Earthquake Response and Preparedness:
Modeling Human/Structure Interaction

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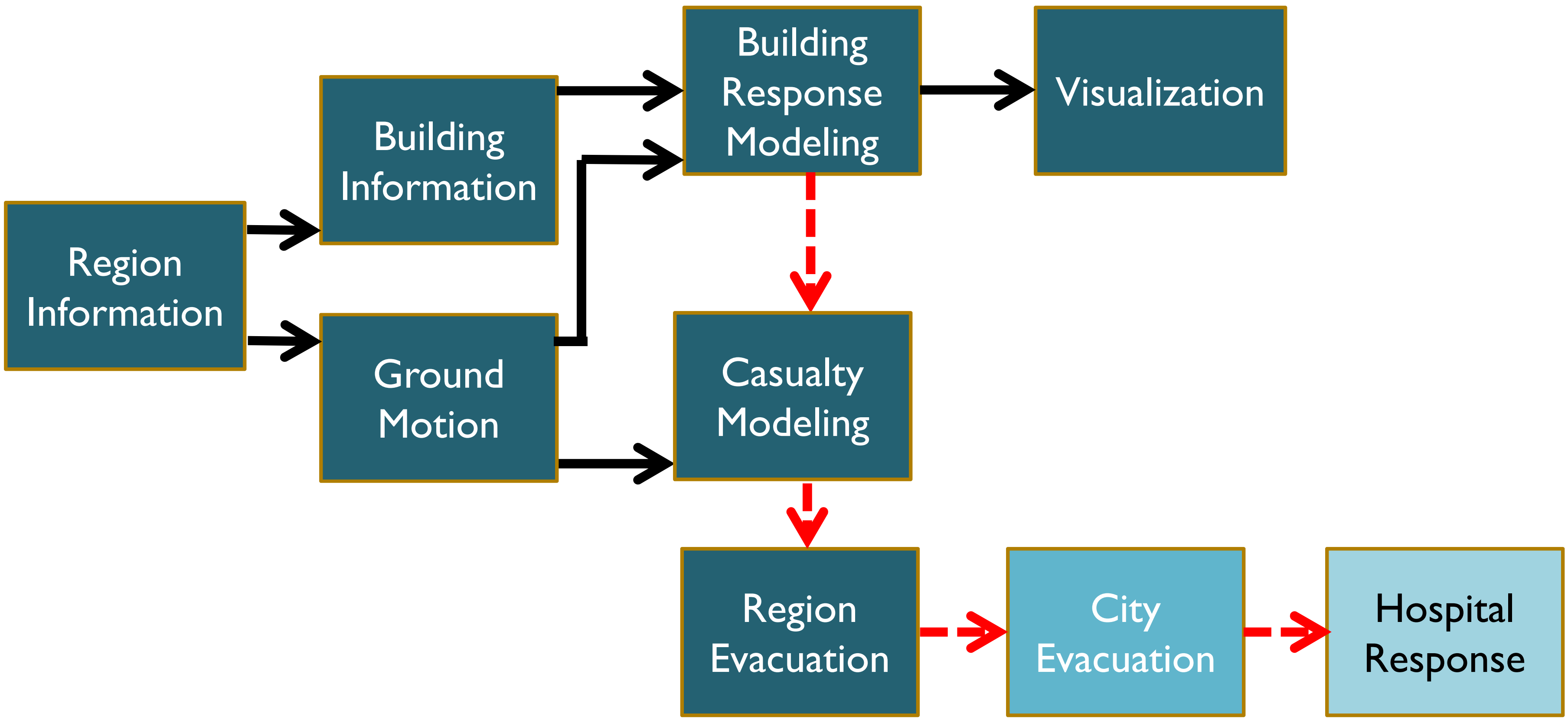
Introduction

- Earthquake response – humans/building interaction
- Assess the preparedness of Los Angeles to
  - Mass evacuation
  - Healthcare response
- Structural and non-structural building response
- Effect of damage and injury on evacuation
- Agent-based simulations of human activity and evacuation

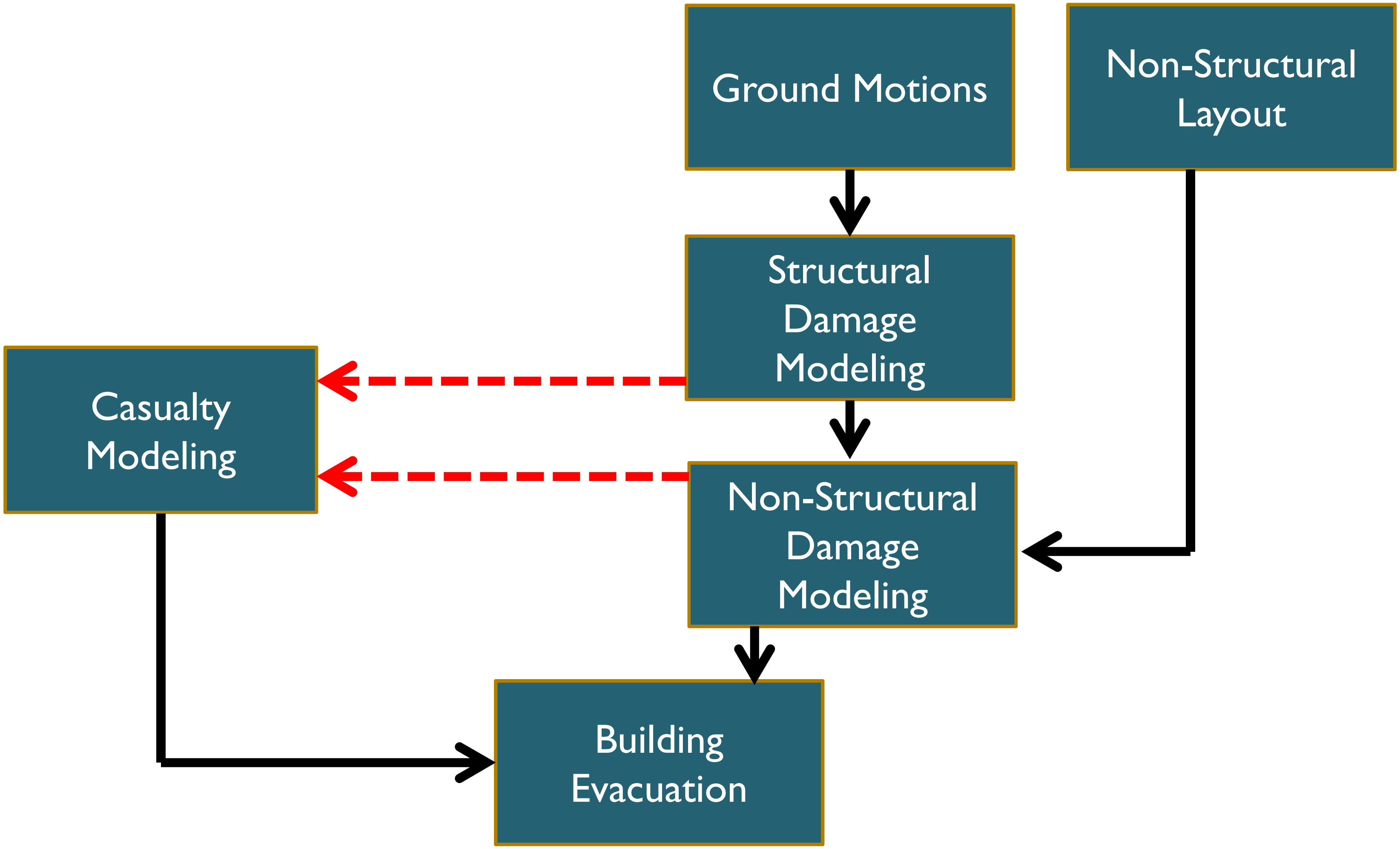
Outline

- Project Approach
- Site Information
- Ground Motion Input
- Structural Simulations
- Non-Structural Layout
- Non-Structural Damage Analysis
- Test Structure Evacuation Model
- Evacuation of City Block
- Casualty Modeling
- Regional Modeling and Animation
- Future Work

