AVANCES RECIENTES
EN EL INCREMENTO DE LA
RESILIENCIA Y LA SUSTENTABILIDAD
DE LA INFRAESTRUCTURA
FÍSICA EDUCATIVA

Del 24 al 26 febrero de 2021

Performance-Based Engineering Approach to Design for Community Resilience

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Stanford University

PEER

Stanford ENGINEERING | Blume Earthquake Engineering Center

SimCenter NHERI
Center for Computational Modeling and Simulation

Impetus for California's School Safety

Online Archive of CA/USGS (Jefferson Jr. High School)


W.L. Huber/USGS (John Muir School)

1933 Long Beach Earthquake

- March 10, 1933 at 5:54 PM
- Mw 6.4 (Mercalli intensity VII)
- 115 fatalities

Damage to Schools

- 70 destroyed
- 120 major damage
- primarily unreinforced masonry
- one student fatality

Legislation for California's School Safety

April 10, 1933 – Field Act: regulates public school construction, with higher design and Q/A standards

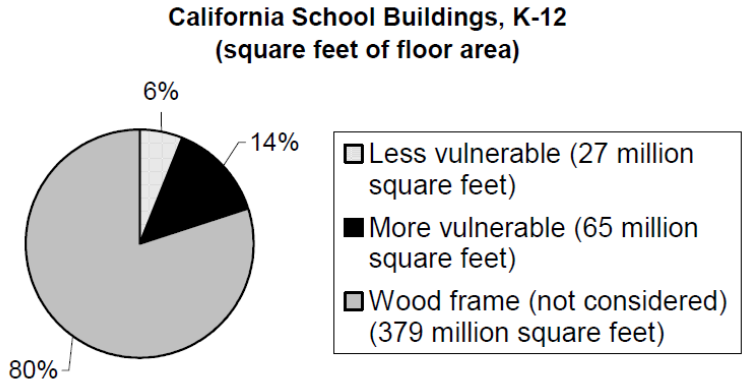
1939/1968 - Garrison Act: requires review/retrofit of pre-1933 schools, by 1977

1967/1976 Geologic Hazards Legislation: requires geologic hazards studies for new schools, prohibits construction within 50 ft of geologic fault

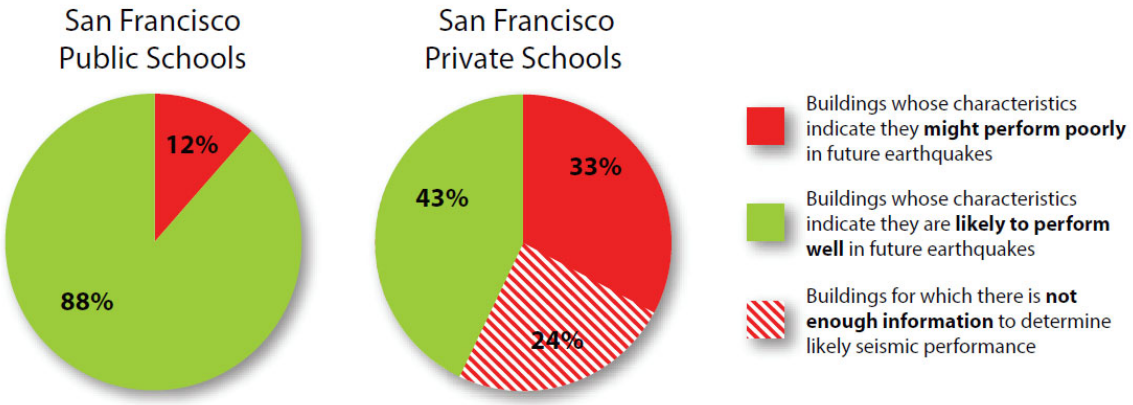
1999 Assembly Bill 300: requires inventory of potential "at risk" school buildings, built before 1978 (excluding wood framed buildings)

Retrofit of "at risk" schools is largely left to local (city) jurisdictions to develop programs and raise funds

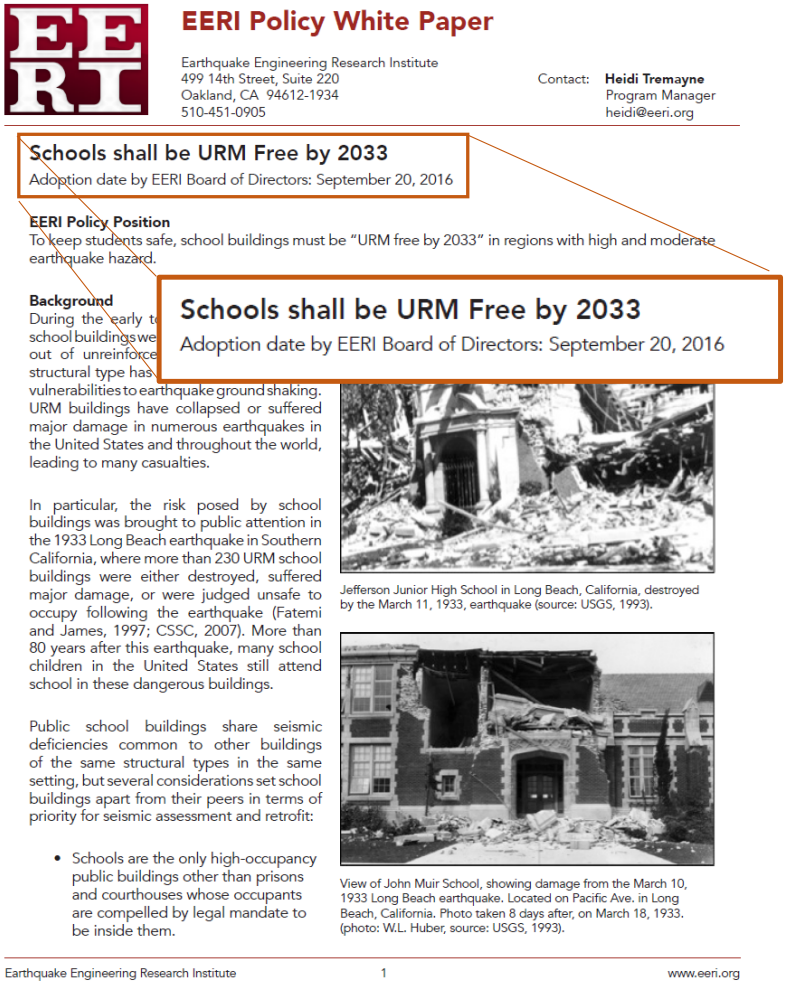
Progress and Gaps in California's School Safety



Statewide Survey of Schools (Dept. of General Services, 2002)



Earthquake Risk and San Francisco's Private Schools (2013)



EERI Policy White Paper

Earthquake Engineering Research Institute
499 14th Street, Suite 220
Oakland, CA 94612-1934
510-451-0905

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Program Manager
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Schools shall be URM Free by 2033
Adoption date by EERI Board of Directors: September 20, 2016

EERI Policy Position
To keep students safe, school buildings must be "URM free by 2033" in regions with high and moderate earthquake hazard.

Background
During the early t
school buildings we
out of unreinforce
structural type has
vulnerabilities to earthquake ground shaking. URM buildings have collapsed or suffered major damage in numerous earthquakes in the United States and throughout the world, leading to many casualties.

In particular, the risk posed by school buildings was brought to public attention in the 1933 Long Beach earthquake in Southern California, where more than 230 URM school buildings were either destroyed, suffered major damage, or were judged unsafe to occupy following the earthquake (Fatemi and James, 1997; CSSC, 2007). More than 80 years after this earthquake, many school children in the United States still attend school in these dangerous buildings.

Public school buildings share seismic deficiencies common to other buildings of the same structural types in the same setting, but several considerations set school buildings apart from their peers in terms of priority for seismic assessment and retrofit:

- Schools are the only high-occupancy public buildings other than prisons and courthouses whose occupants are compelled by legal mandate to be inside them.

Schools shall be URM Free by 2033
Adoption date by EERI Board of Directors: September 20, 2016

Jefferson Junior High School in Long Beach, California, destroyed by the March 11, 1933, earthquake (source: USGS, 1993).

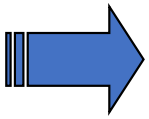
View of John Muir School, showing damage from the March 10, 1933 Long Beach earthquake. Located on Pacific Ave. in Long Beach, California. Photo taken 8 days after, on March 18, 1933. (photo: W.L. Huber, source: USGS, 1993).

Performance-Based Framework

To transform earthquake engineering assessment and design …

Traditional Approach

- Non-scientifically defined seismic hazard
- Indirect design approaches
- Undefined and uncertain outcomes



Performance-Based

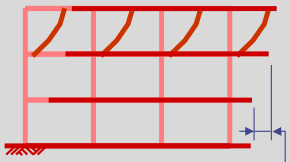
- Scientifically-defined seismic hazard
- Direct design approaches
- Defined outcomes with probabilities of achieving them

Performance-Based Framework

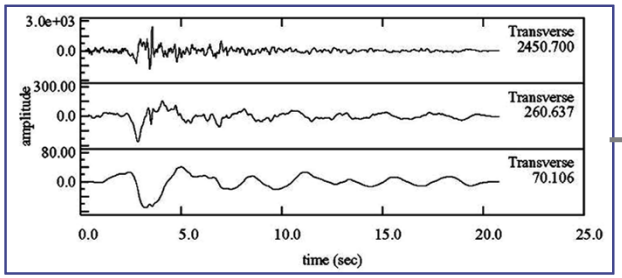
- Collapse & Casualties
- Direct Financial Loss
- Downtime

