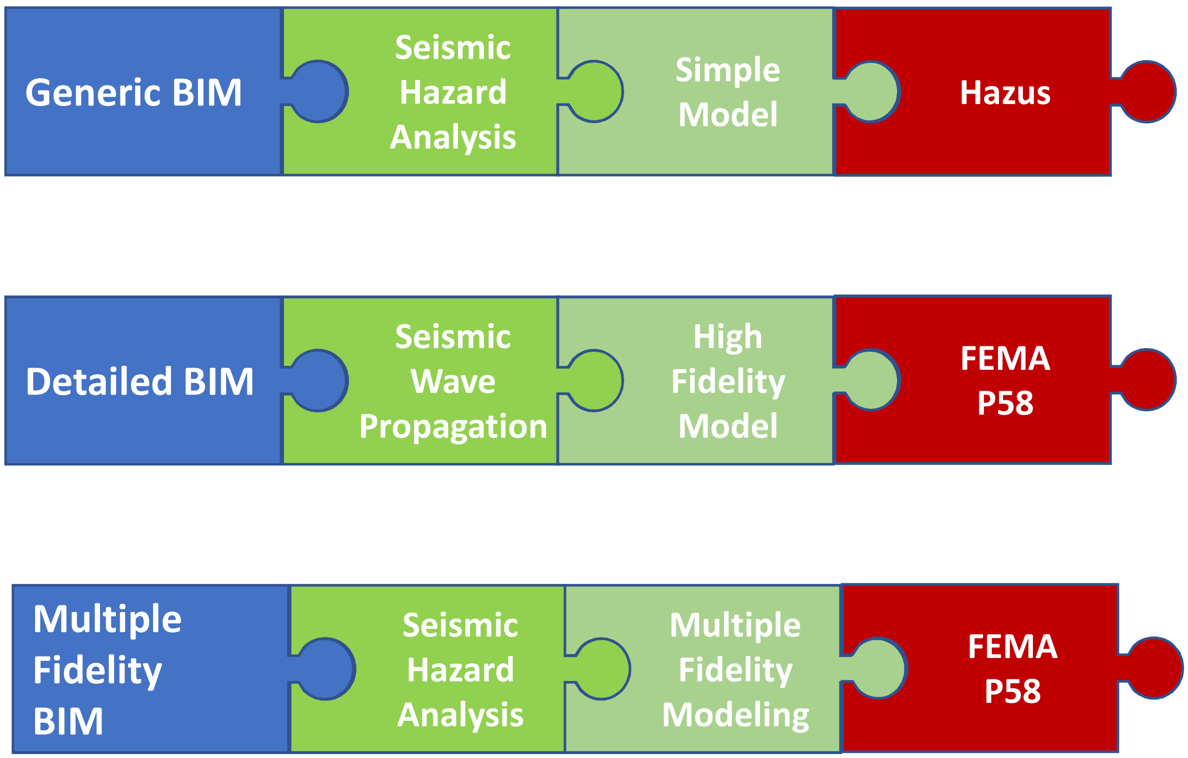
Configuration

Chain a set of applications into a building workflow

Low Fidelity Configuration

High Fidelity Configuration

Multiple Fidelity Configuration



JASON script for Regional Loss Simulation

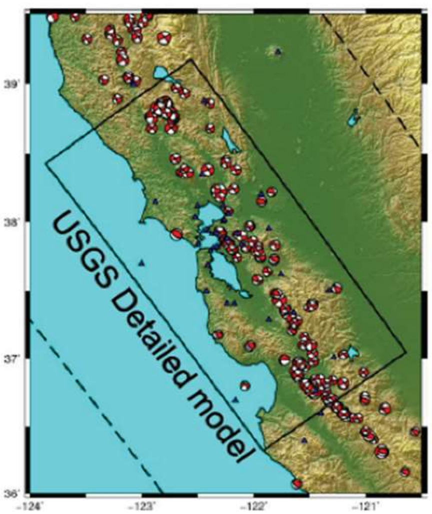
Untitled — Edited

Workflow — emacs Workflow1.json — 137×55

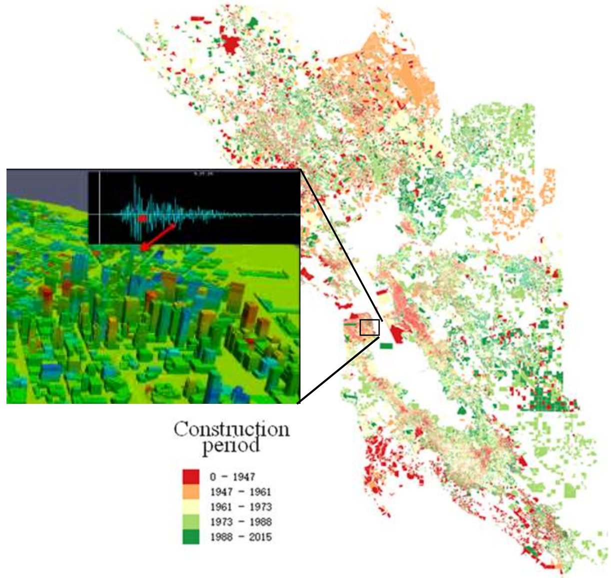

```
{
   "Name": "Workflow 1",
   "Author": "fmk",
   "WorkflowType": "Regional Simulation",
   "buildingFile":"buildings.json",
   "Applications": {
      "Buildings": {
         "BuildingApplication": "UrbanSimDatabase",
         "ApplicationData": {
            "Min": "1",
            "Max":"1856000",
            "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",
            "ApplicationData": {}
      },
      "Simulation": {
         "SimulationApplication": "OpenSees",
         "ApplicationData": {}
      },
      "UQ-Simulation": {
         "UQApplication": "Dakota-FEM",
         "ApplicationData": {}
      },
      "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
```