Approach - City

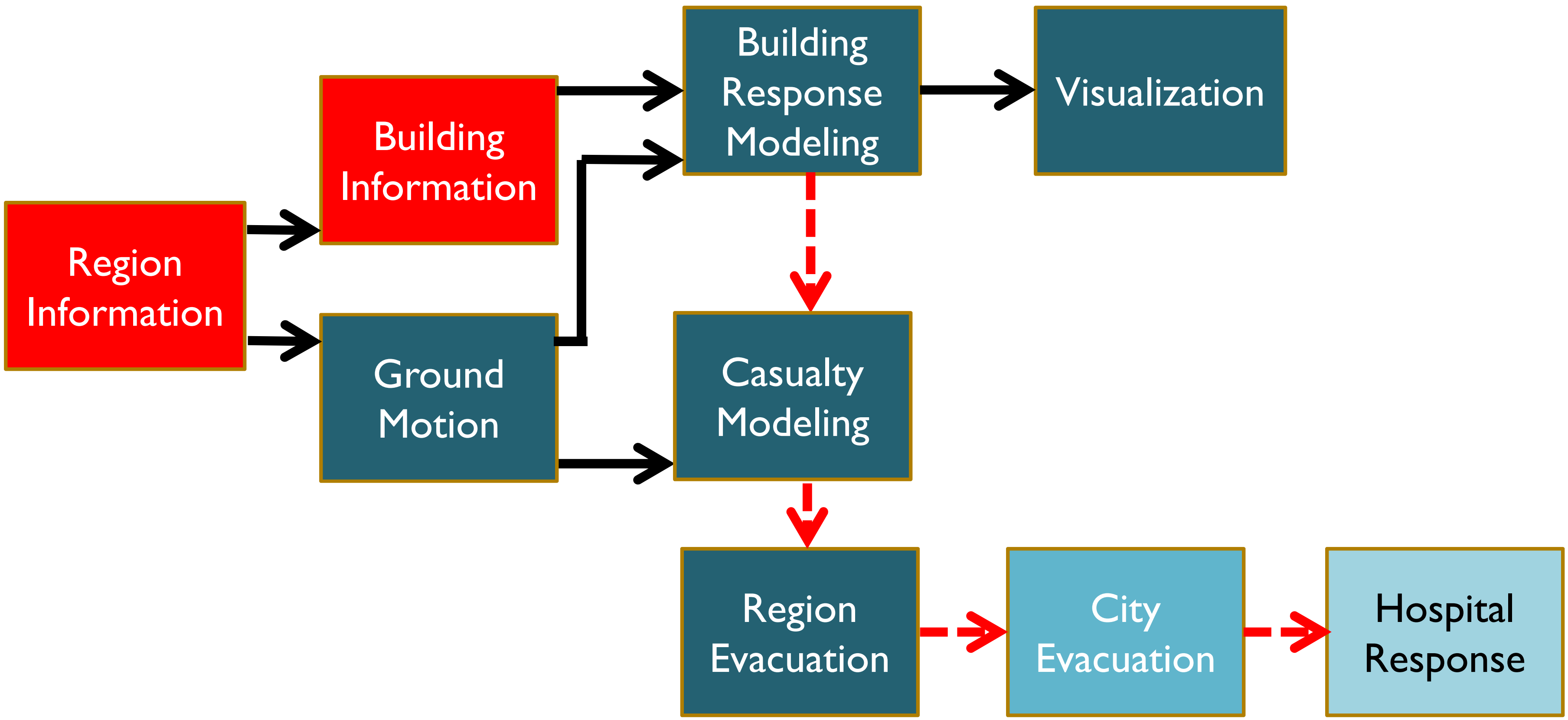


Approach – Test Structure

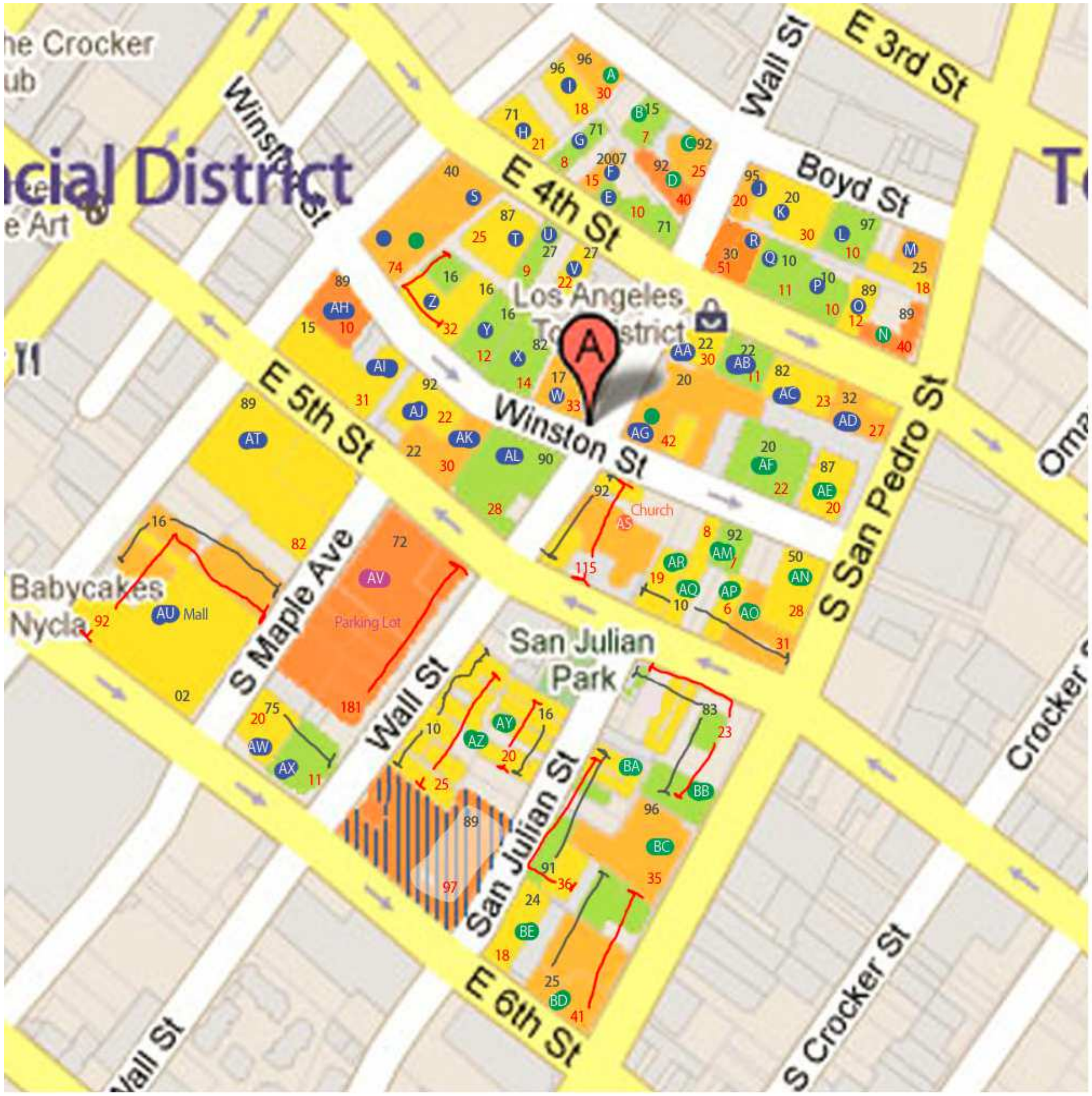


Site Information

Approach - City



Region



= 1 story

= 2 story

= 3 story

= 4 story

BA = Residential

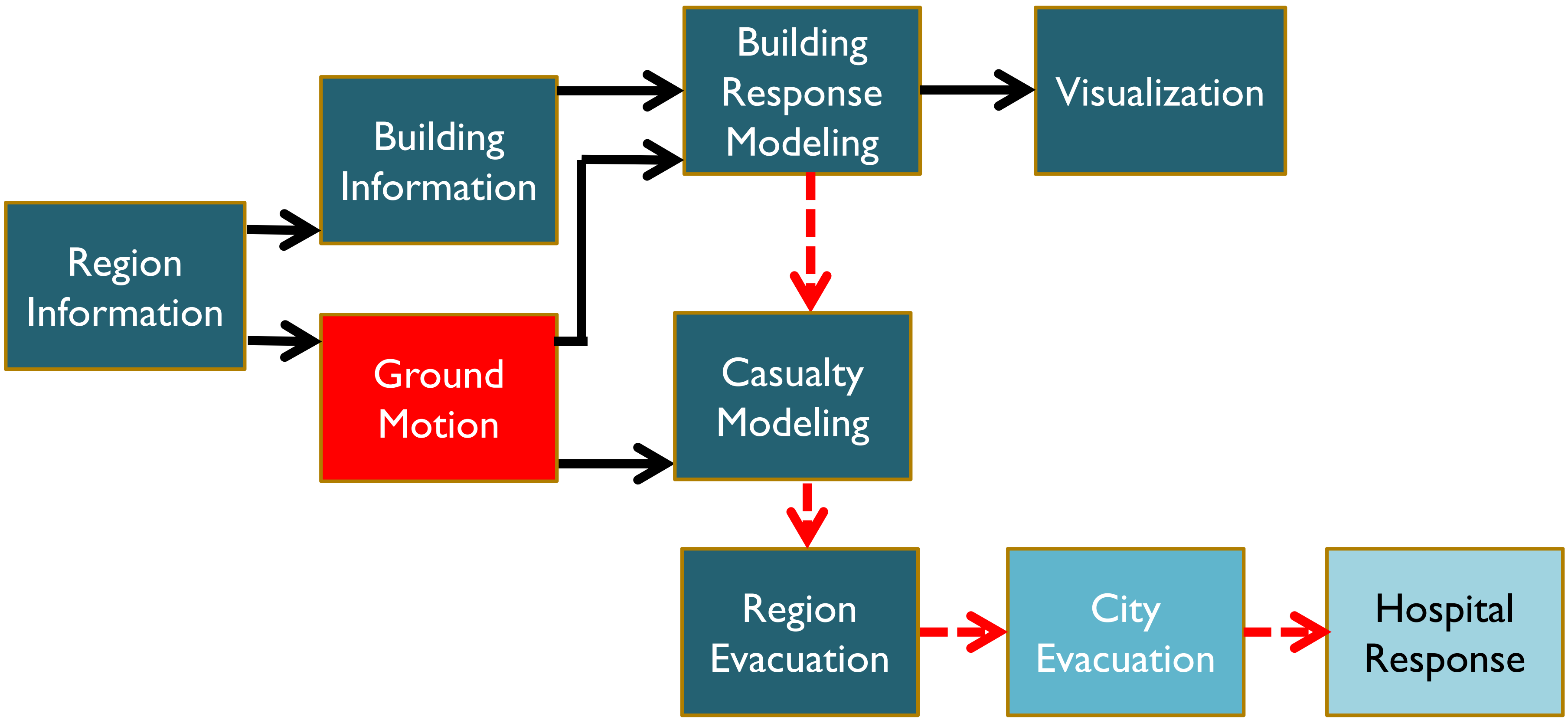
AX = Commercial

AV = Other

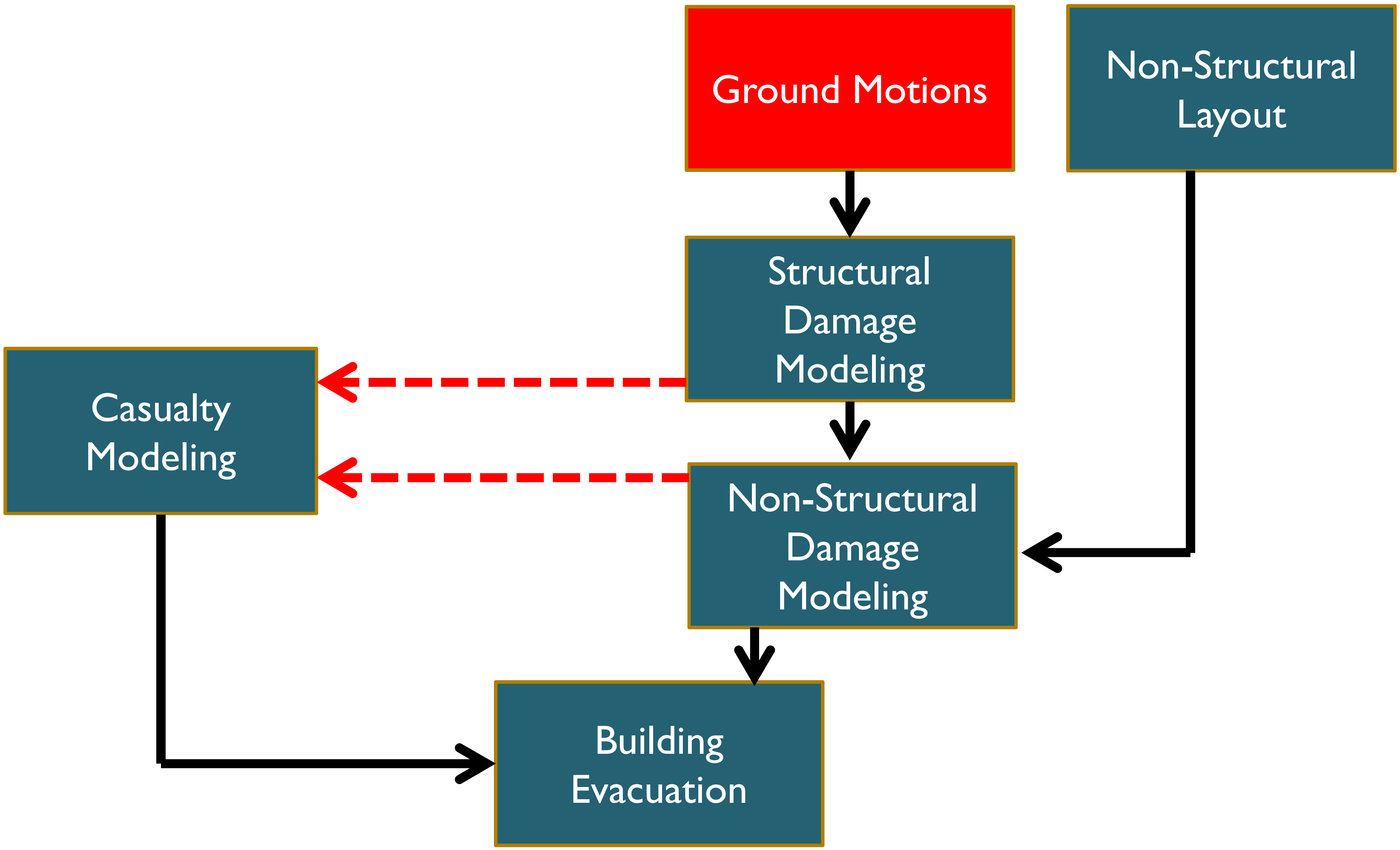
Red numbers are square footages.
Black are the year built (19--)