Decision Variable

Damage Measure



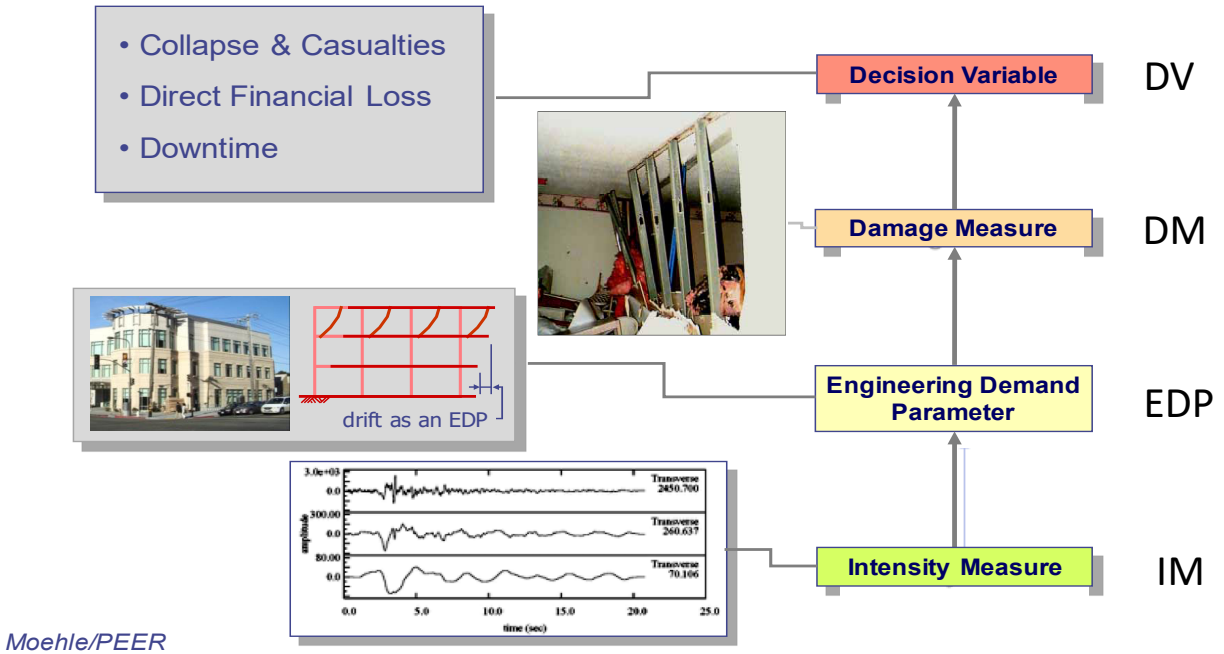
Engineering Demand Parameter



Intensity Measure

Moehle/PEER

Performance-Based Framework



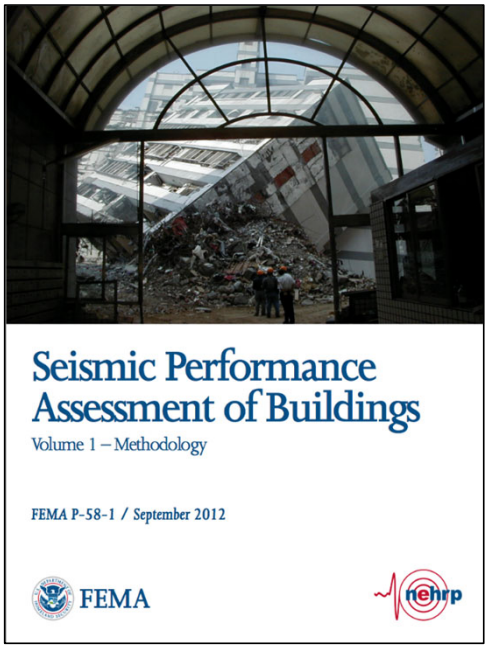
Moehle/PEER

$$v(DV) = \iiint G\langle DV \mid DM \rangle \mid dG\langle DM \mid EDP \rangle \mid dG\langle EDP \mid IM \rangle \mid d\lambda(IM)$$

Impact | **Performance (Loss) Models and Simulation** | **Hazard**

Performance-Based Framework

FEMA P-58 (2012) Performance Assessment of Buildings



Provides a methodology, basic building information, response quantities, fragilities and consequence data to evaluate the seismic performance of buildings

Procedures are probabilistic

Performance metrics:

- ***life safety risks***
- ***direct economic losses***
- ***downtime and indirect losses***

Recommended Use –

- ✓ Evaluate performance of new and existing buildings
- ✓ Provide the basis for performance-based design of new buildings and retrofit of existing buildings

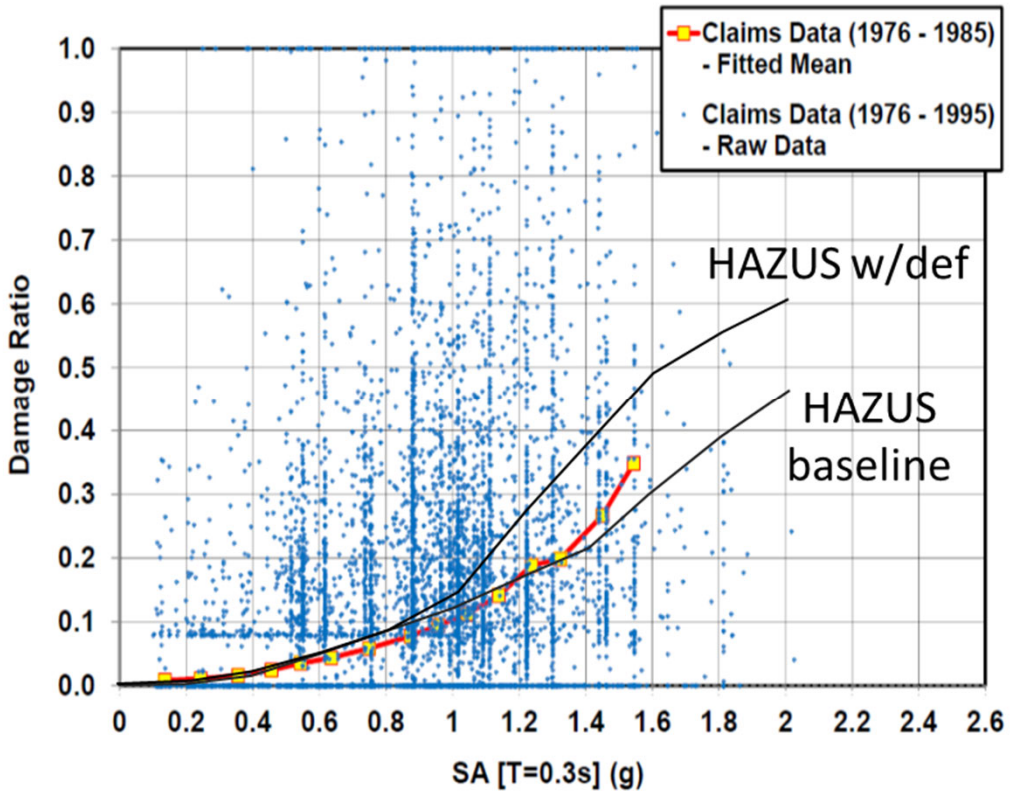
Illustrative Application

Wood-Frame House Risk Mitigation

Economic Benefits/Incentives of Foundation Wall Retrofit

PEER CEA CALIFORNIA EARTHQUAKE AUTHORITY™

Wood-Frame House Risk Mitigation



HAZUS vulnerability (loss) functions are empirically determined using post-earthquake damage and insurance claims information

Limitations to “The Law of Averages”

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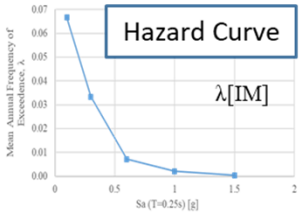
Wood-Frame House Risk Mitigation

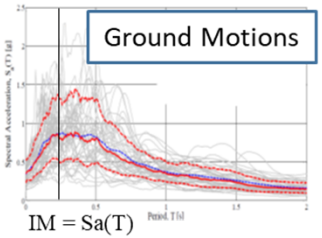
Building Variants

Existing Retrofit

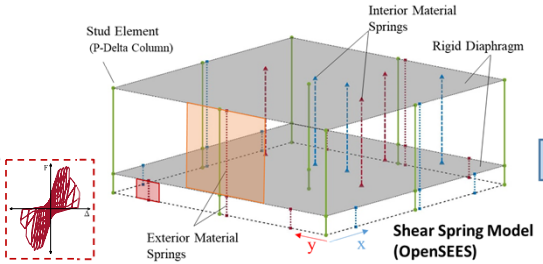
Hazard Curve



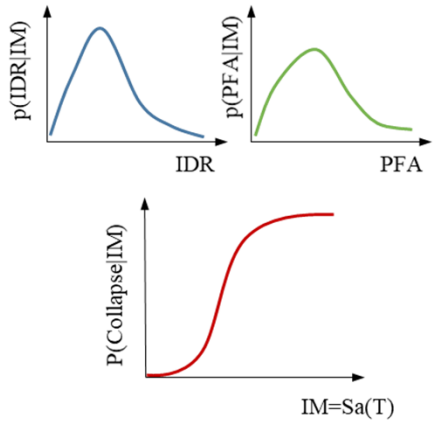
Ground Motions



IM = Sa(T)