SimCenter NHERI

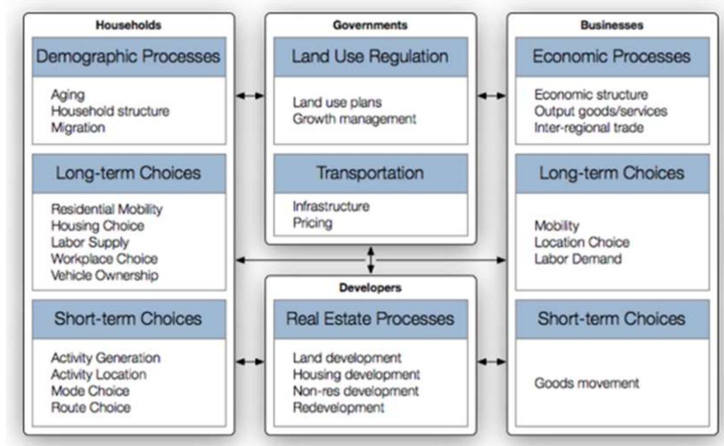
Regional Testbed (EQ)



M7.0 Hayward Fault



1.8 million buildings in SF Bay Area



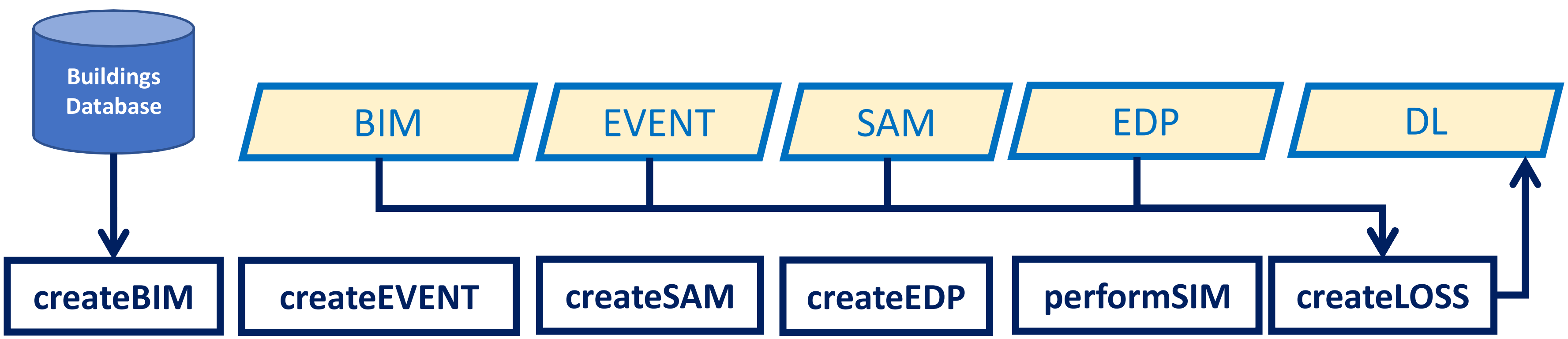
Policy/Planning: *building losses & downtime in 2010 and 2040*

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

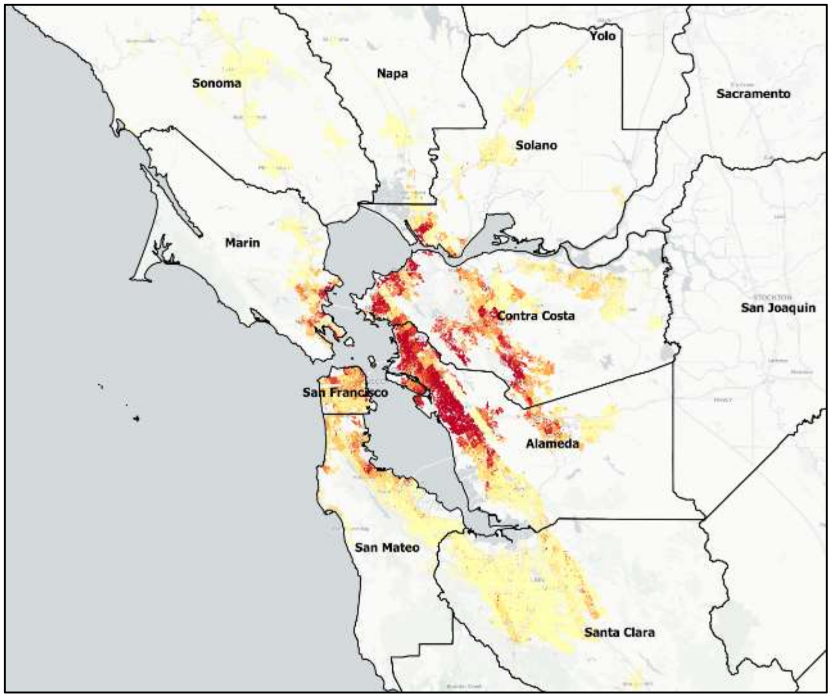
Ground Motions: 3D simulation, GM's at 2km grid (Rodgers, Pitarka & Petersson)
Building Inventory: UrbanSim and DataSF Portal; geometry, age, occupancy
Building Analyses: OpenSees, simplified NL MDOF, FEMA P58 (w/Cheng & Lu, Tsinghua)
Visualization: Q-GIS, UrbanSim
Interpretation: UrbanSim - urban growth,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