Ground Motion Input

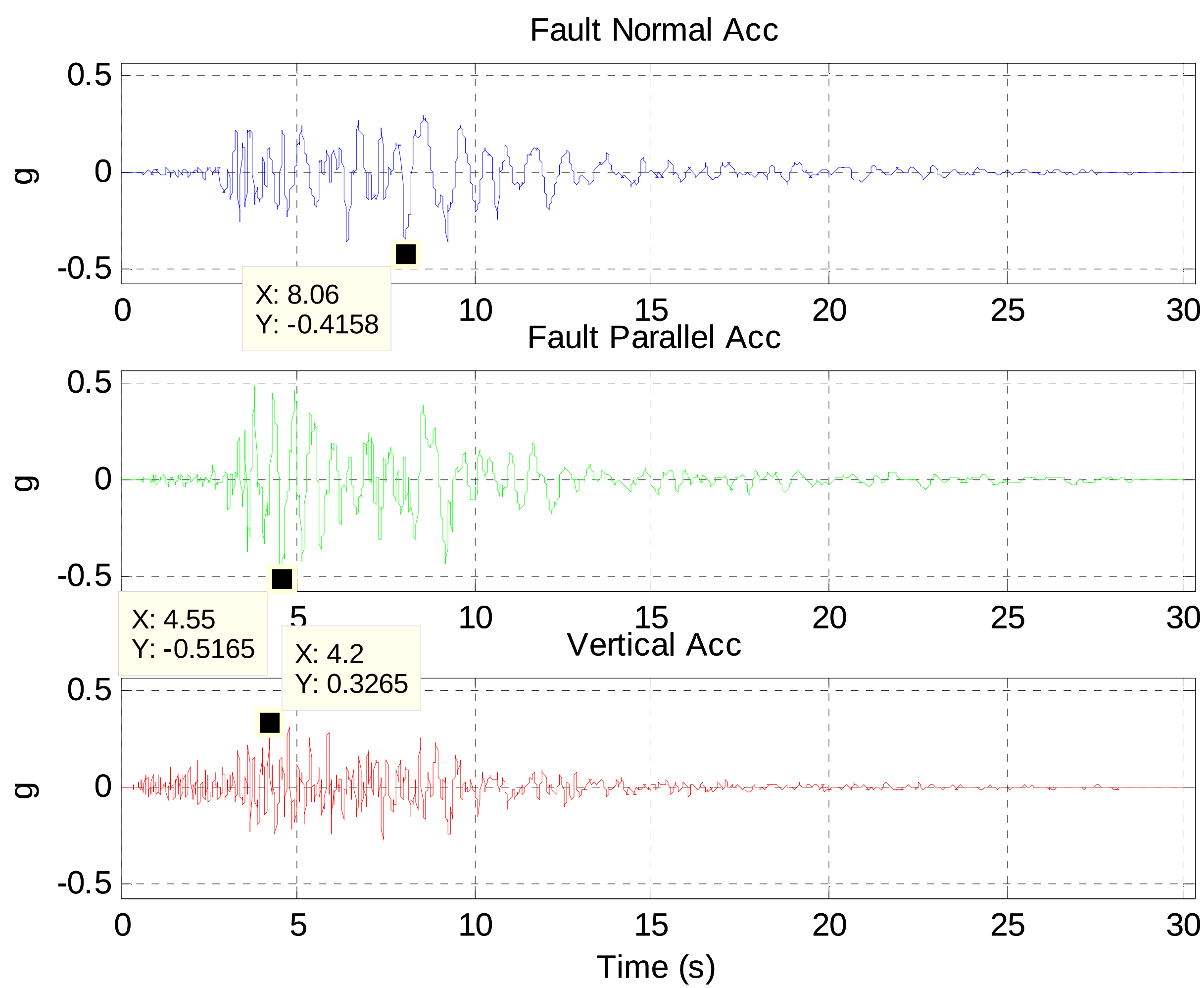
Approach - City



Approach – Test Structure



Ground Motion Input (Northridge earthquake 1994)

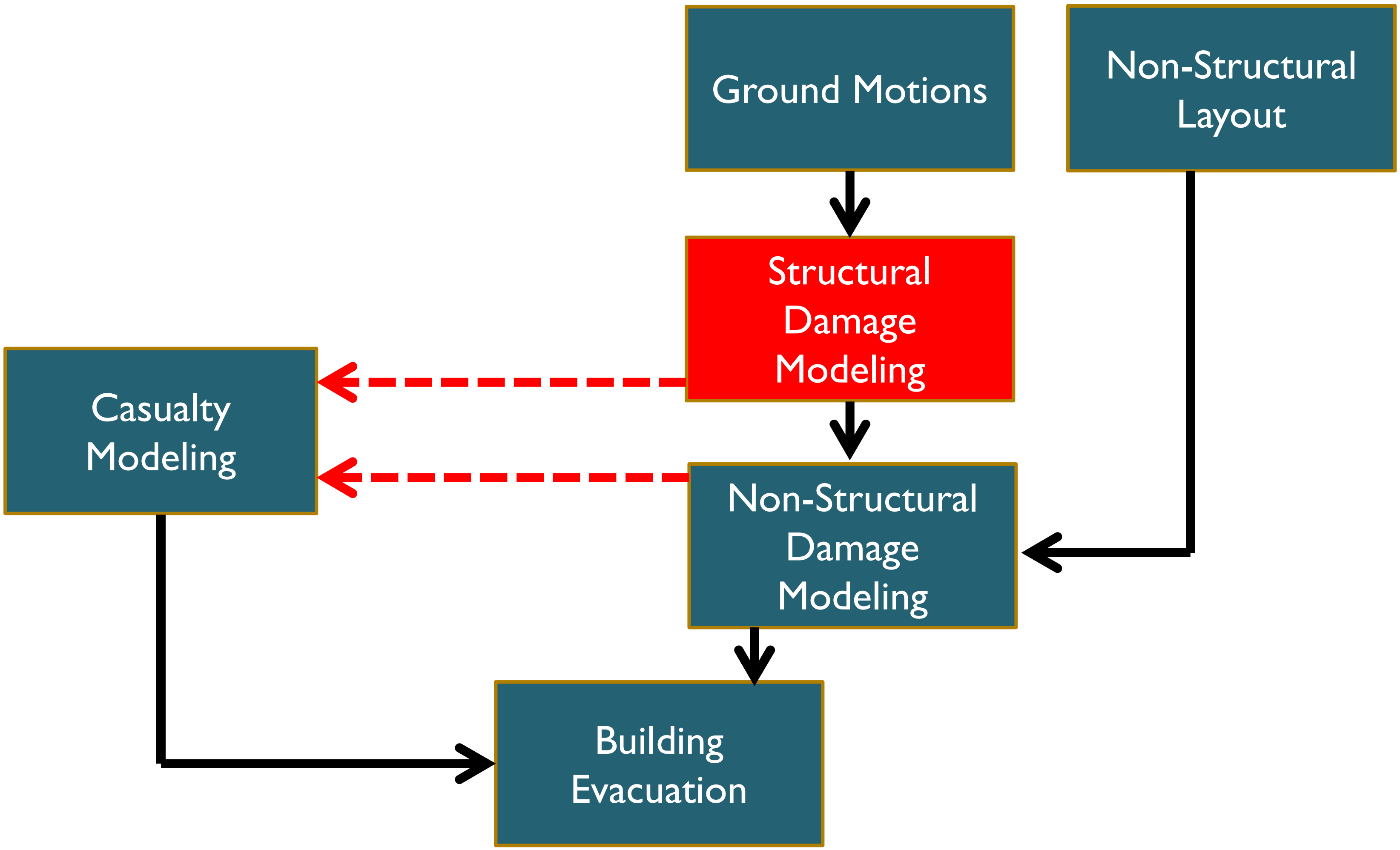


- Far field record
- PGA 0.52 g
- Vs30 355.8 m/s

Structural simulations

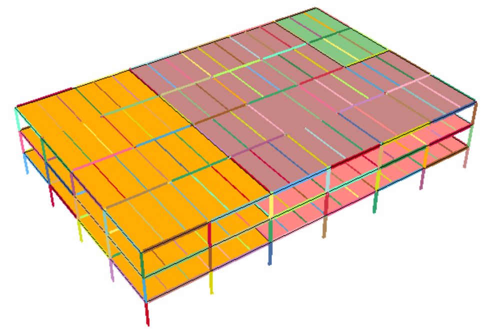
High resolution

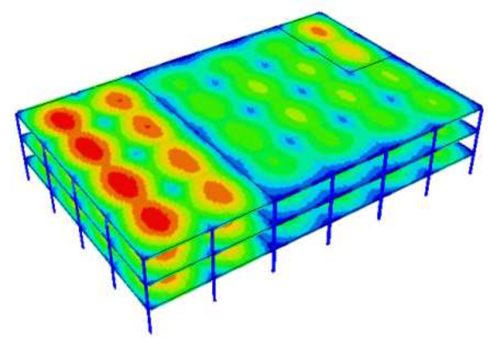
Approach – Test Structure



3 story archetypical building

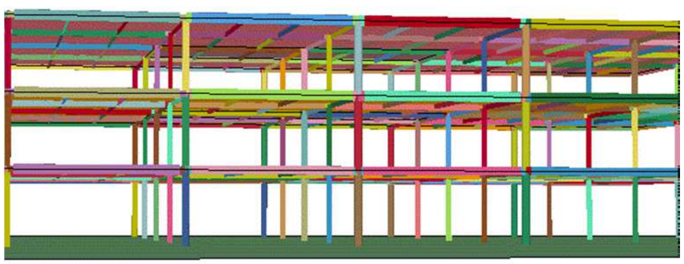
- Typical 3-story office-building
- Employed in seismic study by Gupta and Krawinkler
- Moment-resisting steel framed structure
- Light composite concrete decks
- Dead load, D = 4 [kPa]
  - Deck self-weight ≈ 3 [kPa]
  - Ceilings/fireproofing, etc. ≈ 1 [kPa]
- Office live load, L = 2.5 [kPa]

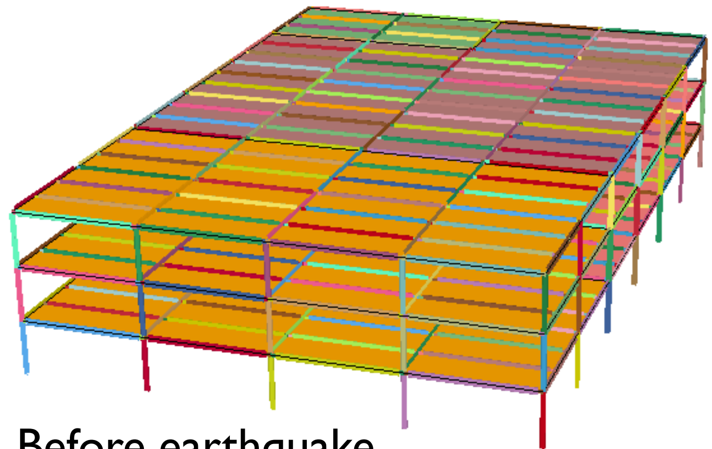




Physics based simulations

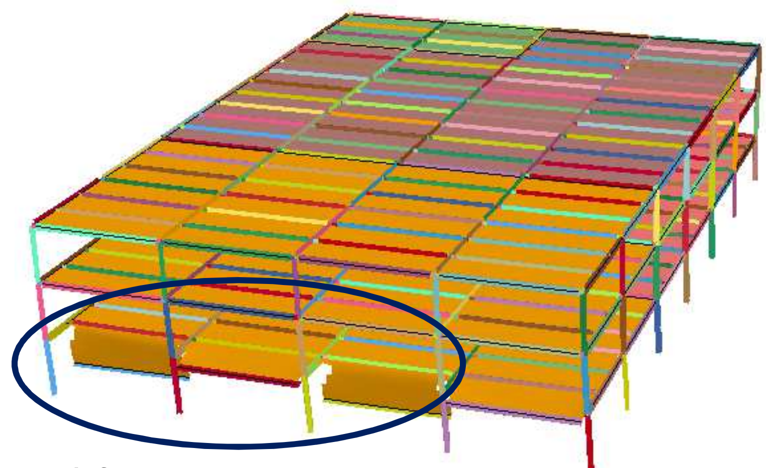
- Methodology from studies on progressive collapse