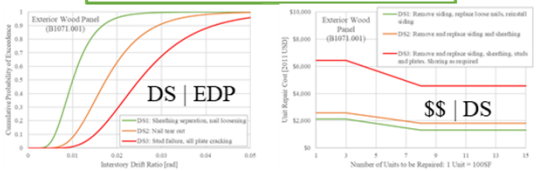
EDP Response and Collapse Fragility



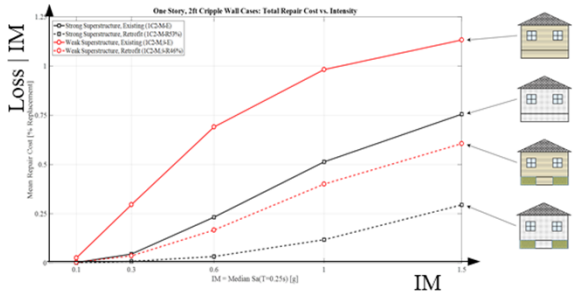
Define Damageable Inventory

- Exterior wall material
- Interior wall material
- Number of interior walls

Assign Damage Fragilities and Consequence Functions



Estimate Seismic Performance



FEMA P-58 Loss Assessment

Welch/Deierlein 2020

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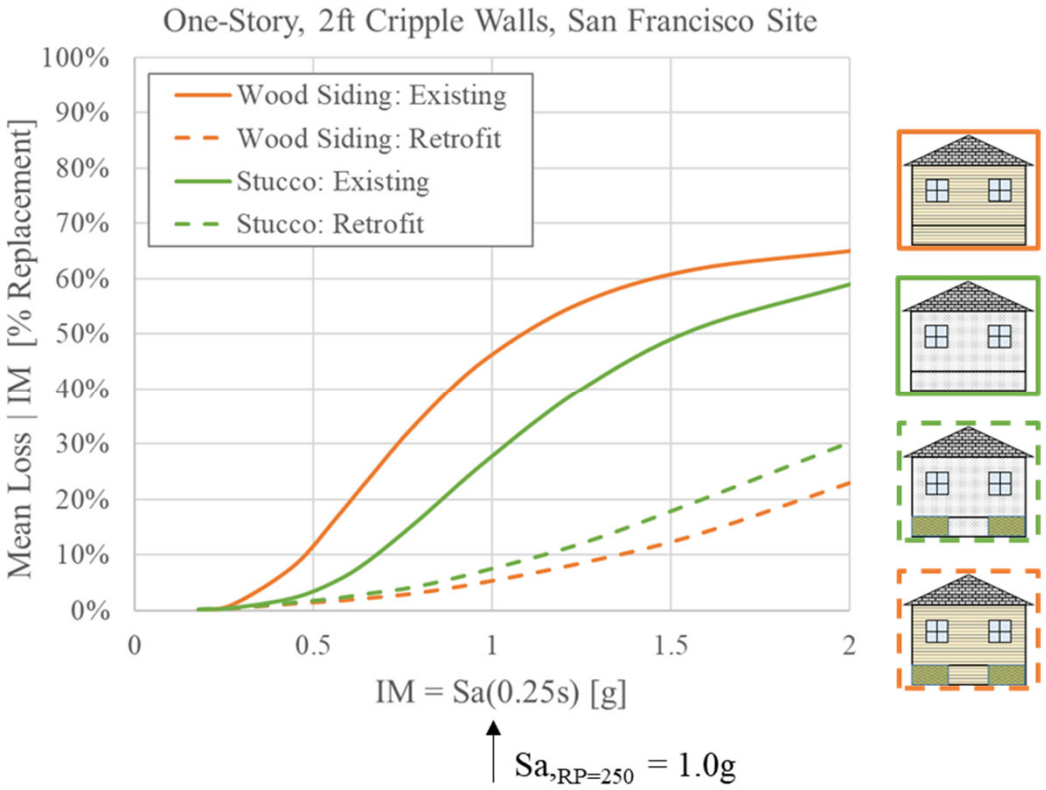
Wood-Frame House Risk Mitigation



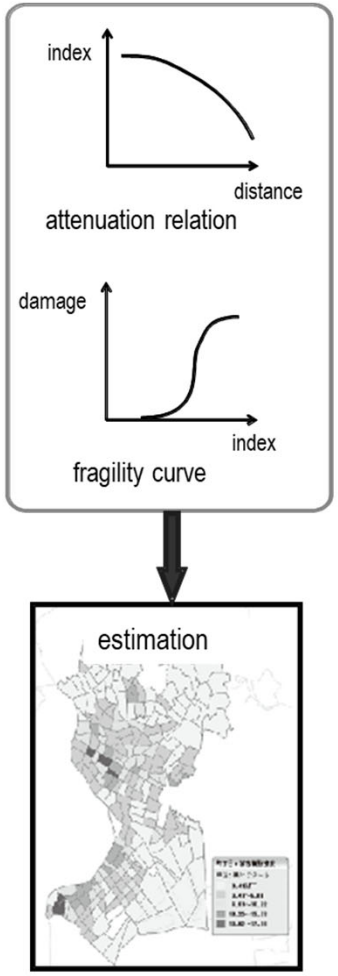
Loss versus Earthquake Intensity

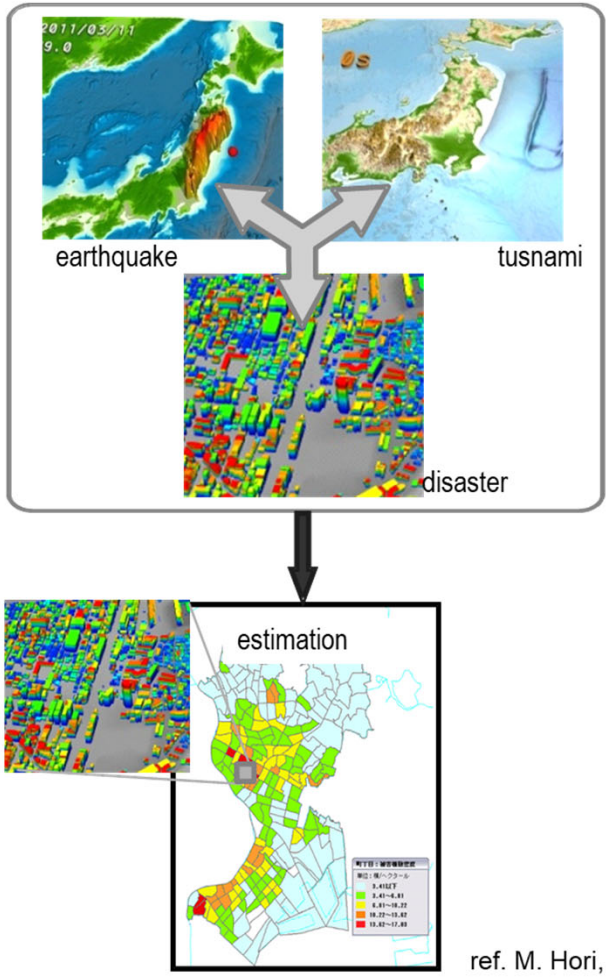
Loss at 20% in 50 year EQ Intensity

Welch/Deierlein 2020

Computational Workflow Components

CURRENT (e.g., HAZUS)
Empirical Models
Census Block Inventory

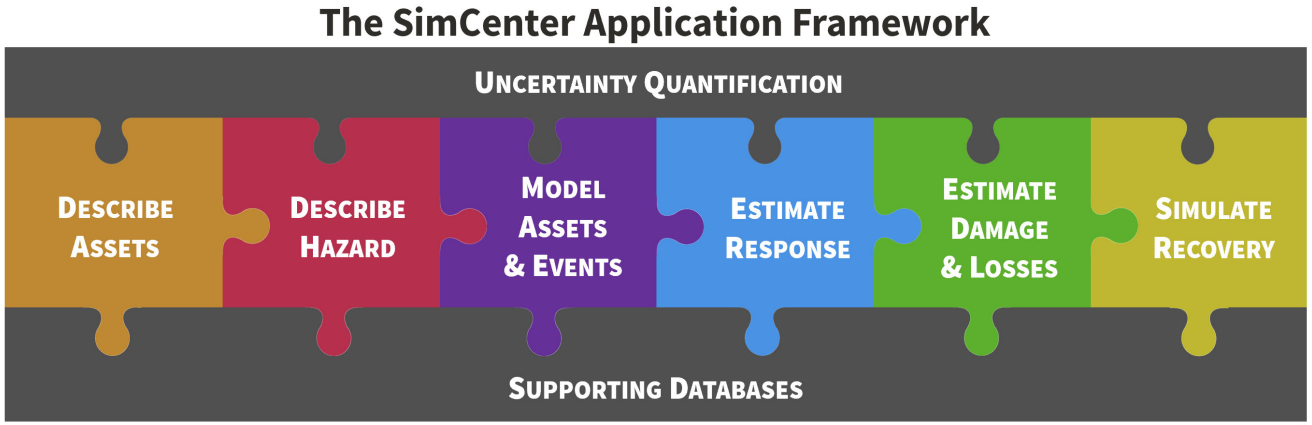


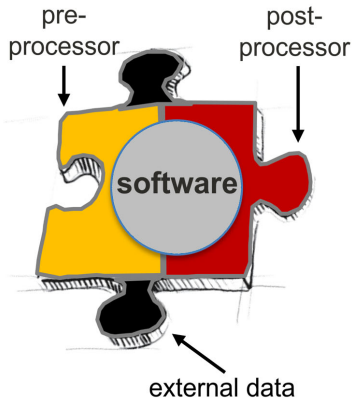


GOAL
Direct Simulation
Detailed Inventory
Multiple models

ref. M. Hori, Univ. of Tokyo

Computational Workflow Components





OpenSource :: Multi-Fidelity :: Multi-Hazard

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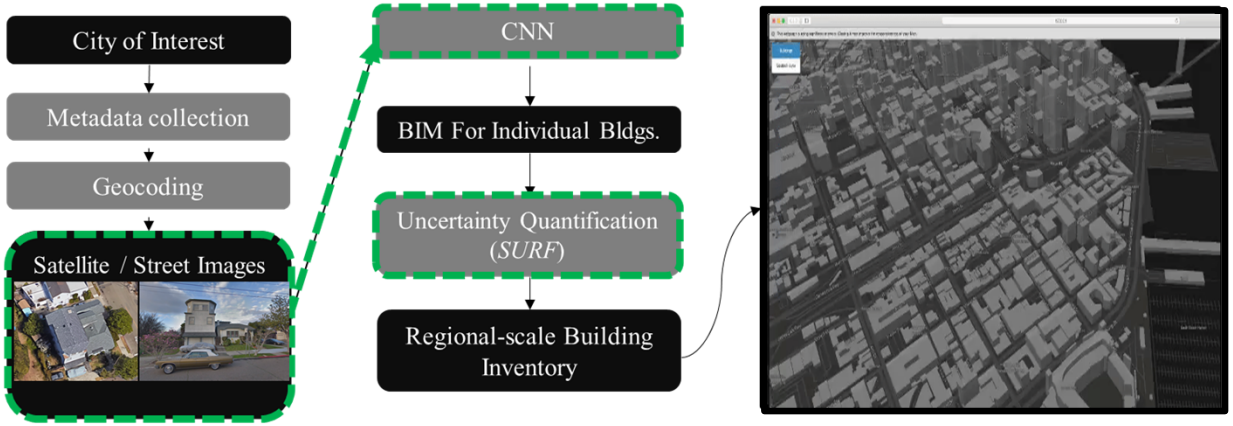
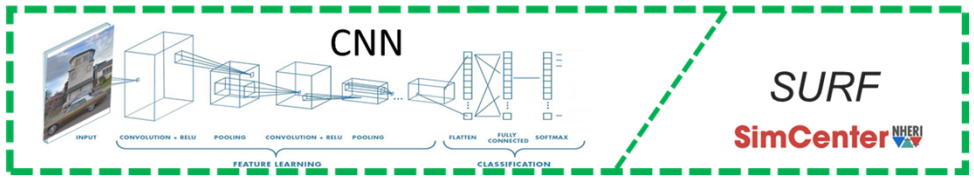
Center for Computational Modeling and Simulation