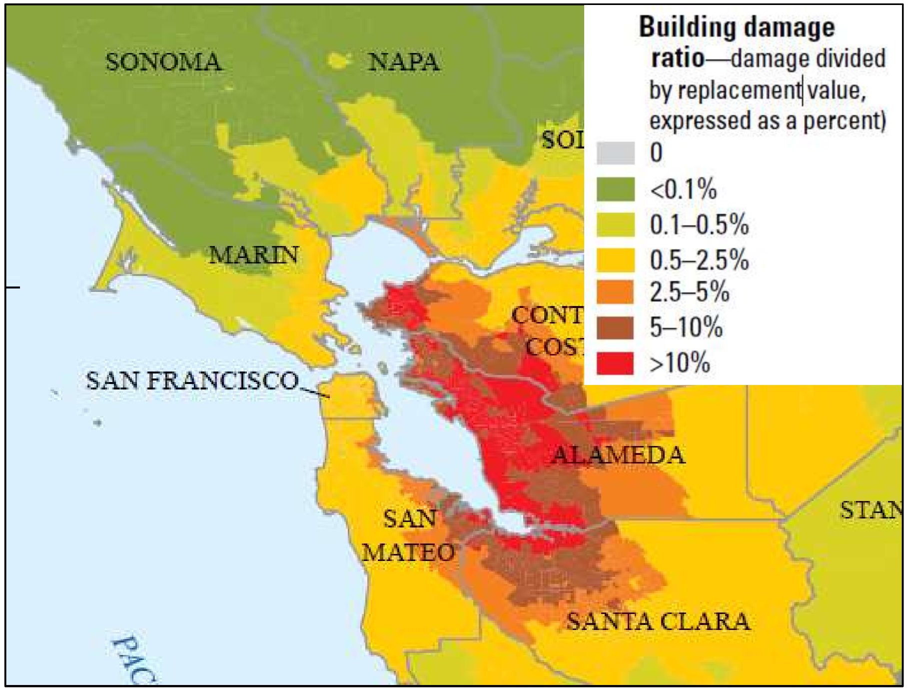
Registered Workflow Applications

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

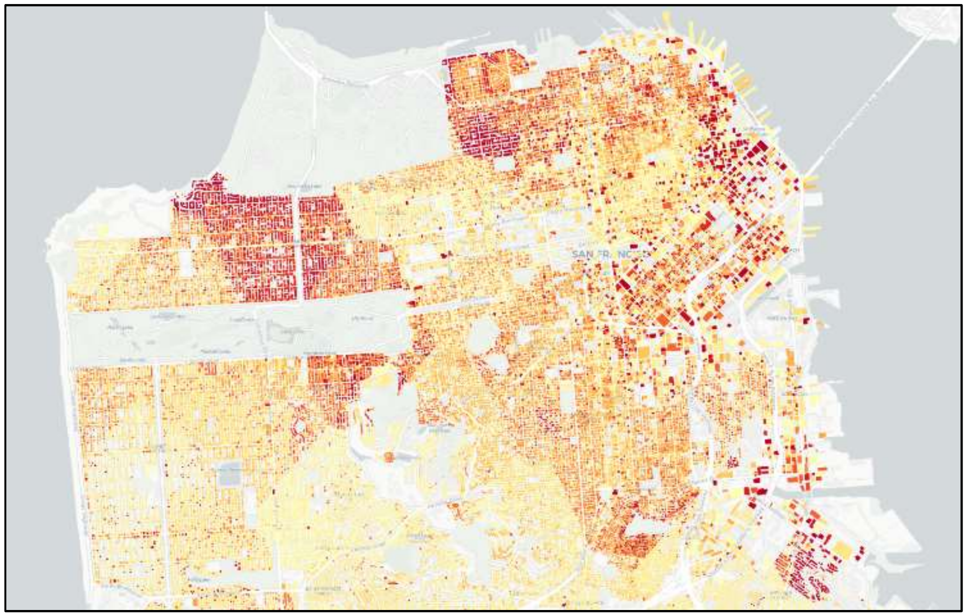
- **HayWired Scenario:** A study lead by USGS, involving approximately 60 partners, to simulate the effects and consequences of a hypothetical, yet scientifically realistic, magnitude M7.0 earthquake on the Hayward fault.