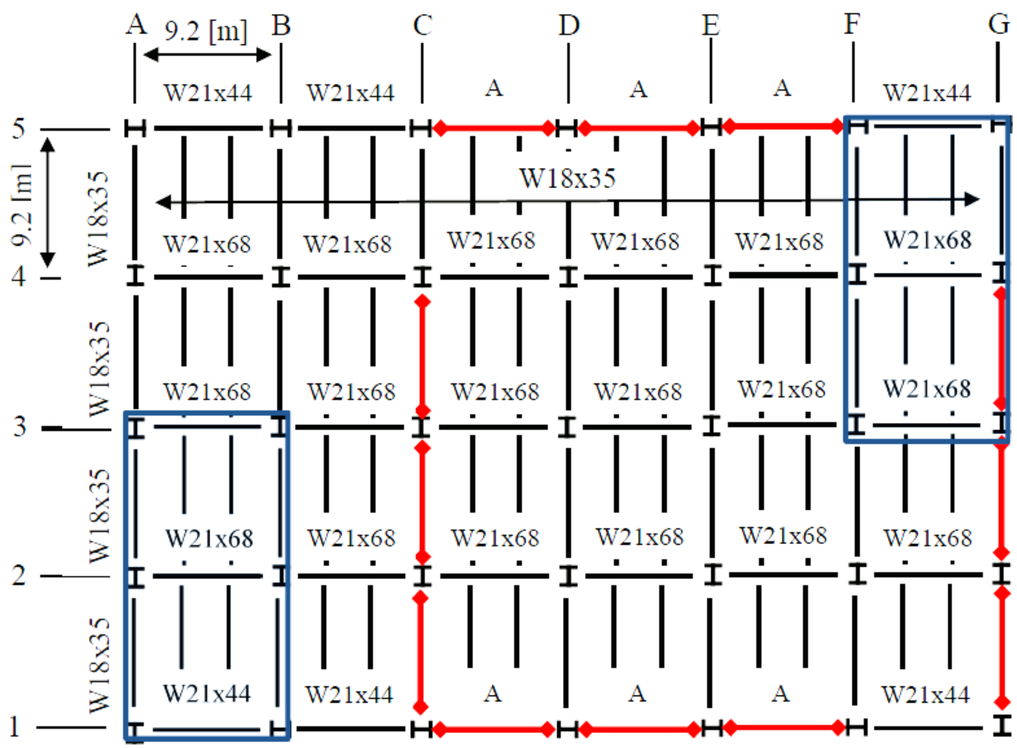
Before earthquake

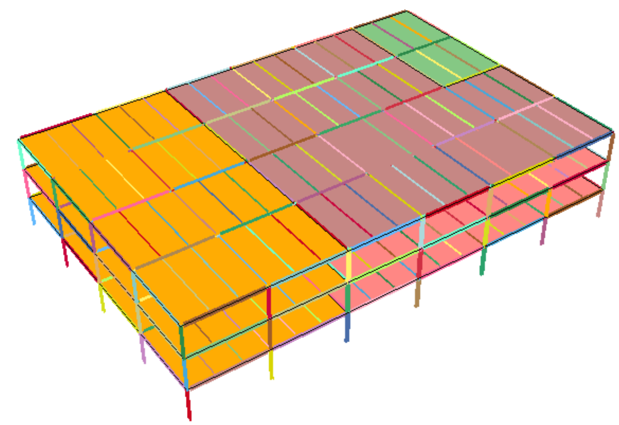
- Large strains and geometric nonlinearities
- Contact and impact of falling members