Workflow Component: Inventory Development

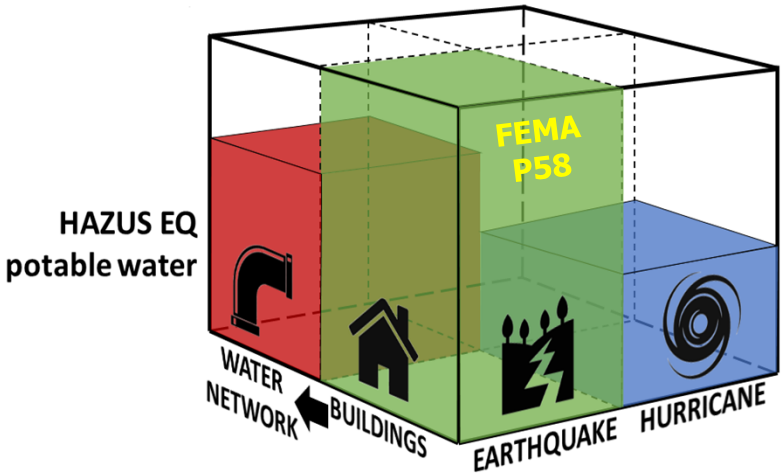
Building Feature Identification using AI-enabled Evaluation of Images



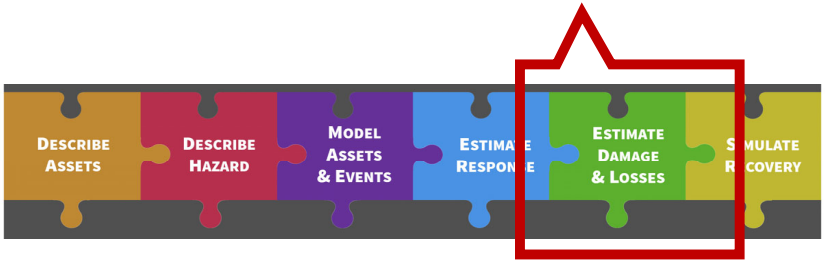


Wang

Workflow Component: Damage & Consequences



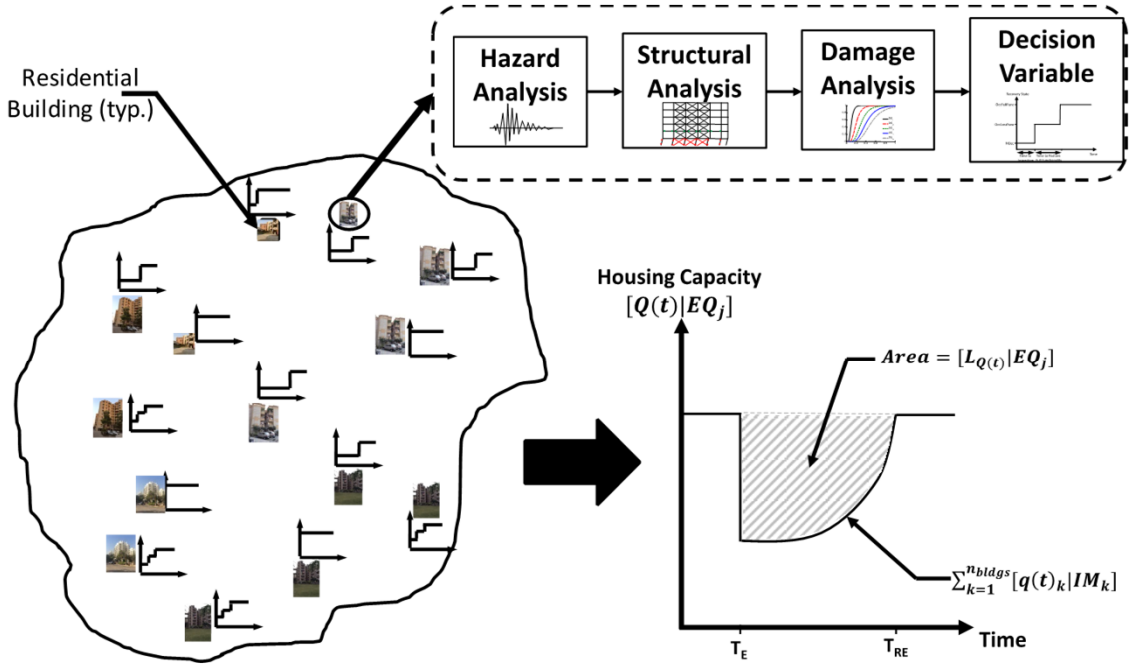
- **Multi-Hazard**
- **Multi-Fidelity**
- **Multi-System**



PELICUN Library

(PROBABILISTIC ESTIMATION OF LOSSES, INJURIES, & COMMUNITY RESILIENCE UNDER NATURAL DISASTERS)

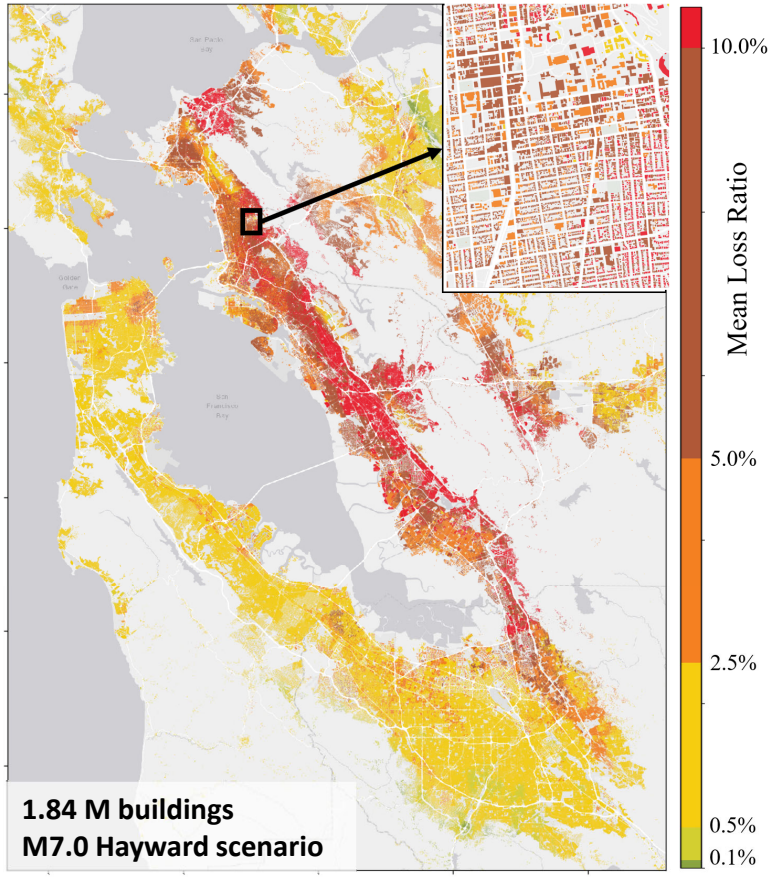
Workflow Component: Recovery and Resilience