	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

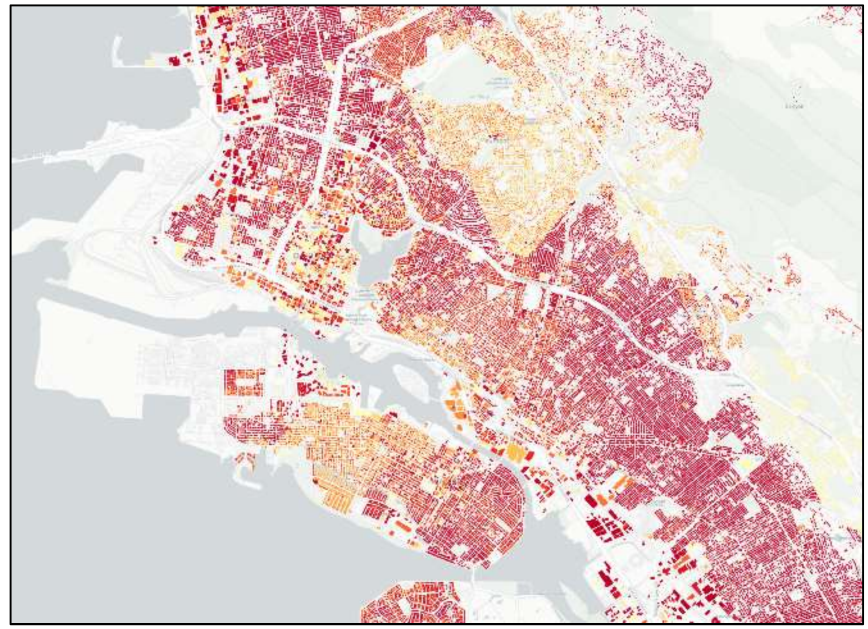
Detweiler, S.T., and Wein, A.M., eds., 2018, The HayWired earthquake scenario—Engineering implications: U.S. Geological Survey Scientific Investigations Report 2017–5013–I–Q, 429 p., https://doi.org/10.3133/sir20175013v2.

High Resolution Results

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



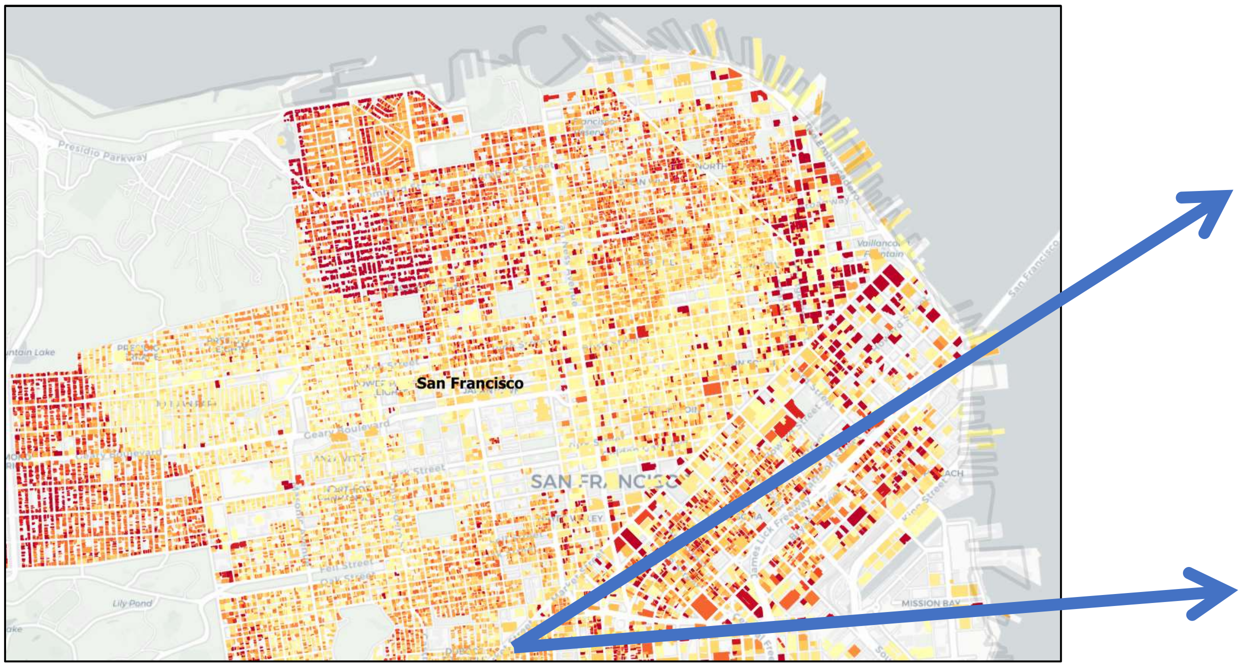
San Francisco



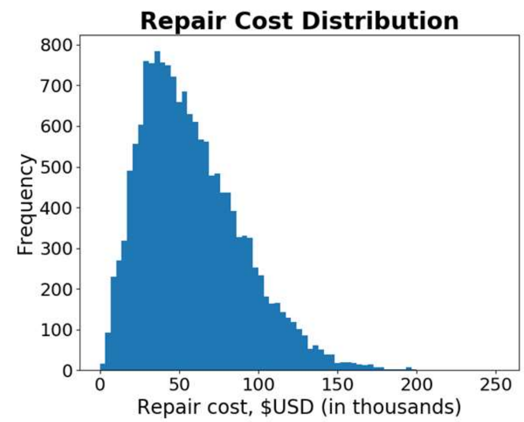
Oakland - Alameda

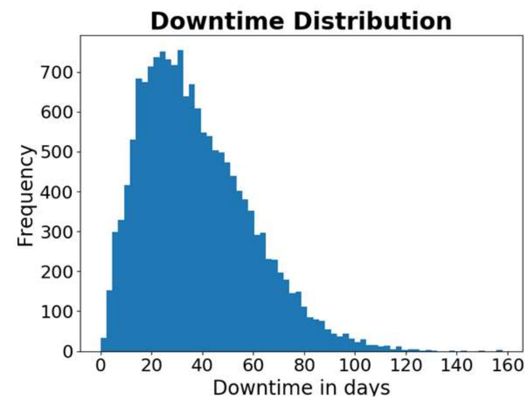
Opportunities to evaluate planning and policy decisions (land use, retrofit, etc.)

