rWHALE: Regional Workflow for Hazards and Loss Estimation

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NHERI SimCenter
Programming Bootcamp 2019
Outline

- Overview of the Computational Framework
- Regional Workflows using rWHALE
- Regional Testbed Simulations
  - San Francisco Testbed
  - Anchorage Testbed
- Demos & Exercises
  - Local computer
  - High performance computer (HPC)
NHERI SimCenter

“Transforming the nation’s ability to understand and mitigate adverse effects of natural hazards on the built environment through computational simulation”

- Cloud-enabled research tools, scalable to run on HPC
- Emphasis on uncertainty quantification
- Educational resources
Framework for Building Workflow Applications

- **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.

Run in the cloud
OR
Run Locally
Computations Workflow

- Regional workflow
  - Buildings Database
  - Hazard
  - Regional Simulation
  - Damage & Loss

- Single building workflow
  - Buildings Database
  - Hazard
  - BIM
  - EVENT
  - SAM
  - EDP
  - DL

BIM: Building Information Model
SAM: Structural Analysis Model
EDP: Engineering Demand Parameters
DL: Damage & Loss
Workflow Overview

- Applications & Interfaces

BIM: Building Information Model
SAM: Structural Analysis Model
EDP: Engineering Demand Parameters
DL: Damage & Loss

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:** Parameterized BIM  
**pSAM:** Parameterized SAM

### Registered Applications For Regional Earthquake Simulations

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>createBIM</td>
<td>GenericBimDatabase</td>
<td>Creates a simple BIM from a building flat file (csv)</td>
</tr>
<tr>
<td></td>
<td>UrbanSimDatabase</td>
<td>Creates a simple BIM from UrbanSim simulation outputs</td>
</tr>
<tr>
<td>createEVENT</td>
<td>LLNL_SW4</td>
<td>Gets Event input from SW4 outputs</td>
</tr>
<tr>
<td></td>
<td>SHA-GM</td>
<td>Computes event input using SHA and record selection/scaling</td>
</tr>
<tr>
<td>createSAM</td>
<td>MDOF_LU</td>
<td>Creates a MDOF shear building model</td>
</tr>
<tr>
<td>createEDP</td>
<td>StandardEarthquakeEDP</td>
<td>Defines the standard EDPs used for a seismic event</td>
</tr>
<tr>
<td>performSIM</td>
<td>OpenSeesSimulation</td>
<td>Performs simulation using OpenSees and calculates the EDPs</td>
</tr>
<tr>
<td>createLOSS</td>
<td>FEMAP58_LU</td>
<td>Calculates damage and loss estimates using FEMA P-58 procedure</td>
</tr>
<tr>
<td>performUQ</td>
<td>DakotaFEM</td>
<td>Propagates uncertainty in all applications using Dakota</td>
</tr>
</tbody>
</table>
# Registered Applications For Regional Wind Simulations

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<tr>
<th>Type</th>
<th>Name</th>
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<tbody>
<tr>
<td>createBIM</td>
<td>GenericBimDatabase</td>
<td>Creates a simple BIM from a building flat file (csv)</td>
</tr>
<tr>
<td></td>
<td>UrbanSimDatabase</td>
<td>Creates a simple BIM from UrbanSim simulation outputs</td>
</tr>
<tr>
<td>createEVENT</td>
<td>ASCE 7-10</td>
<td>Generate wind loading using ASCE7-10 procedure</td>
</tr>
<tr>
<td></td>
<td>Stochastic Wind</td>
<td>Generate wind loading using stochastic process models</td>
</tr>
<tr>
<td>createSAM</td>
<td>MDOF_LU</td>
<td>Creates a MDOF shear building model</td>
</tr>
<tr>
<td>createEDP</td>
<td>StandardWindEDP</td>
<td>Defines the standard EDPs used for a wind event (e.g. pressure)</td>
</tr>
<tr>
<td>performSIM</td>
<td>OpenSeesSimulation</td>
<td>Performs simulation using OpenSees and calculates the EDPs</td>
</tr>
<tr>
<td>createLOSS</td>
<td>PELICUN(Hazus)</td>
<td>Calculates damage and loss estimates using Hazus methodology</td>
</tr>
<tr>
<td>performUQ</td>
<td>DakotaFEM</td>
<td>Propagates uncertainty in all applications using Dakota</td>
</tr>
</tbody>
</table>
Regional Simulation Tools

San Francisco Bay Area Testbed

M7.0 Hayward

Building Inventory

Hazard Consequences
Regional Simulation Tools

Regional simulation using HPC through DesignSafe Workspace
Regional Simulation Tools

Small scale simulation using Local Computer

- Applications
- data
- LowFidelity.json
- MultipleFidelity.json
- RegionalEarthquakeSimulation.py
- WorkflowApplications.json
- WorkflowUtils.py

Applications, Sample Data & Examples

Runs Locally as a console application
The Framework provides applications with standard interfaces

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Hazard</th>
<th>Modeling</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic BIM</td>
<td>LLNL_SW4</td>
<td>MDOF_LU</td>
<td>FEMA P58_LU</td>
</tr>
<tr>
<td>UrbanSIM</td>
<td>SHA-GM.py</td>
<td>Concrete Shear Walls</td>
<td>Pelicun</td>
</tr>
<tr>
<td>Document Database</td>
<td>NNGM.py</td>
<td>Multiple Fidelity Modeling</td>
<td></td>
</tr>
</tbody>
</table>