Regional Resilience Determination Tool

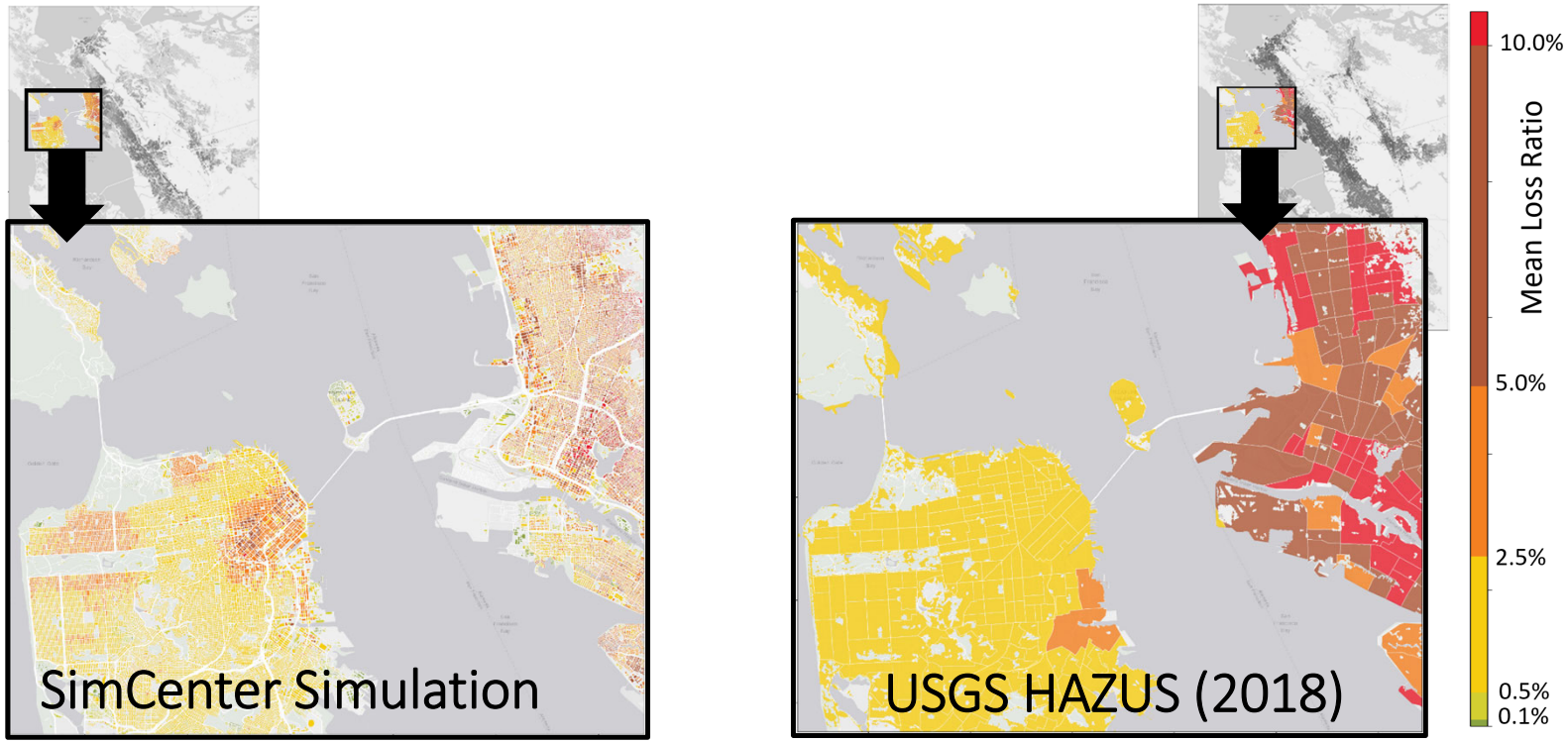
San Francisco Bay Area M7.0 Earthquake Testbed

- **M7.0 Hayward simulation (LLNL-SW4)**
- **1.84 M individual buildings**
- **Parcel-level inventory enhanced by AI tools**
- **Building Evaluations**
  - *HAZUS building configurations*
  - *OpenSees MDOF (story shear) models*
  - *25 pairs of ground motions*
  - *HAZUS story-level damage functions*
  - *modeling uncertainty*
- **DesignSafe HPC (Stampede2)**
  - *16 hr runtime on 12,800 cores*



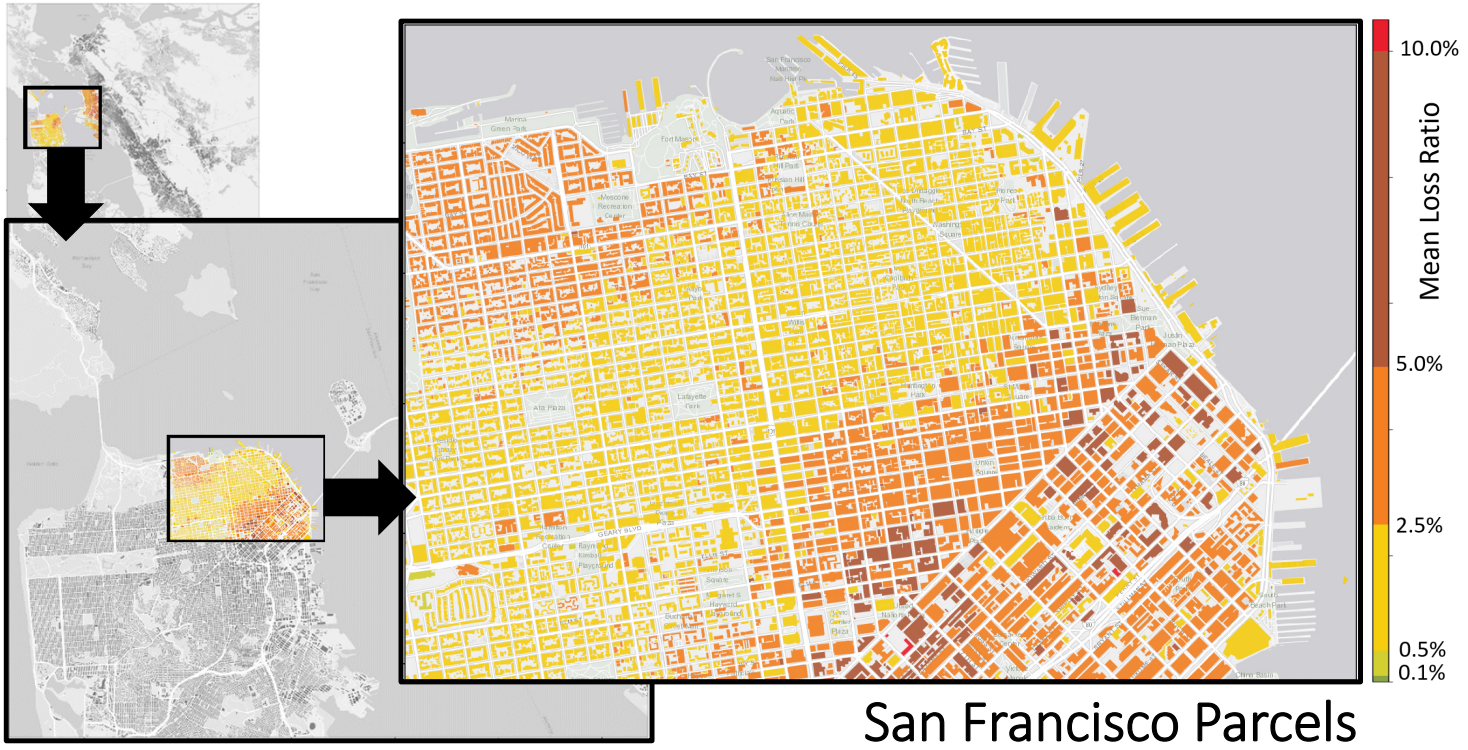
San Francisco Bay Area M7.0 Earthquake Testbed

High Resolution Modeling:
Building parcel versus census block resolution of losses

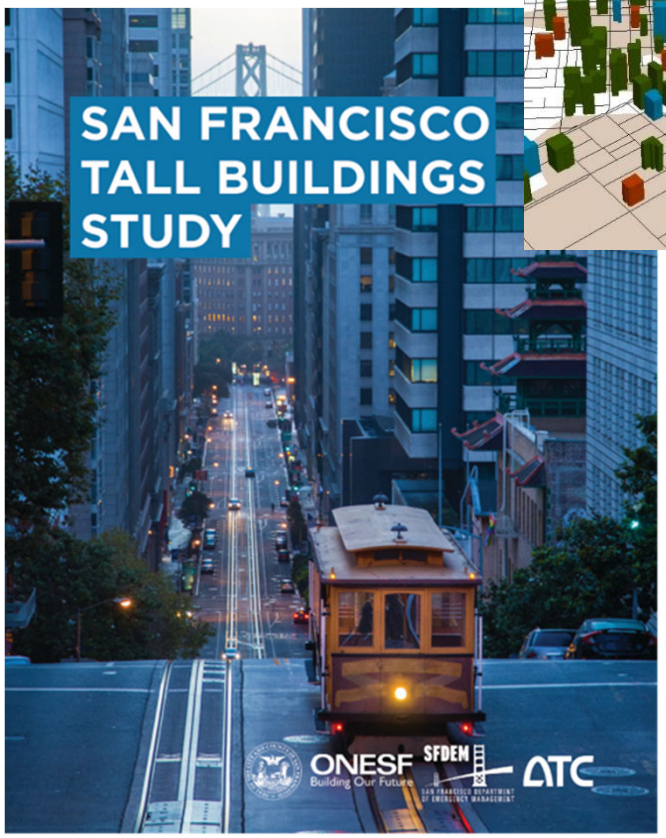


San Francisco Bay Area M7.0 Earthquake Testbed

High Resolution Modeling: Parcel-level resolution enables unprecedented quantification of *engineered interventions for policy level decisions*



SF Downtown Recovery



Structural System

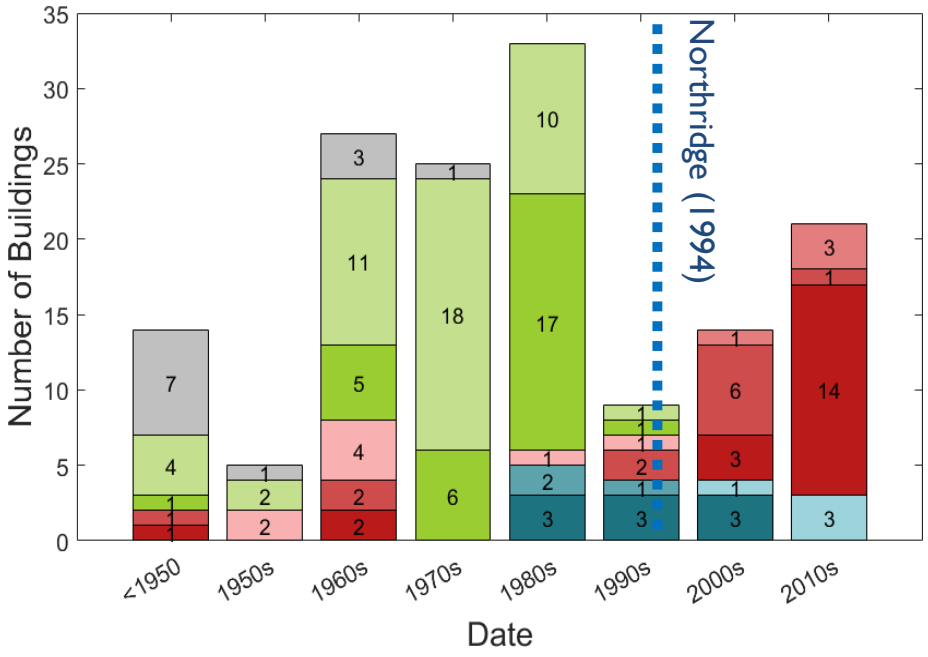
- Steel Moment Frame
- RC Shear Wall (with or without dual system)
- Steel Braced Frame