Parcel Level Results



Loss Ratios





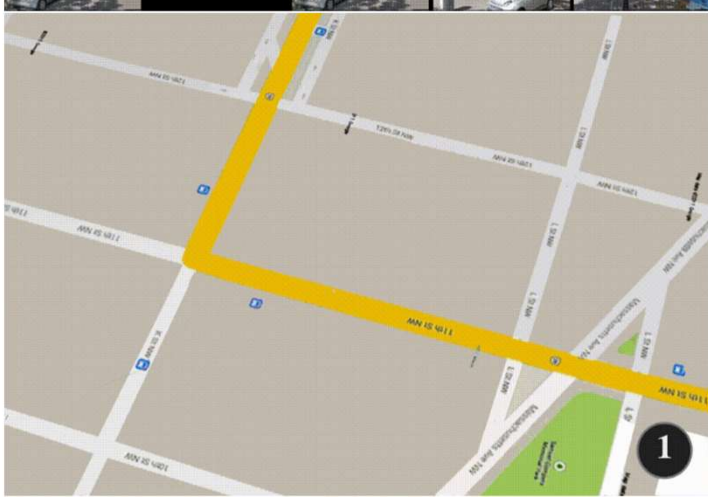
Additional SimCenter Products

- 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
- BRAILS: Building Recognition using AI at Large Scale
  - 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 → building properties

camera pose
3D models

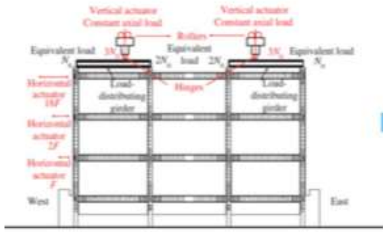
building properties:
- Height
- Construction type
- Number of stories
- ……

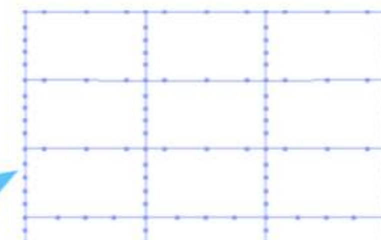
- SF building footprints: 117023 buildings, height, GPS coordinates, …
- SF building permits: 1+ million records, #stories, construction types, GPS coordinates, …
- SF land use: 115,468 records, land use types, year built, GPS coordinates, …