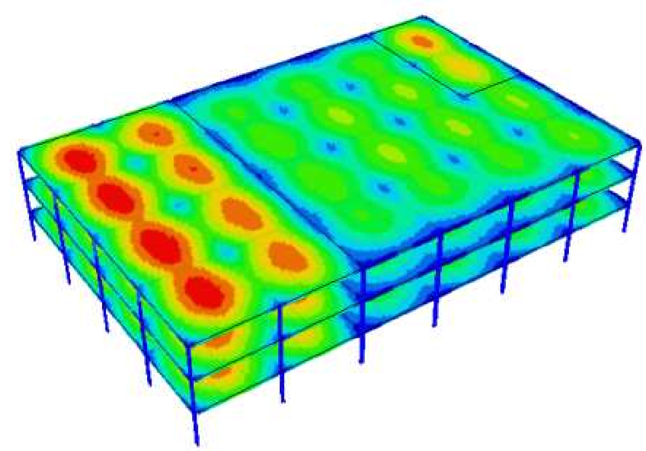


After earthquake

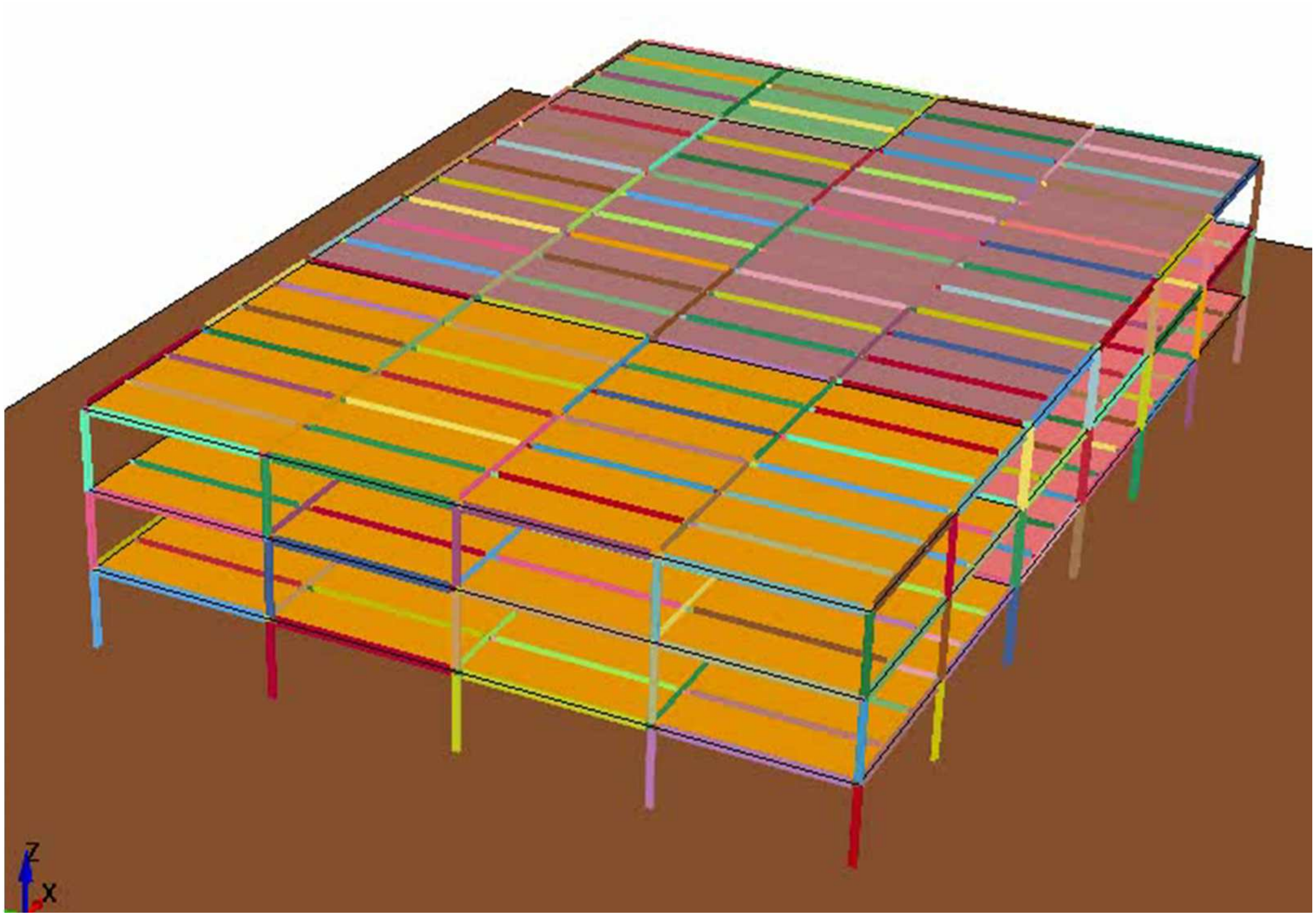
3 story building. Case study



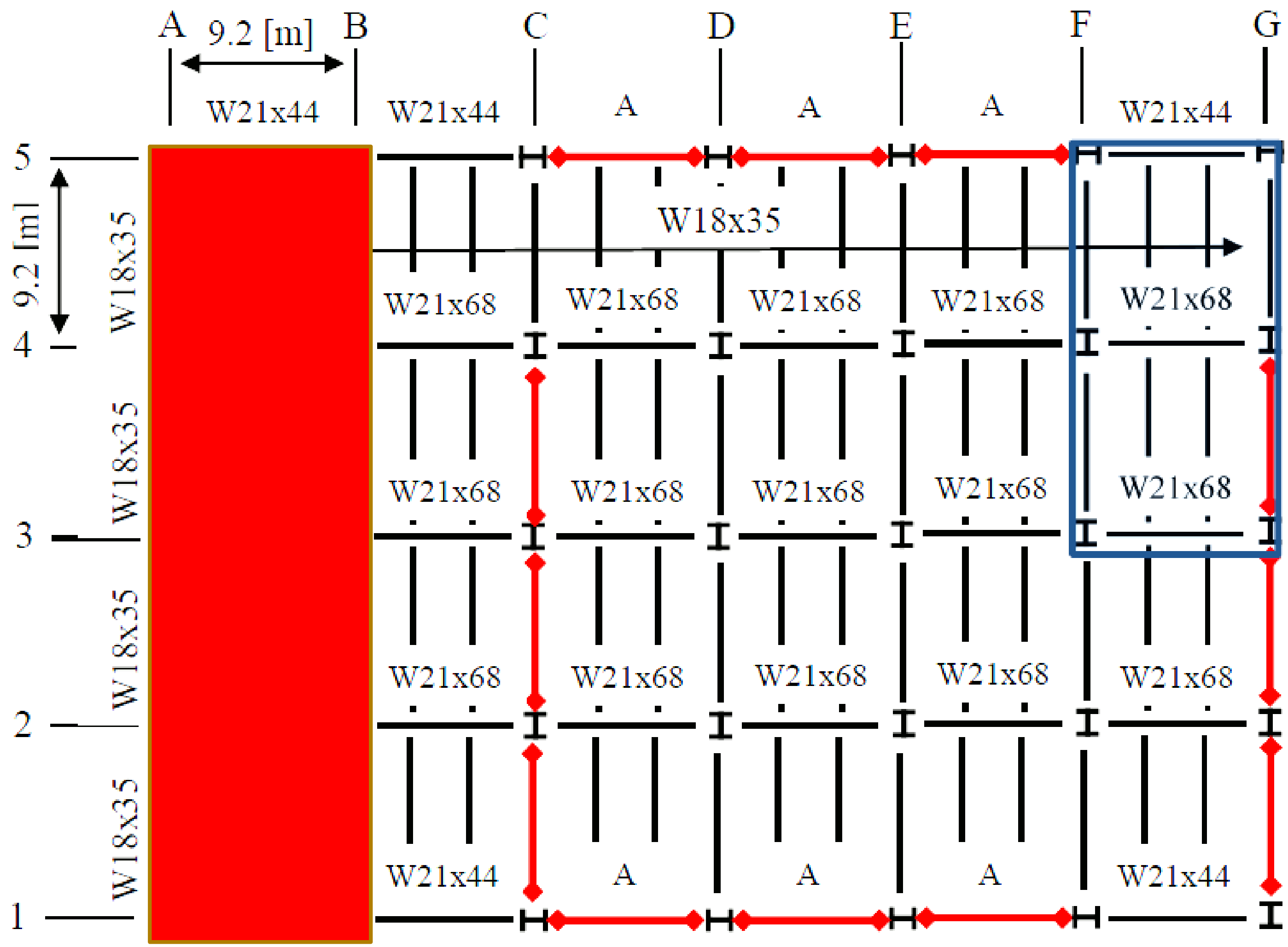




3 story building - Visualization

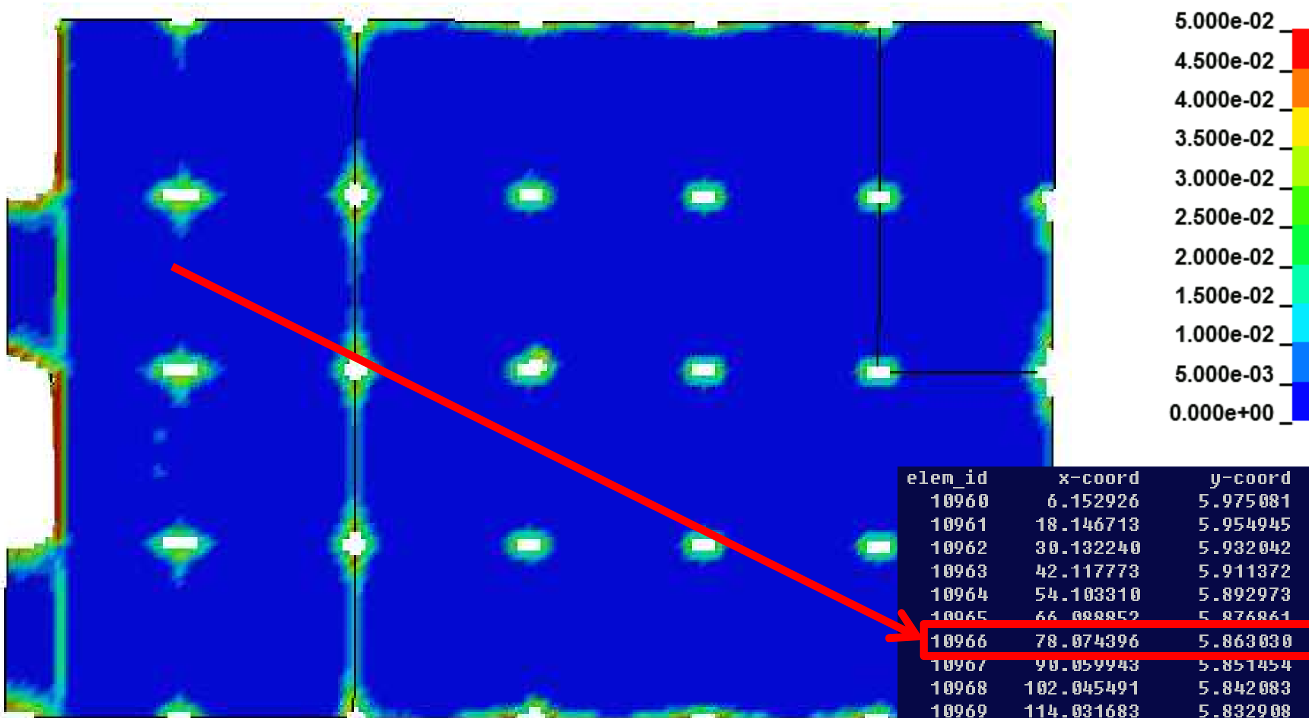


Damage assessment



Floor damage

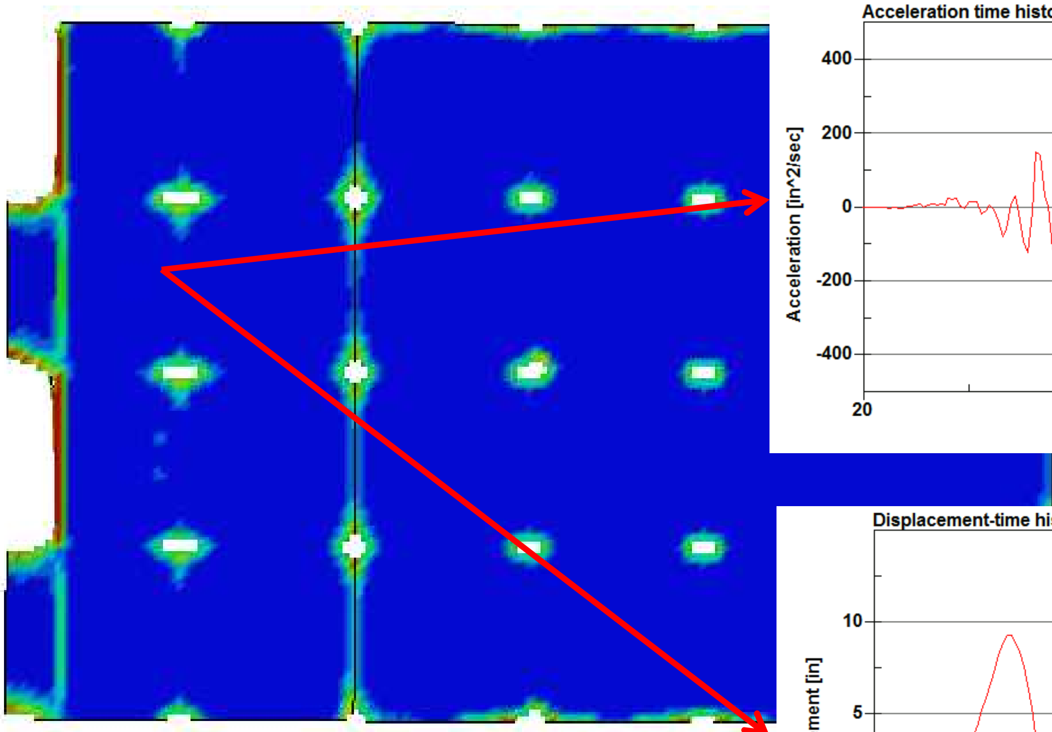
- Damage resulting in partial collapse



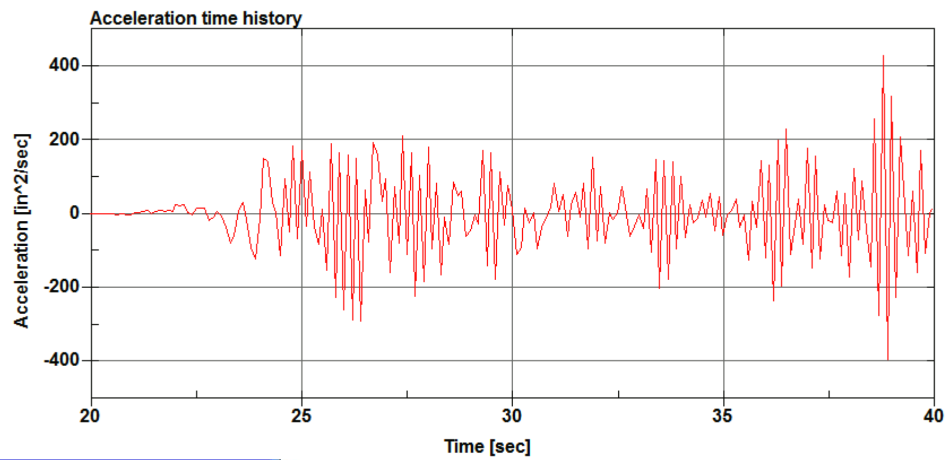
2nd floor slab (effective plastic strain)

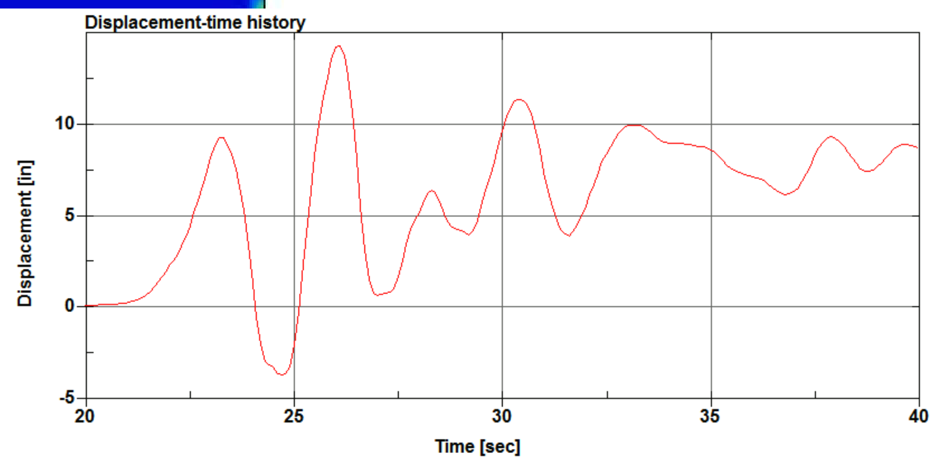
elem_id	x-coord	y-coord	z-coord	1=OK 0=del	perm_z-disp
10960	6.152926	5.975081	155.955000	0	0.000000
10961	18.146713	5.954945	155.949270	0	0.000000
10962	30.132240	5.932042	155.944623	0	0.000000
10963	42.117773	5.911372	155.940730	0	0.000000
10964	54.103310	5.892973	155.937605	0	0.000000
10965	66.088852	5.876861	155.935252	0	0.000000
10966	78.074396	5.863030	155.933670	1	-4.440545
10967	90.059943	5.851454	155.932847	1	-4.063509
10968	102.045491	5.842083	155.932770	1	-3.886452
10969	114.031683	5.832908	155.933922	1	-3.803761
10970	126.021343	5.834796	155.938785	1	-3.826692
10971	138.014470	5.847525	155.947348	1	-3.884346
10972	150.008238	5.859799	155.957108	1	-3.922487
10973	162.002005	5.873242	155.967565	1	-3.939513
10974	173.995772	5.887562	155.978745	1	-3.933934
10975	185.989537	5.902485	155.990675	1	-3.905024
10976	197.983300	5.917742	156.003385	1	-3.853736
10977	209.977062	5.933066	156.016923	1	-3.781118
10978	221.970825	5.948186	156.031335	1	-3.685833
10979	233.962812	5.960761	156.043115	1	-3.579895
10980	245.952060	5.972372	156.063883	1	-3.469615
10981	257.938568	5.982837	156.093710	1	-3.339540
10982	269.923300	5.990238	156.121097	1	-3.190973
10983	281.908030	5.996584	156.149635	1	-3.031114

Accelerations and displacements



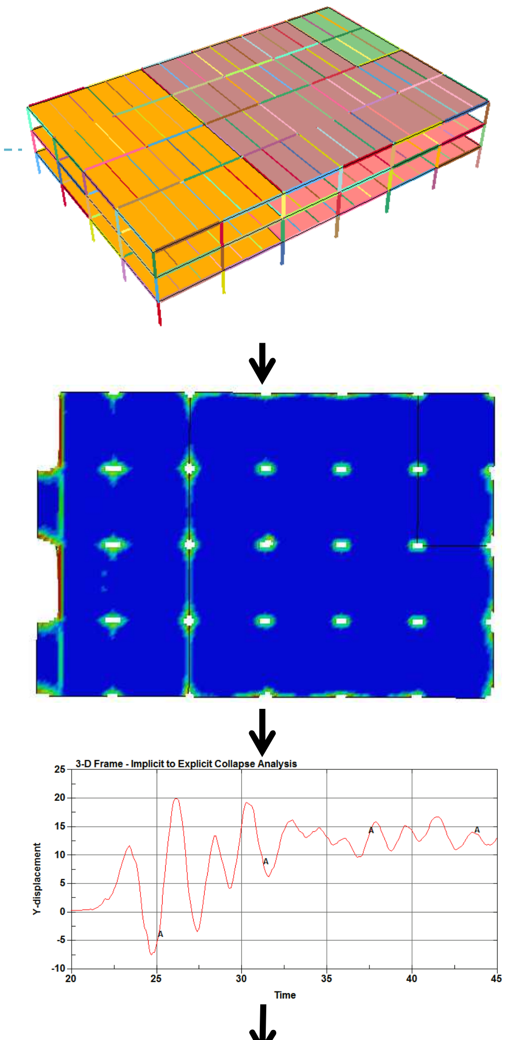
2nd floor slab (effective plastic strain)