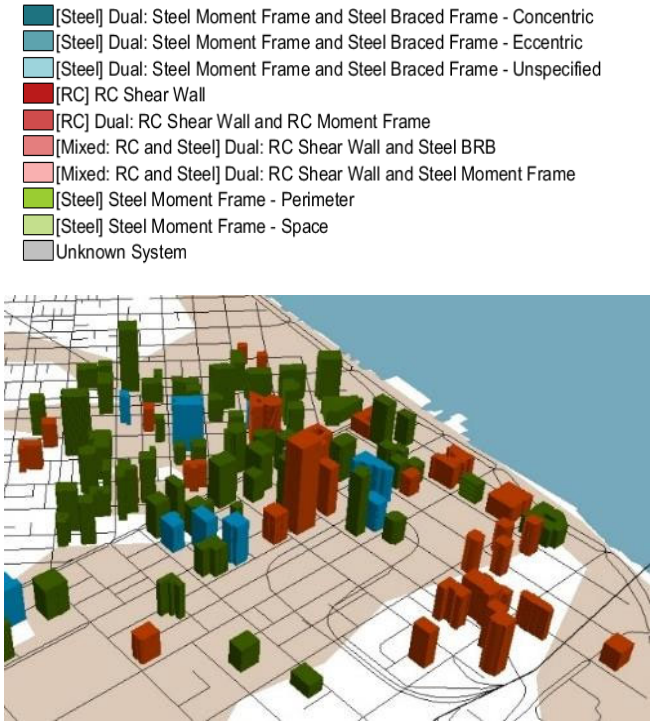
RECOVERY TARGETS FOR SAN FRANCISCO

	Months		
	4	36	36+
COMMUNITY FUNCTIONS			
All residences repaired, replaced or relocated	◆		X
95% neighborhood retail businesses open	◆	X	
50% offices and workspaces open	◆		X
Non-emergency city services		X	
All businesses open		◆	X

Adapted from *The Resilient City*, SPUR 2009

SF Downtown Recovery





Tall Building Inventory

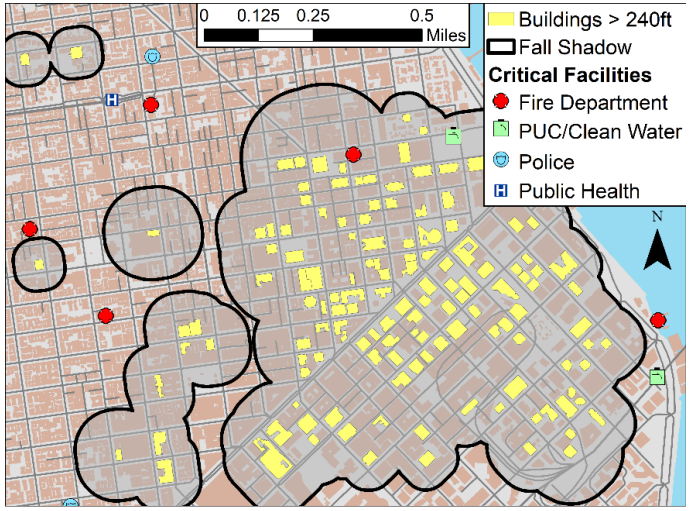
- 69 “Pre-Northridge” Steel Moment Frame Buildings (>75 m tall)
- Significant portion of SF’s downtown commercial office space

Hulsey/Yen/Deierlein 2018

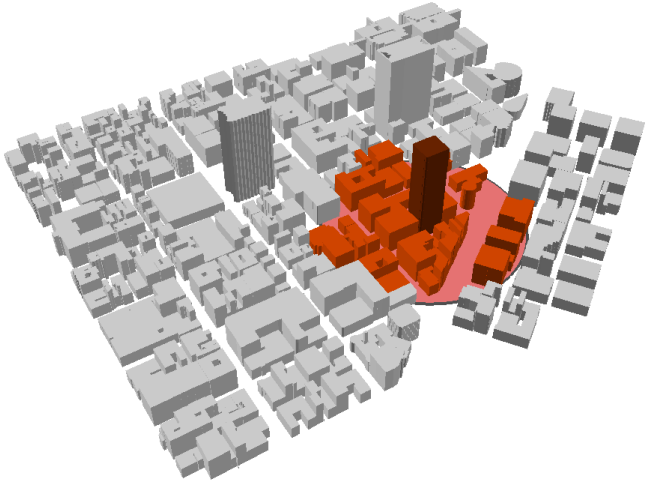
SF Downtown Recovery

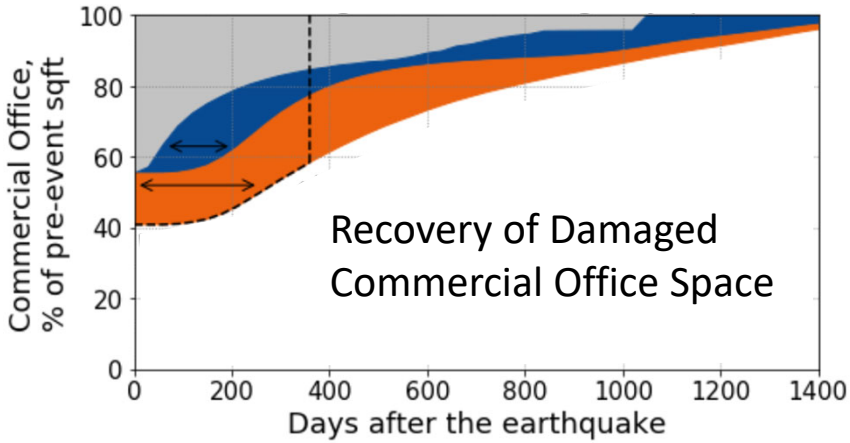
Impact of Tall Building Cordons:

- Emergency Response
- Neighboring Buildings
- Recovery/Reconstruction
- Downtown Economy



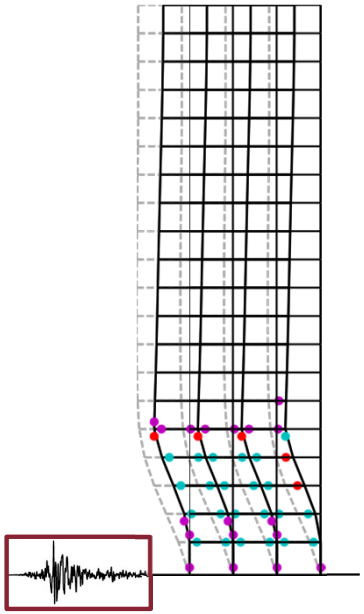
Data Sources: Critical Facilities, Building Footprints, and Streets from DataSF.org





Hulsey/Yen/Deierlein 2018

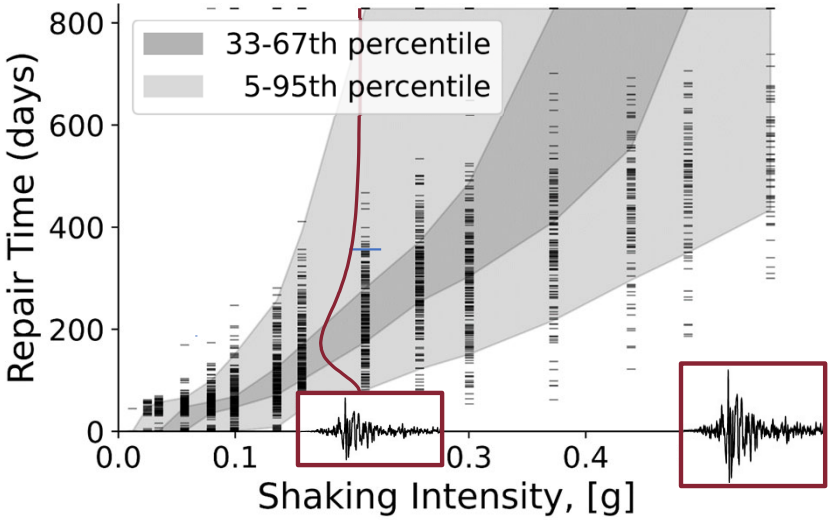
SF Downtown Recovery



Decision Variables:

- repair time until functional
- cordon triggered (Y/N)
- repair time until stable

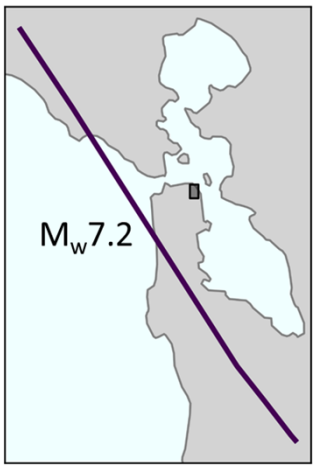
$$dv_i = \begin{cases} t_{functional} \\ Tr_{cordon} \\ t_{stable} \end{cases}$$

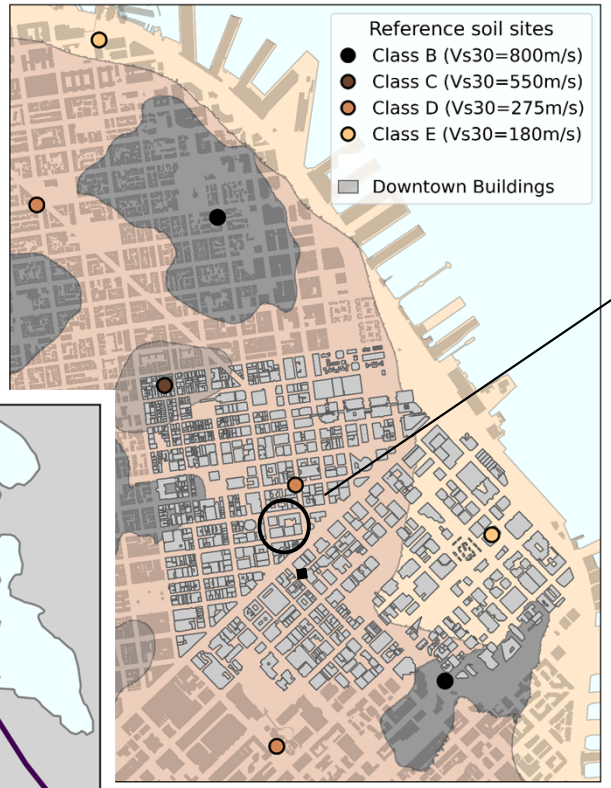


$$v(DV) = \iiint G\langle DV|DM\rangle|\, dG\langle DM|EDP\rangle|dG\langle EDP|IM\rangle d\lambda(IM)$$