AI Applications: BIM to SAM

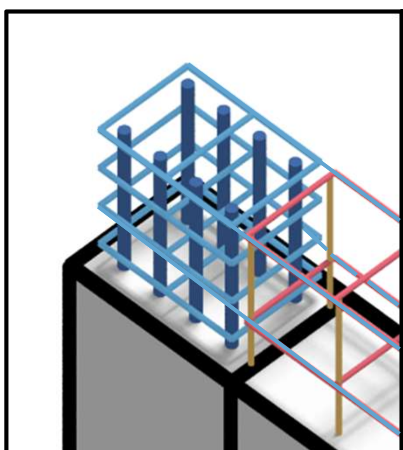
Structural Engineers

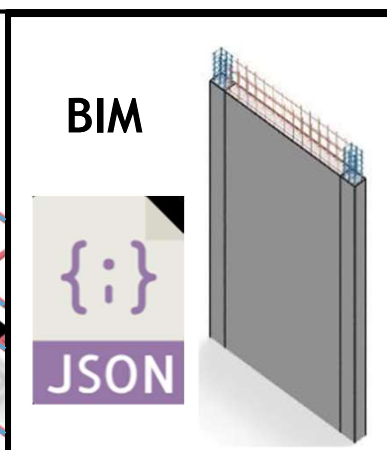
Future Virtual Engineer

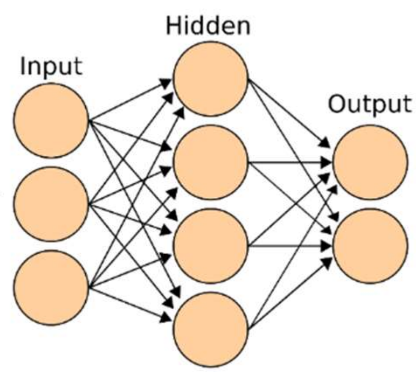


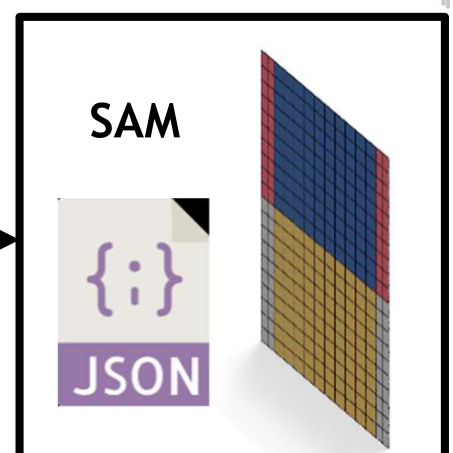


Dataset: 87 walls
Training: 98% accurate
Testing: 93% accurate