**Earthquake Simulation Workflows**

<table>
<thead>
<tr>
<th></th>
<th>Low Fidelity</th>
<th>High Fidelity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic BIM</td>
<td>Seismic Hazard Analysis</td>
<td>Simple Model</td>
</tr>
<tr>
<td></td>
<td>Hazus</td>
<td>FEMA P58</td>
</tr>
<tr>
<td>Detailed BIM</td>
<td>Seismic Wave Propagation</td>
<td>High Fidelity Model</td>
</tr>
</tbody>
</table>
Regional Simulation Configuration

Configuration File

```json
{
    "Name": "Workflow5",
    "Author": "Nael Elhaddad",
    "WorkflowType": "Regional Simulation",
    "buildingFile": "buildings.json",
    "Applications": {
        "Buildings": {...
        },
        "Events": [...
        ],
        "Modeling": {...
        },
        "EDP": {...
        },
        "Simulation": {...
        },
        "UQ-Simulation": {...
        },
        "Damage&Loss": {...
        }
    }
}
```

```
"Events": [
    {
        "EventClassification": "Earthquake",
        "EventApplication": "LLNL-SW4",
        "ApplicationData": {
            "pathSW4results": "/createEVENT/Hayward7.0/",
            "filenameHFmeta": "../build/data/HFmeta"
        }
    }
]
```

```
"Damage&Loss": {
    "Damage&LossApplication": "FemaP58-LU",
    "ApplicationData": {
        "filenameSettings": "../build/data/settings.ini",
        "pathCurves": "../build/data/ATCCurves/",
        "pathNormative": "../build/data/normative/"
    }
}
```
Regional Testbeds Using rWHALE

San Francisco Bay Area Testbed

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

Atlantic City, NJ Storm Testbed

Memphis, TN Lifelines Testbed

Anchorage, Alaska Testbed

- Parcel level damage
- 3,828 red-tagged buildings
- 14.5% net buildings loss ratio
Example Simulation: Earthquake in San Francisco Bay Area

- M7.0 Rupture along the Hayward fault modeled using SW4 [1]
- **1,843,351 buildings** were included in the Simulation
- Building information is based on UrbanSim data
- Damage and Loss calculation using FEMAP58_LU [2]
- Structural analysis models are based on MDOF_LU [3]
- Red tagged buildings: **141,459**
- Buildings damage: **$84.1 billion**
- Net buildings damage ratio: **5.6%**


Visualization on parcel level results can be done in GIS tools (e.g. QGIS)
Parcel Level Results

Loss Ratios

Repair Cost Distribution

Downtime Distribution
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.

<table>
<thead>
<tr>
<th></th>
<th>HayWired Scenario</th>
<th>SimCenter Testbed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Buildings</strong></td>
<td>3 Million</td>
<td>1.84 Million</td>
</tr>
<tr>
<td><strong>Red Tagged Buildings</strong></td>
<td>101,000</td>
<td>141,459</td>
</tr>
<tr>
<td><strong>Building Damage</strong></td>
<td>$30.3 Billion</td>
<td>$84.1 Billion</td>
</tr>
<tr>
<td><strong>Net Damage Ratio</strong></td>
<td>2.91%</td>
<td>5.6%</td>
</tr>
<tr>
<td><strong>Total Buildings Cost</strong></td>
<td>$1.04 Trillion</td>
<td>$1.5 Trillion</td>
</tr>
</tbody>
</table>

Anchorage Earthquake Testbed

- Tax data for 97,421 buildings/parcels (Municipality of Anchorage appraisal records)
- Data was processed to obtain BIM for 84,435 buildings
  - 78,509 Residential and 7,926 Commercial buildings
- Event: Magnitude 7.0 earthquake near Anchorage, Alaska Nov 30th, 2018
  - 12 Recorded ground motions available through CESMD

~12,000 buildings in Eagle River

Anchorage, Alaska Testbed

- 3,828 red-tagged buildings
- 14.5% net buildings loss ratio
Demos
Questions & Discussion
Extra Slides
Research and Educational Tools

**SimCenter Research Tools**

UQ FEM CWE EE PBE

The uQFEM application is intended to advance the use of uncertainty quantification and optimization within the field of numerical methods.

OpenFOAM based CFD analysis software for analyzing the effect of wind on structures and attendant response, including UQ in future releases.

The EE-UQ Tool is an application to determine the response, including UQ, of a structure to an earthquake excitation.

This PBE Tool is an extendable workflow application to perform Performance Based Engineering computations for various hazards. PBE analysis includes multi-ensemble simulation models for UQ.

Open source software: [https://github.com/NHERI-SimCenter](https://github.com/NHERI-SimCenter)
ECO Activities

**Community Engagement**
- Regional Hazard Testbeds
- Open-source, Community Driven Software
- SimCenter Tool Training Workshop (~June 2019)
- Summer Programming Bootcamp (~July 2019)
- SimCenter Webinars
- Dedicated Slack discussions
- Multi-disciplinary REU program

[https://simcenter.designsafe-ci.org/join-community/](https://simcenter.designsafe-ci.org/join-community/)