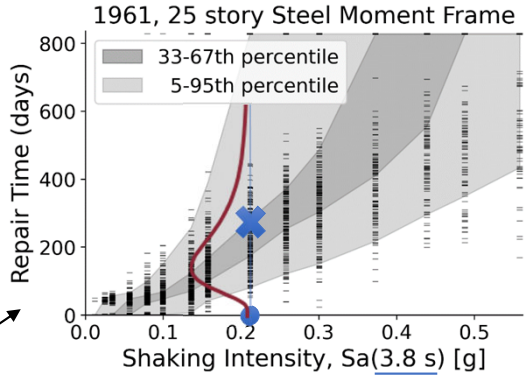
Hulsey/Galvis/Baker/Deierlein 2020

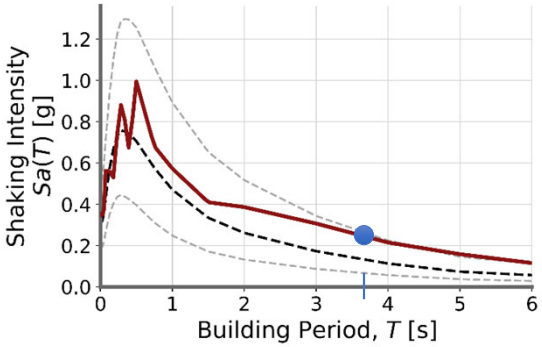
SF Downtown Recovery



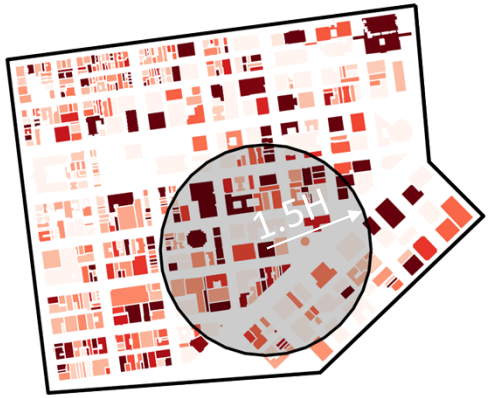


San Andreas M7.2 Scenario





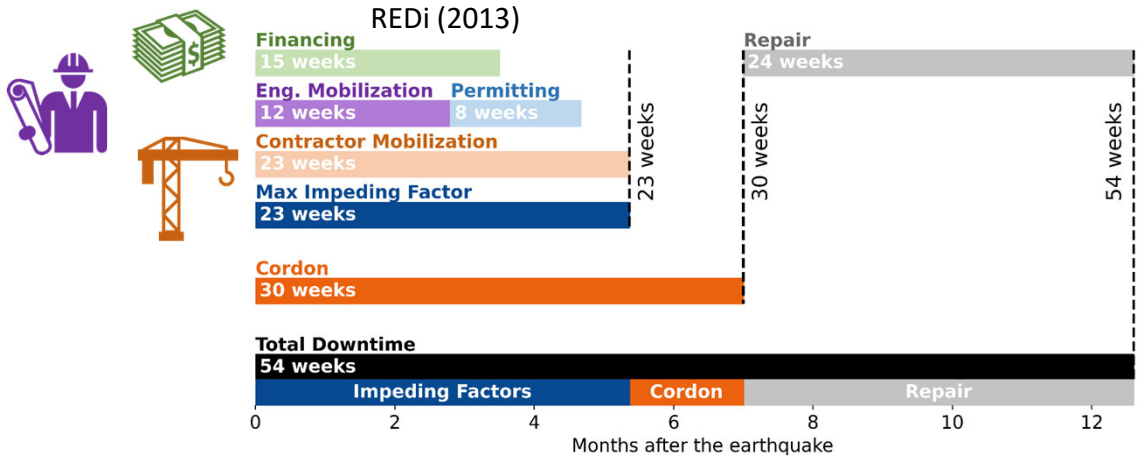
$$dv_i = \begin{cases} t_{functional} \\ Tr_{cordon} \\ t_{stable} \end{cases}$$