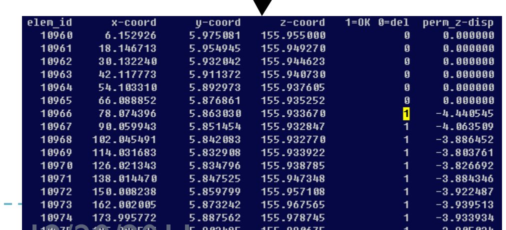




Summary

- Response of buildings to a strong earthquake
  - detailed dynamic, time-history simulations
  - contact and collapse
- Structural damage enables estimates of post-earthquake:
  - obstacles in evacuation routes
  - collapsed slabs
  - buckled columns
  - damaged staircases
- Time floor accelerations and drifts for assessment of non-structural damage





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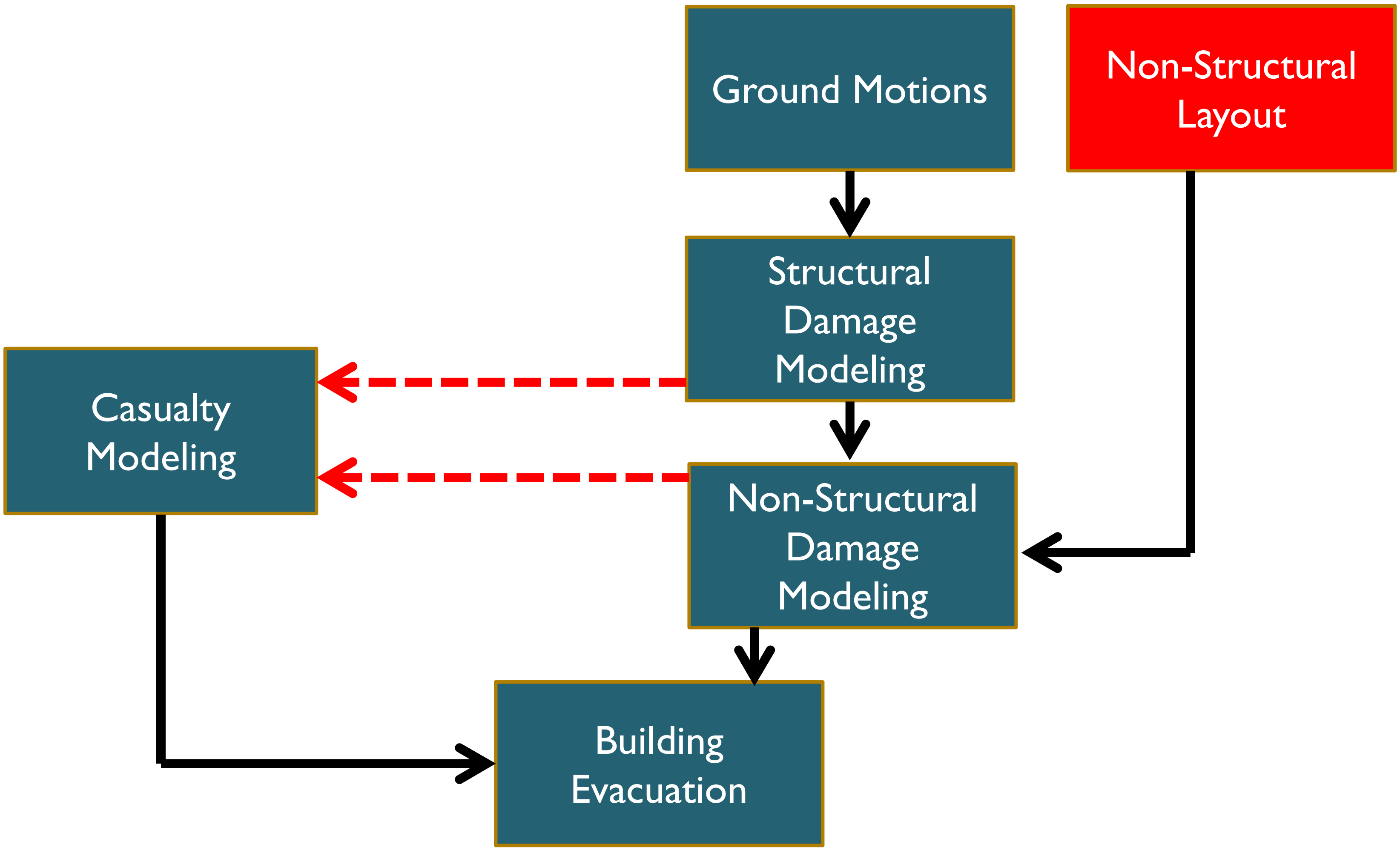
10974	173.995772	5.887562	155.978745	1	-3.933934
10975	[illegible]	5.902485	155.990675	1	-3.905024

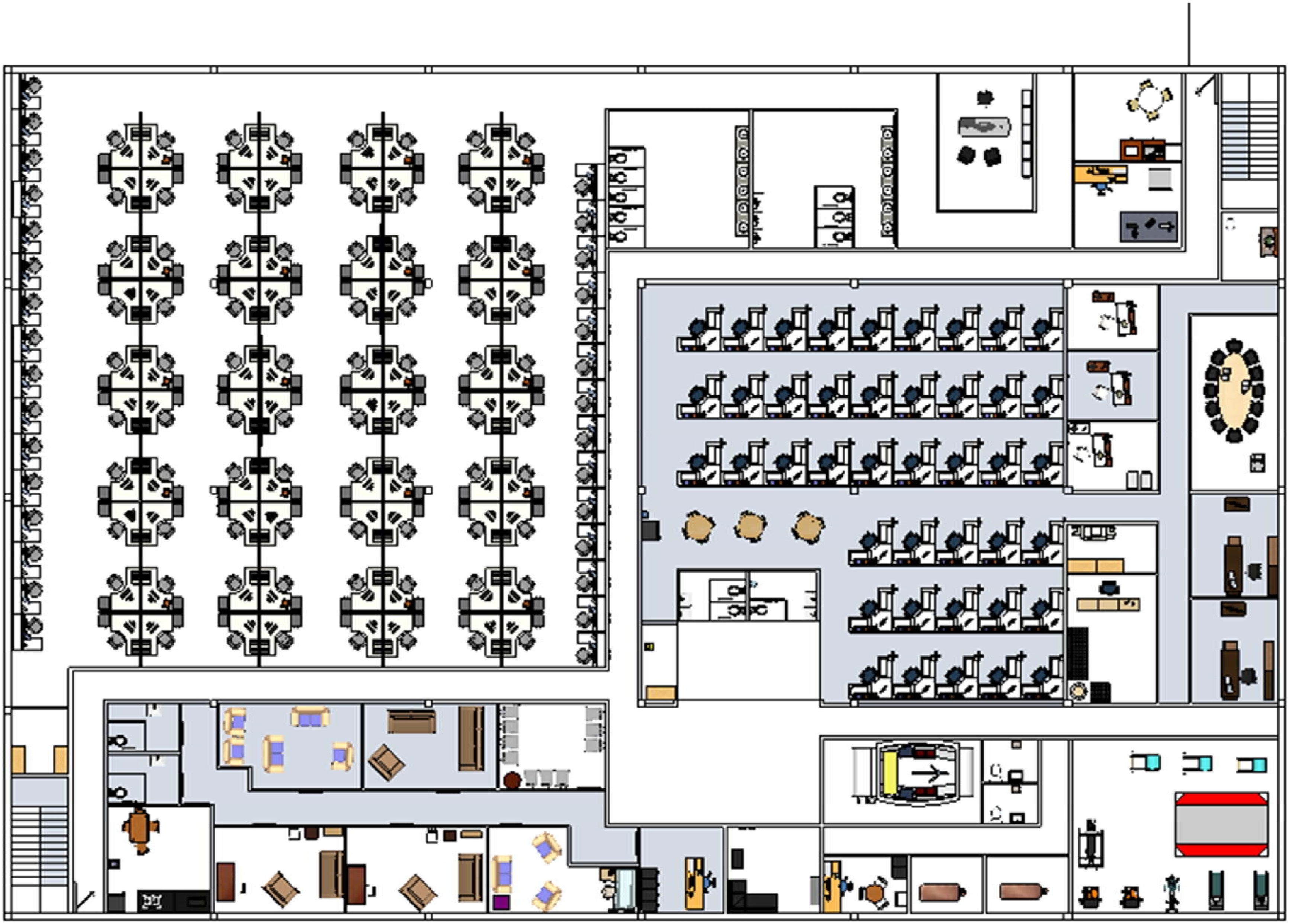
Non-Structural Layout

Approach – Test Structure

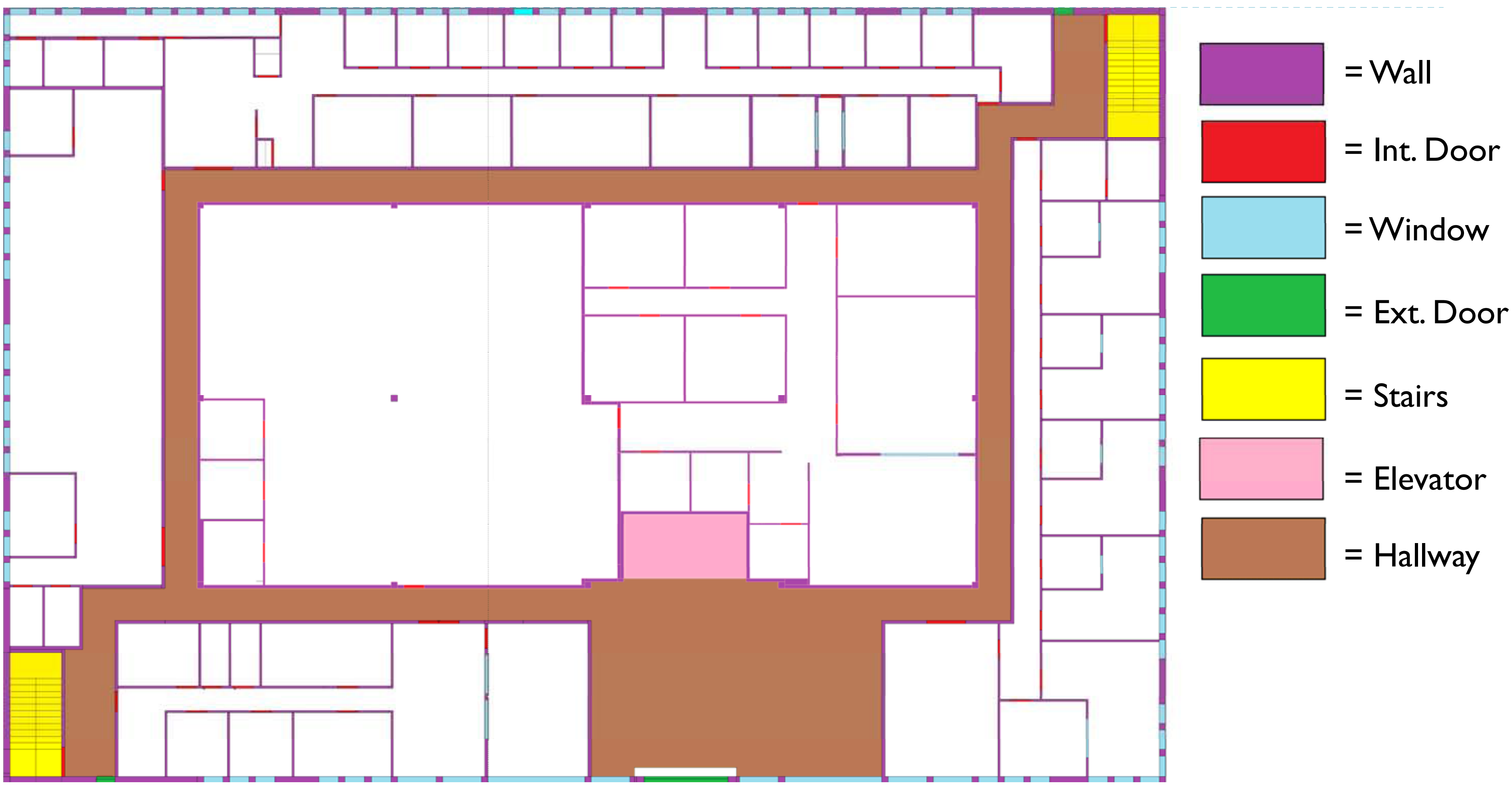


Design of Non-Structural Layout

- Non-structure elements for the test structure only.
- Designed in Google Sketchup according to fire code.
- Non-structural elements present inside walls and ceilings:
  - 1: Evenly distributed with constant density
  - 2: Amounts calculated using ATC 58
- Two floor plans commercial occupancy :
  - a ground floor
  - upper story, repeated for all higher stories.