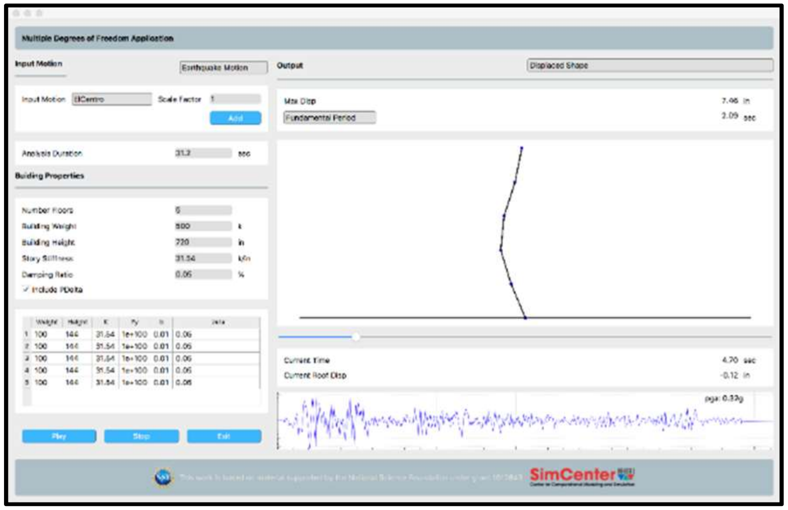




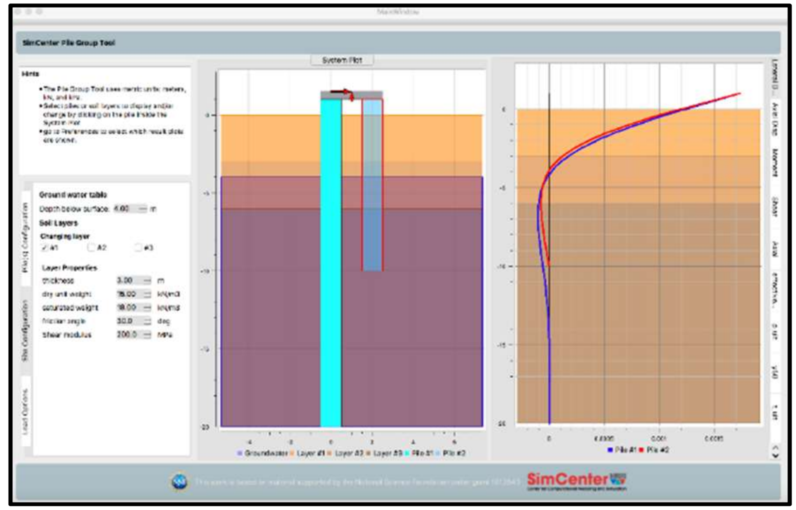


Educational Applications

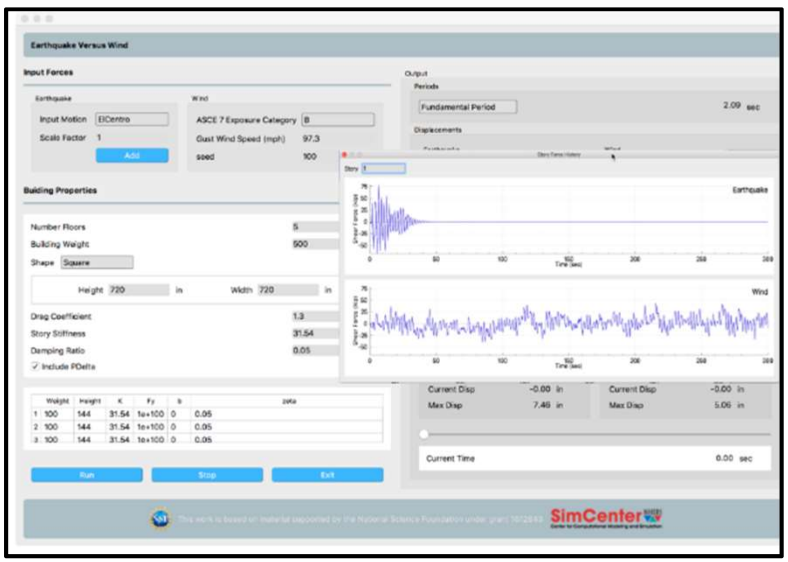
MDOF



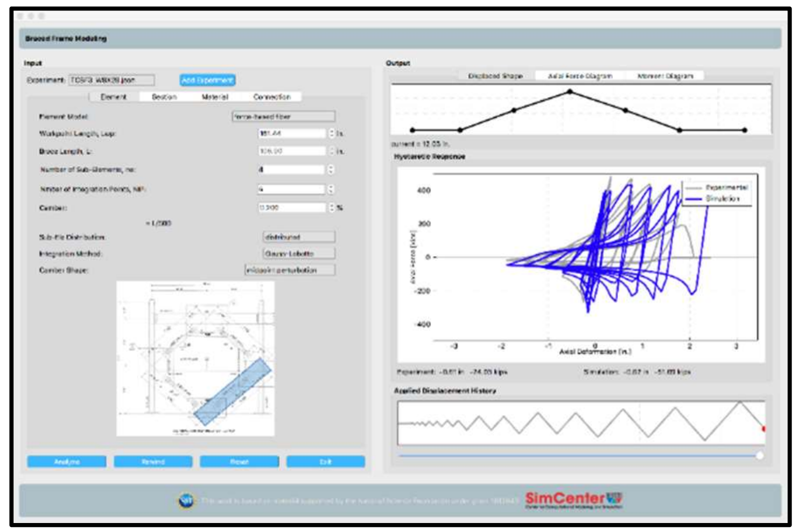
PGT



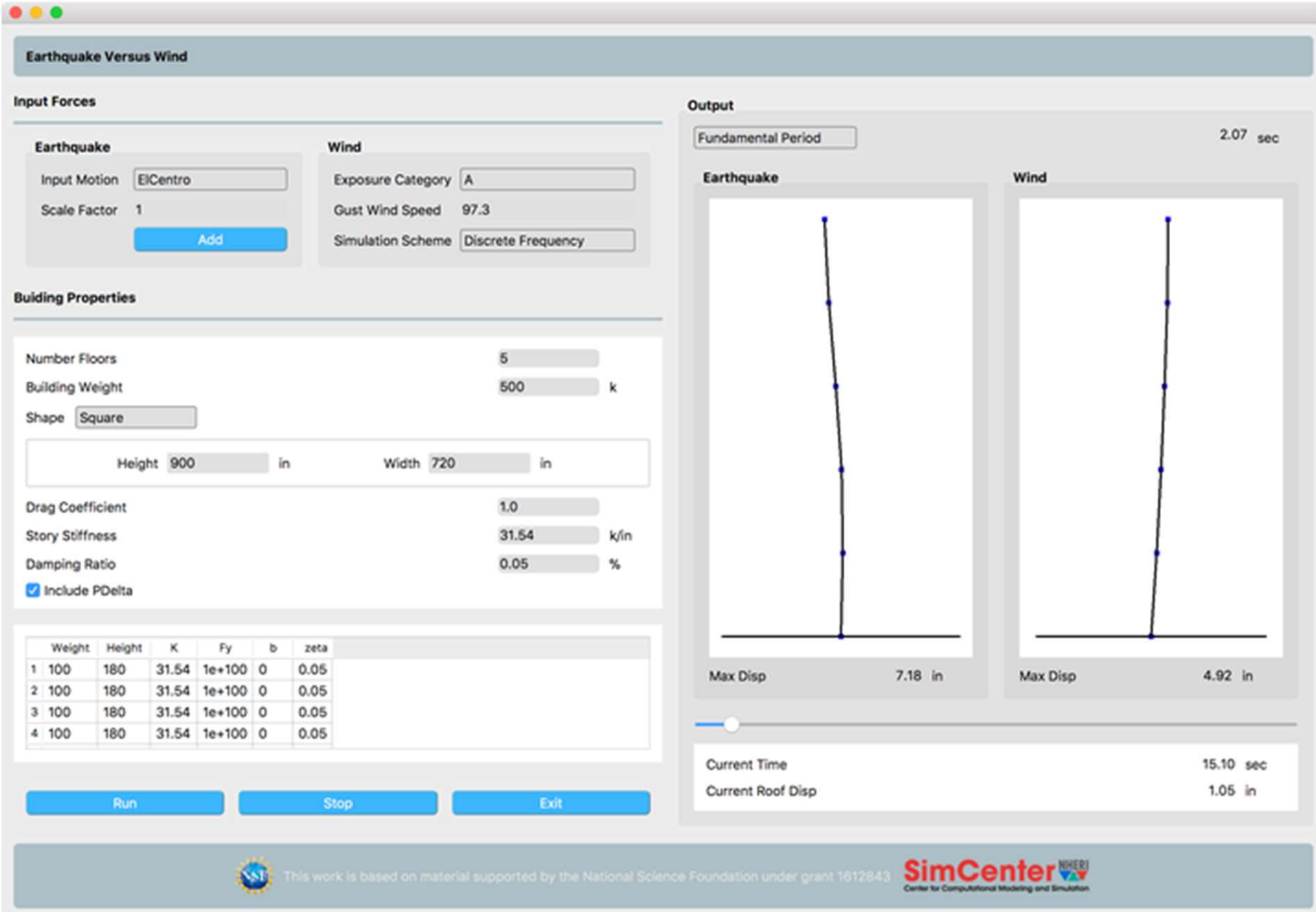
EvW



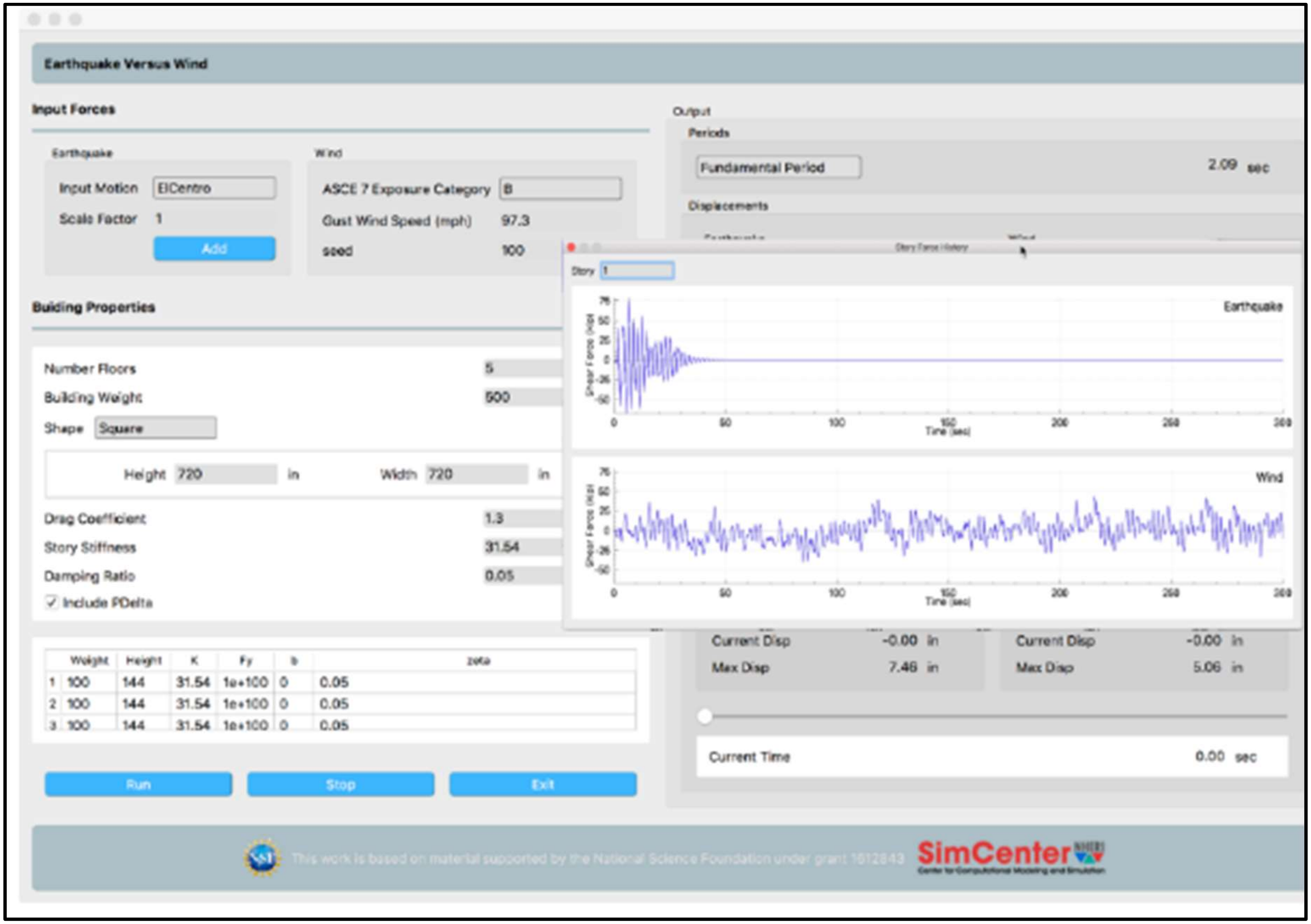
BFM



Educational Applications