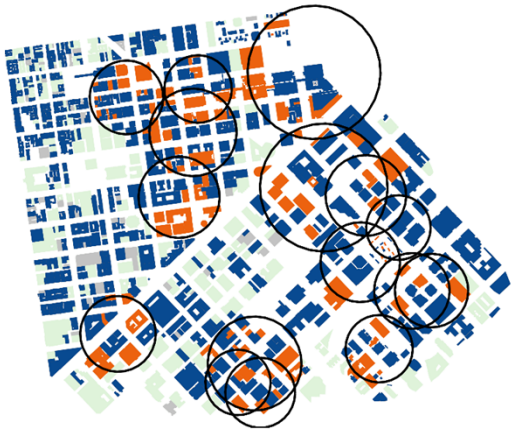


Assumed Safety Cordon of 1.5 x Building Height

Hulsey/Galvis/Baker/Deierlein 2020

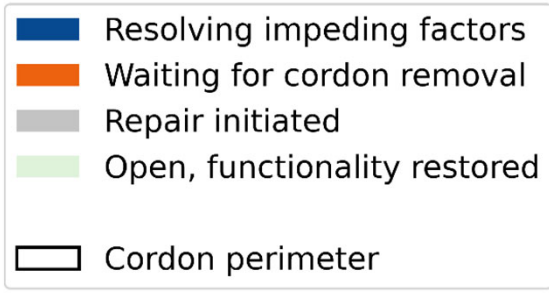
SF Downtown Recovery





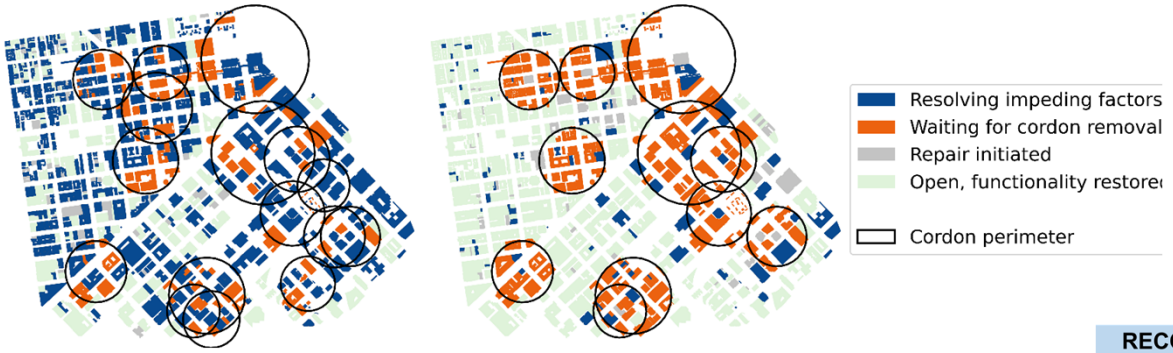
4 months

12 months



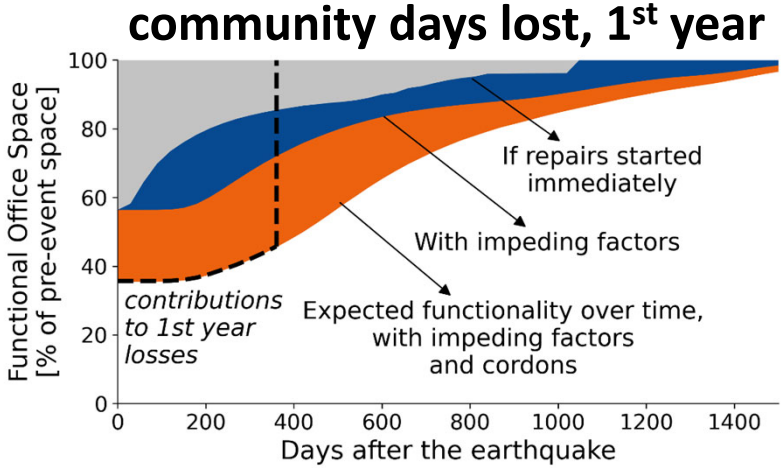
Hulsey/Galvis/Baker/Deierlein 2020

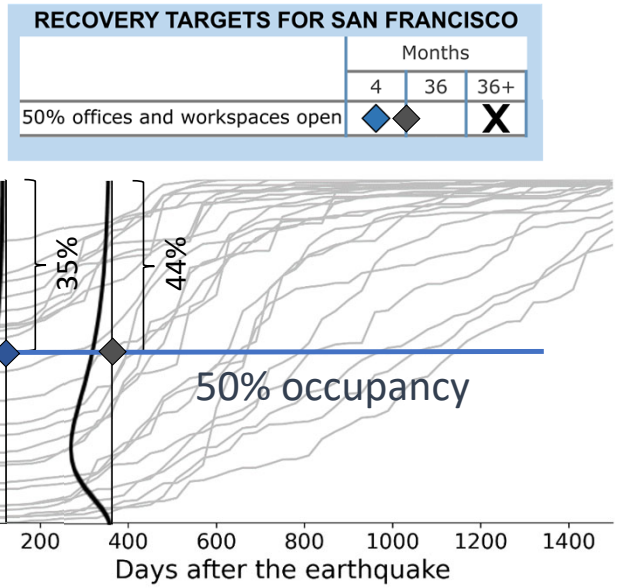
SF Downtown Recovery



4 months

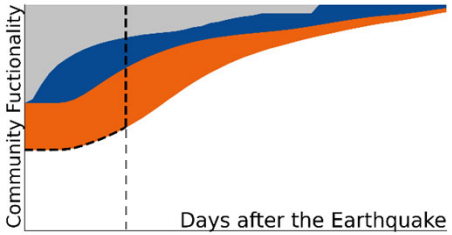
12 months

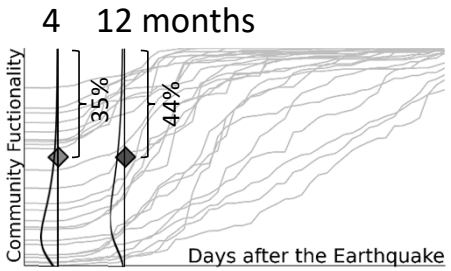


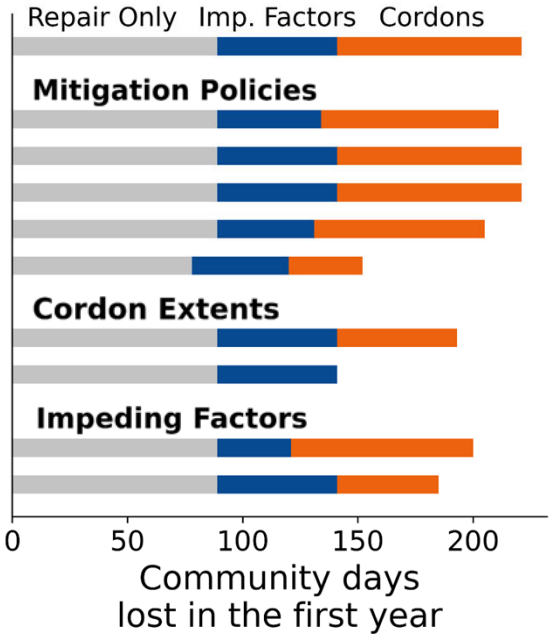


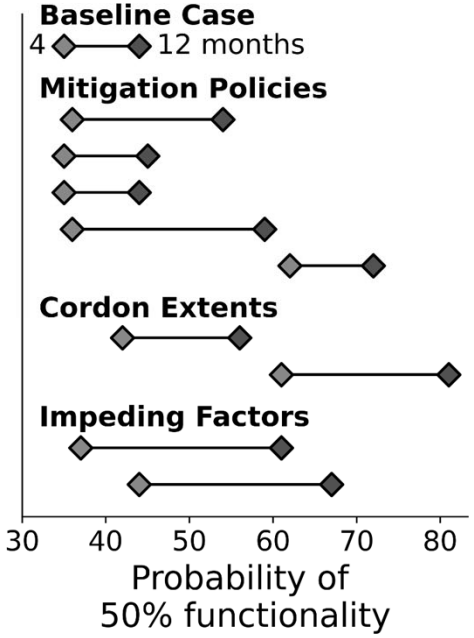
Hulsey/Galvis/Baker/Deierlein 2020

SF Downtown Recovery









Baseline Case
Cordon Extent: 1.5H, REDi Impeding Factors

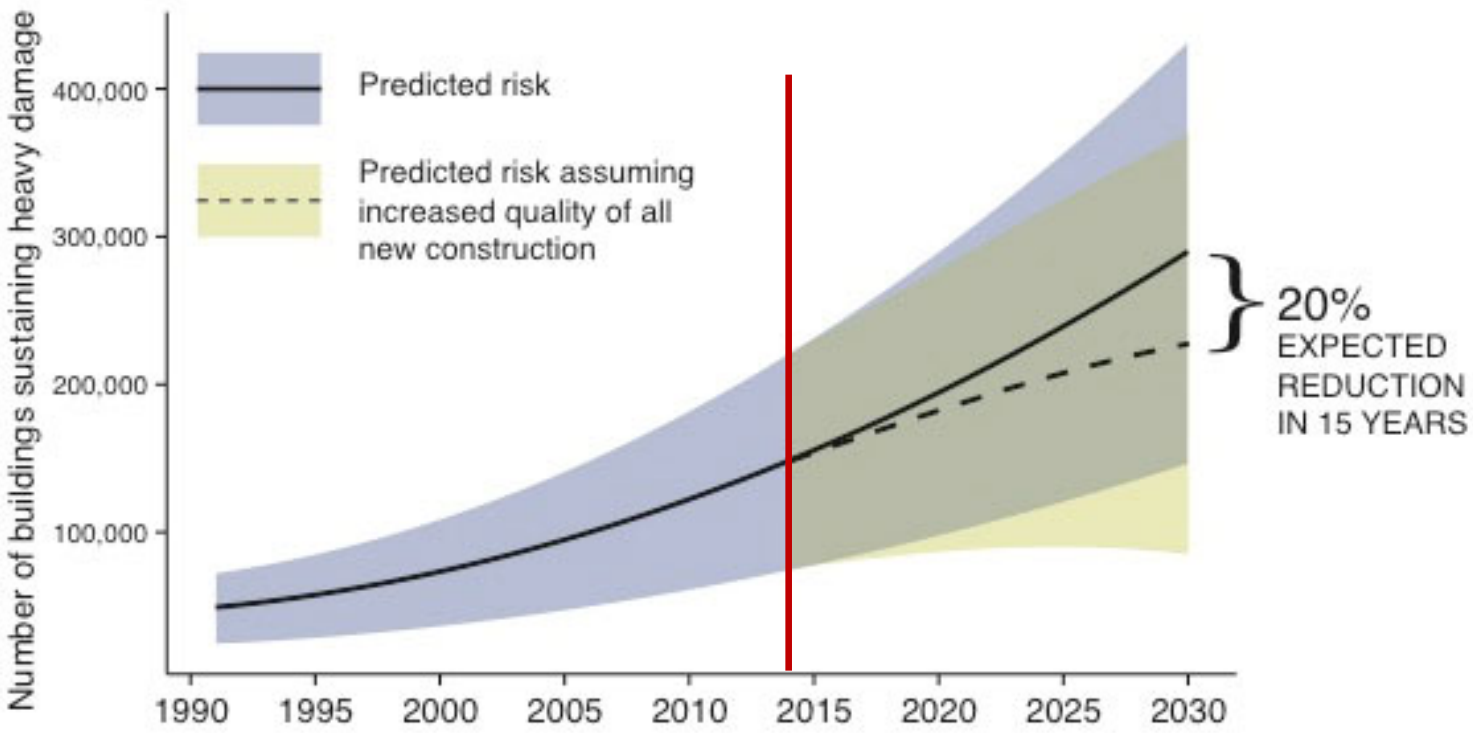
Mitigation Policies for Buildings ≥ 240ft
Contractors on contract
Engineers on contract
Buildings are insured
All contingency plans are in place
Retrofitted to modern code requirements

Sensitivity to the Cordon Extents
Radius reduced to 1.0H
No cordons (only impeding factors)

Sensitivity to Impeding Factors
Reduced by 50% for all buildings
None prior to building stabilization repairs

Hulsey/Galvis/Baker/Deierlein 2020

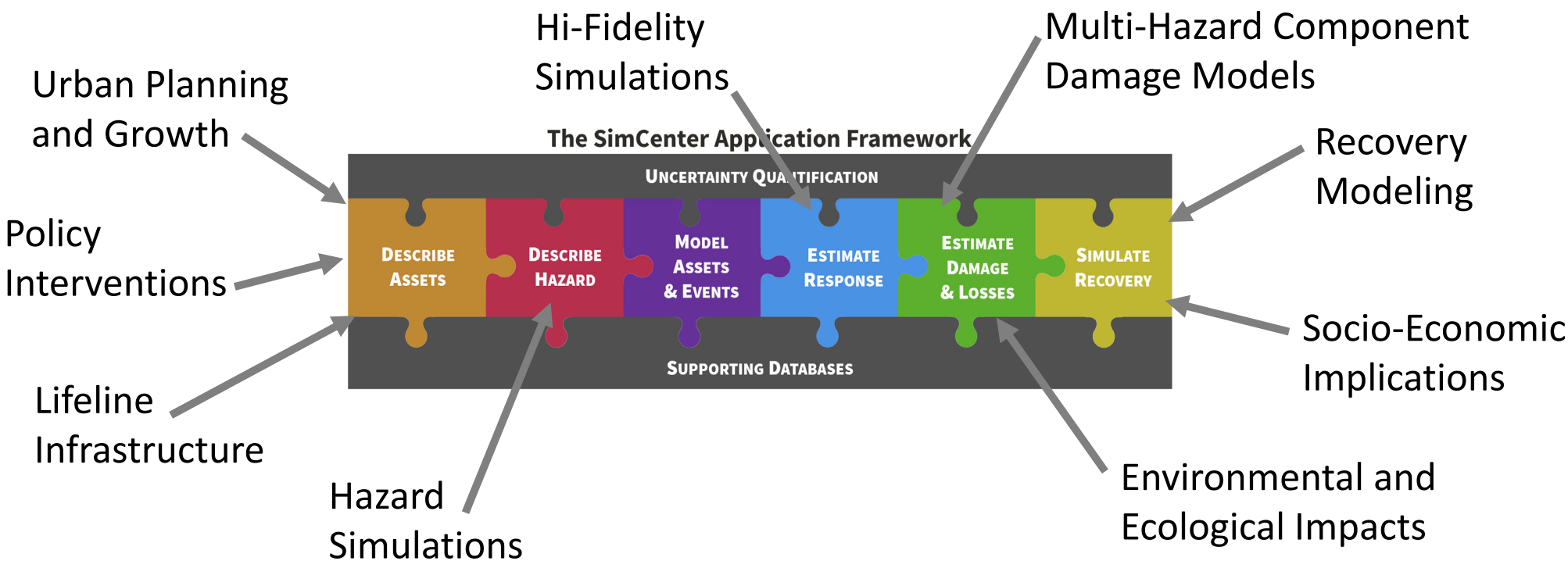
Technologies to Design for the Future



Urban Growth & Evolving Risk

Ref: D. Lallemant

Technologies to Design for the Future



Learn more at: https://simcenter.designsafe-ci.org/