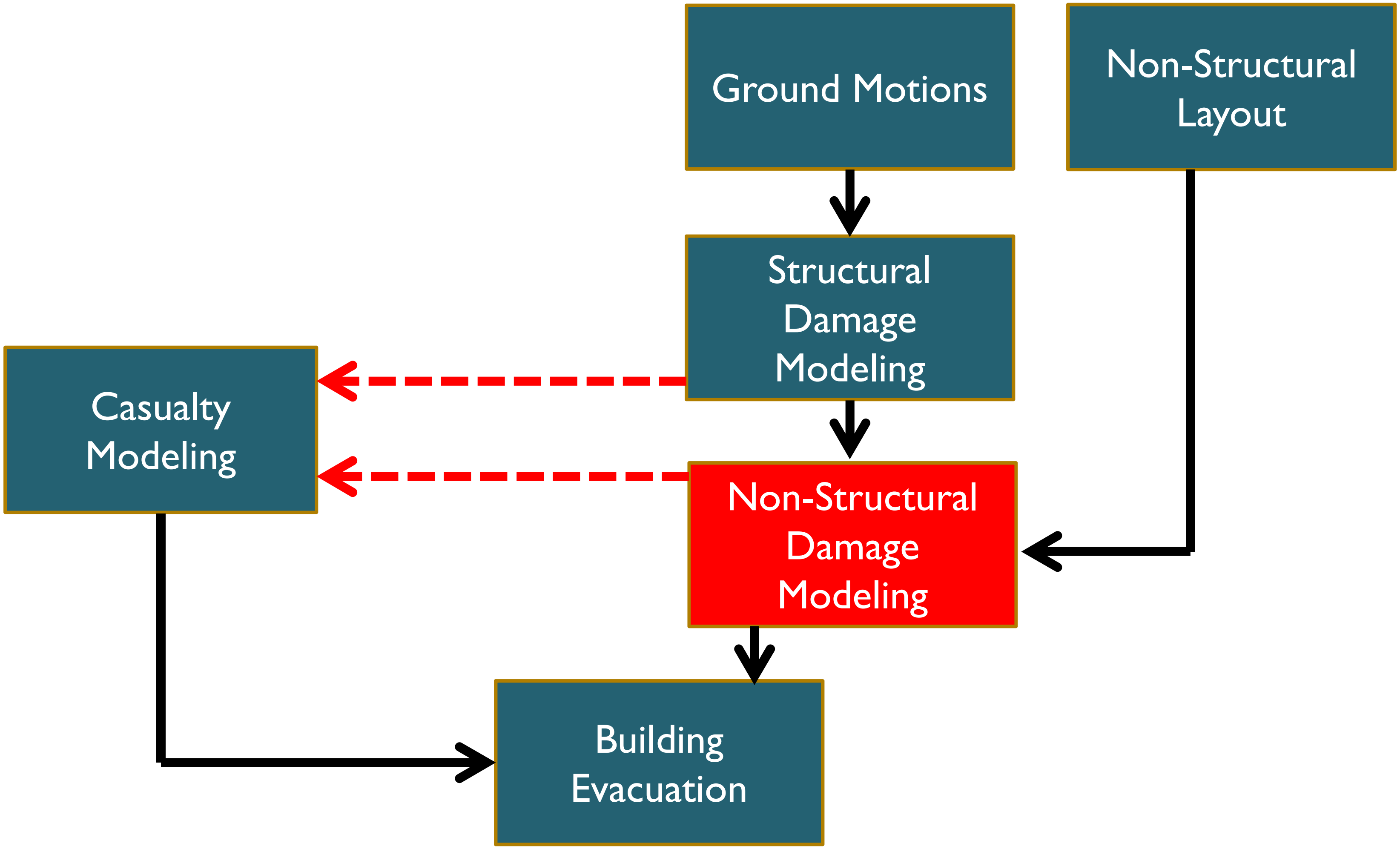
Simplified Floor Plans



Non-Structural Damage Analysis

Assembly based vulnerability

Approach – Test Structure

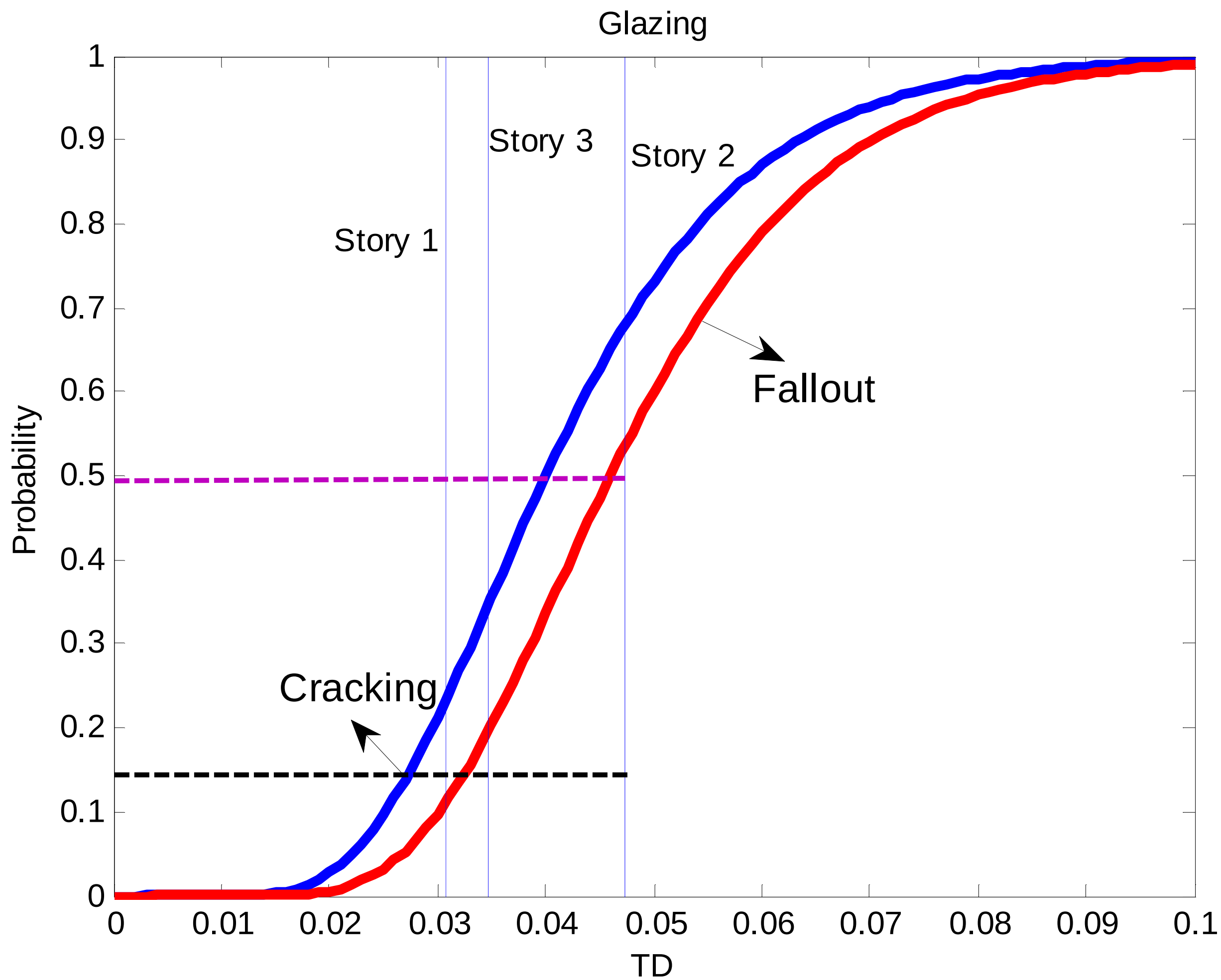


Method

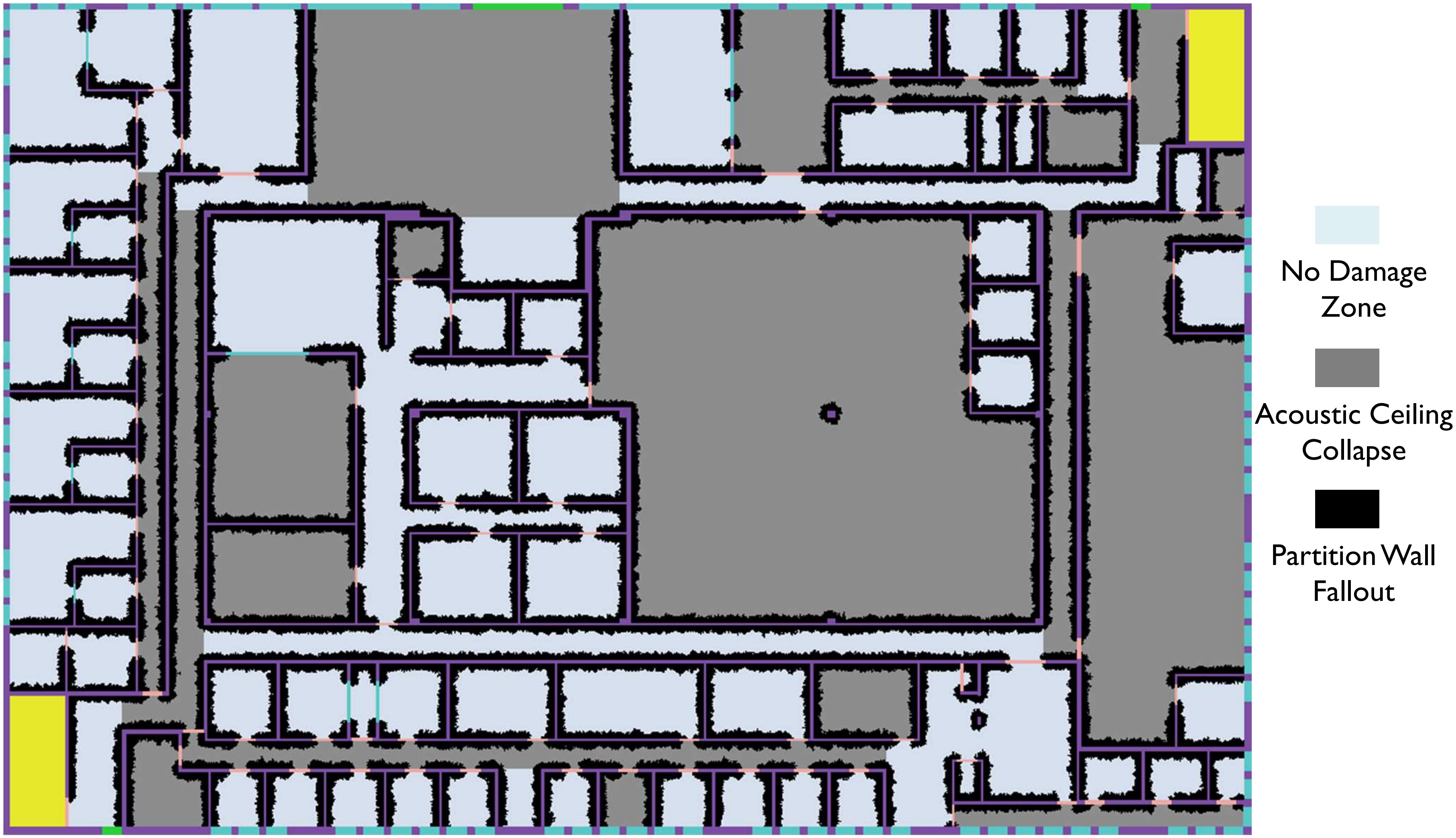
- Step 1: Fragility functions
- Step 2: Location/number of the components
- Step 3: Structural responses from simulation
- Step 4: Run probabilistic non-structural damage analysis
- Step 5: Create damage distribute map.