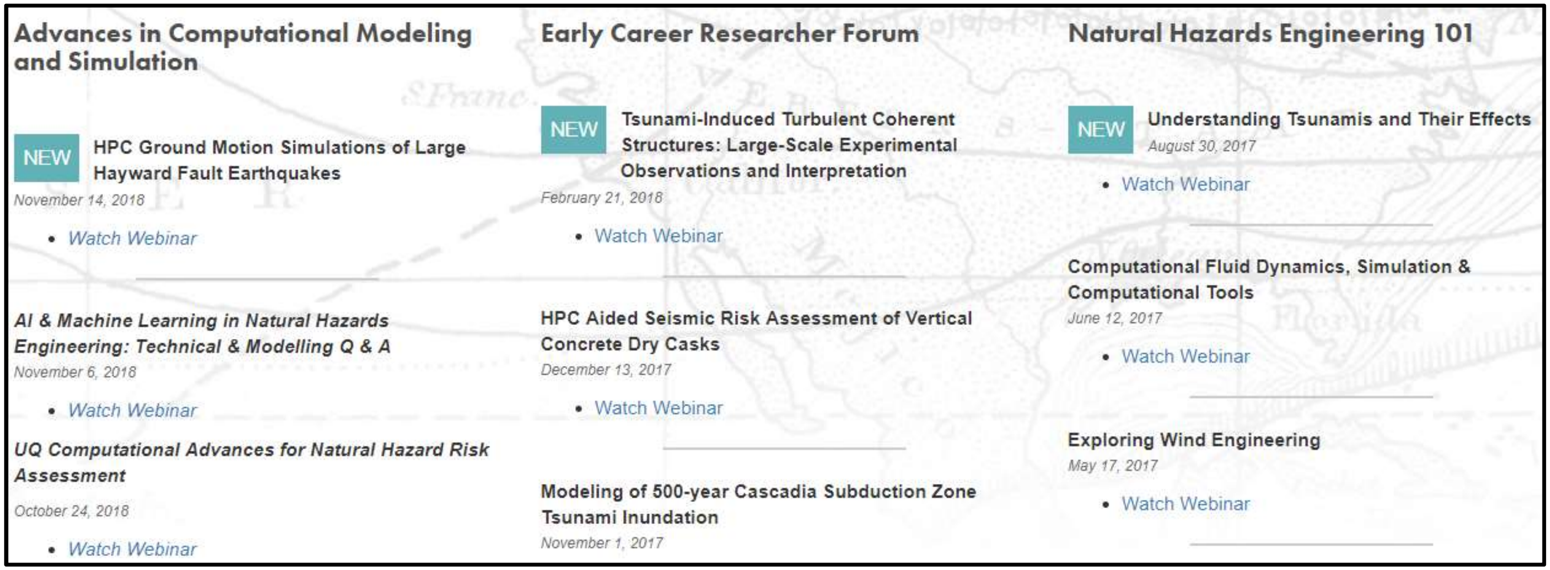


Educational Applications



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

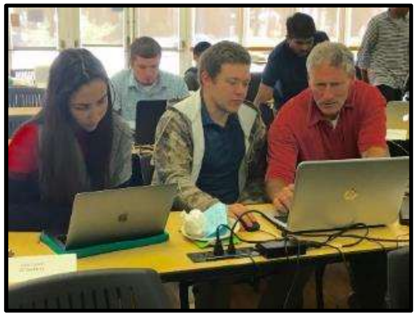
NEW **Understanding Tsunamis and Their Effects**
August 30, 2017
- Watch Webinar

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/collaborate/