Example: Glazing Damage

Floor	Structural Response
1	0.0308
2	0.0474
3	0.0346



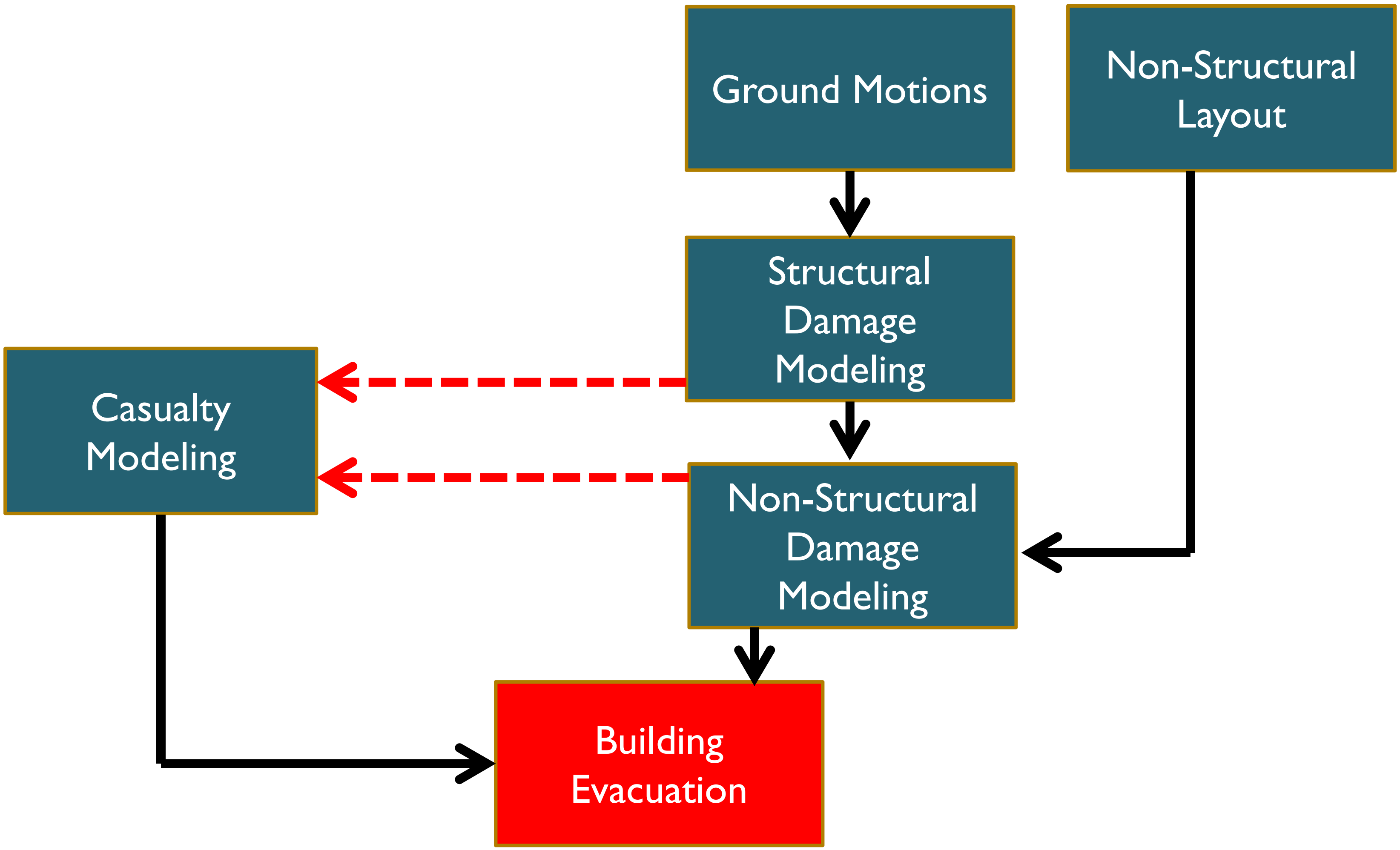
Damage distribution map
(Dry wall partition and Acoustic Ceiling)



Test Structure Evacuation Model

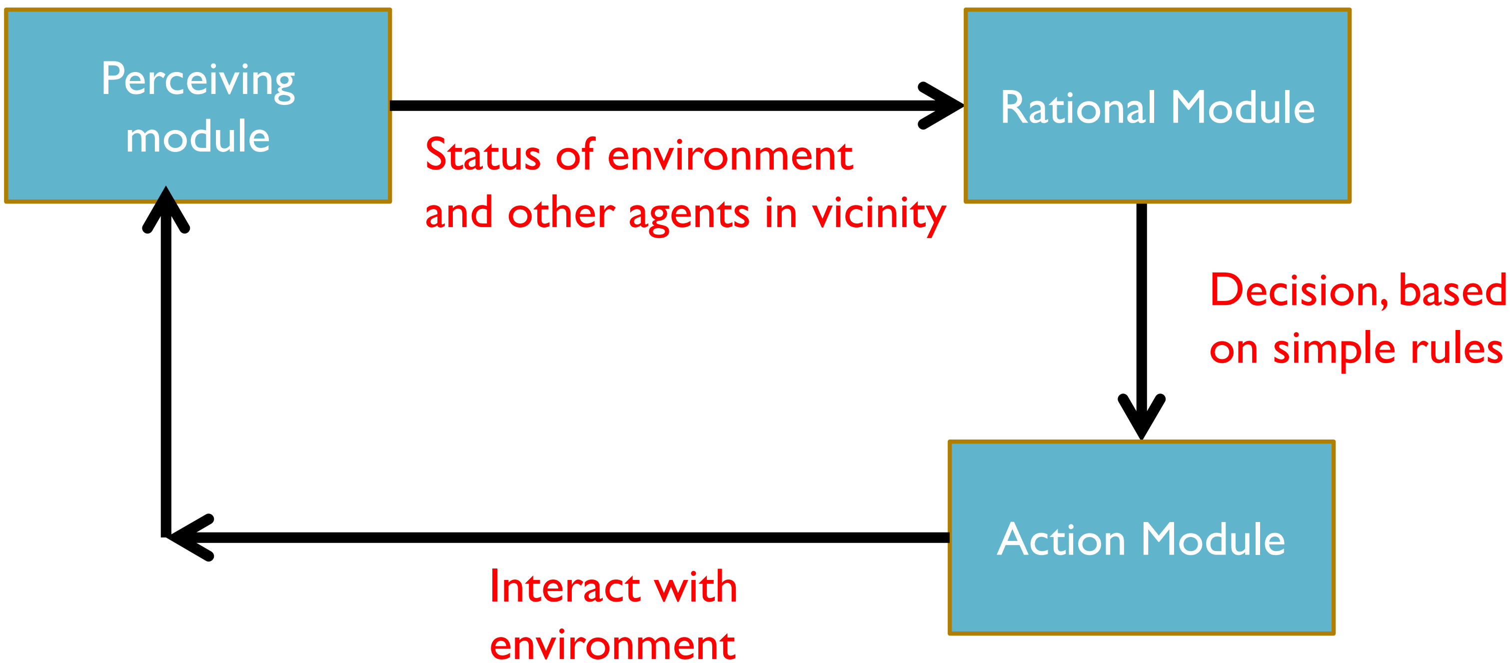
Implement agent based modeling

Approach – Test Structure

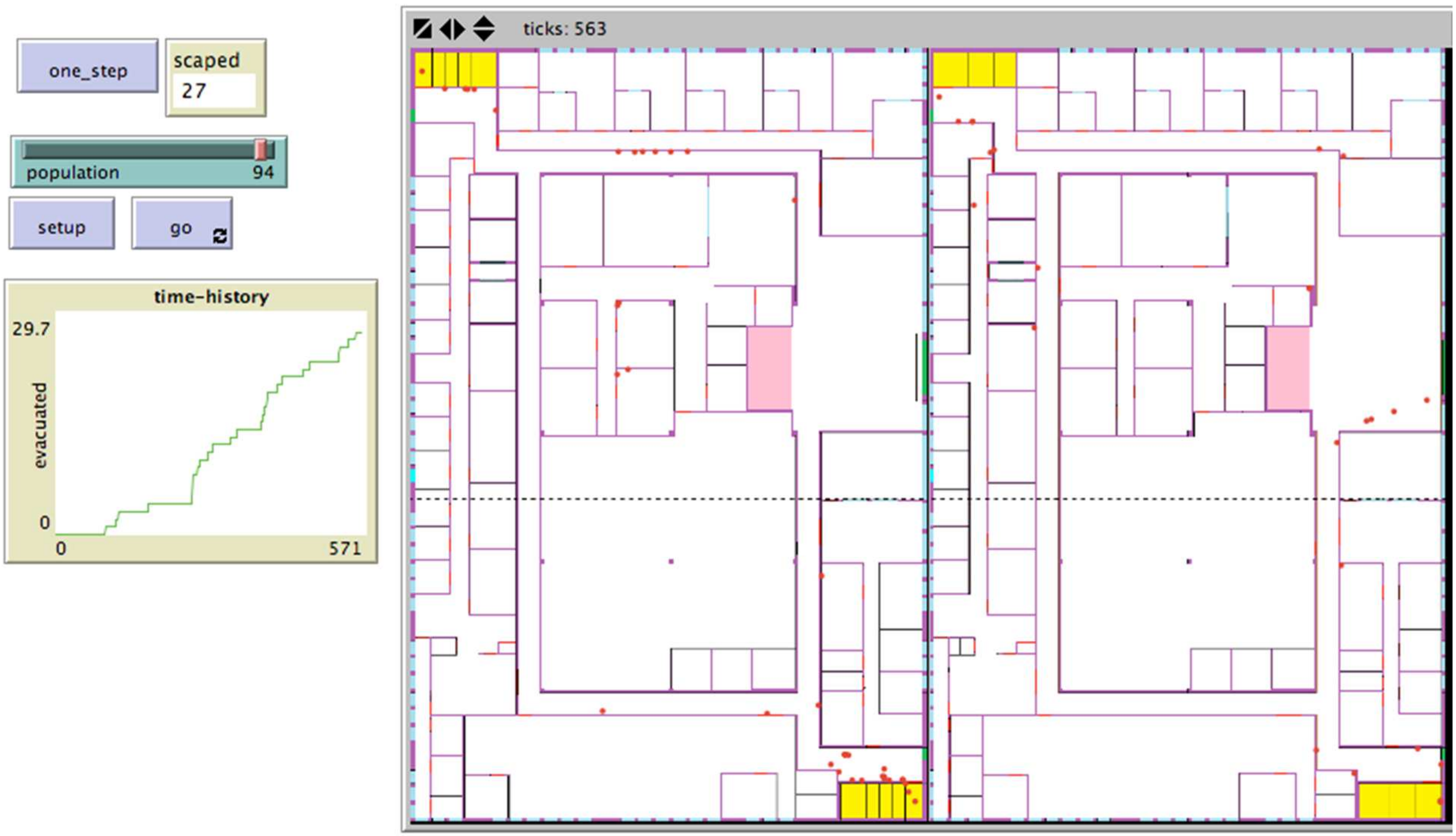


What is agent-based modeling?

- Agents are purposeful, rational, perceiving and decision making artificial life forms that interact with the surroundings.



ABM of test structure



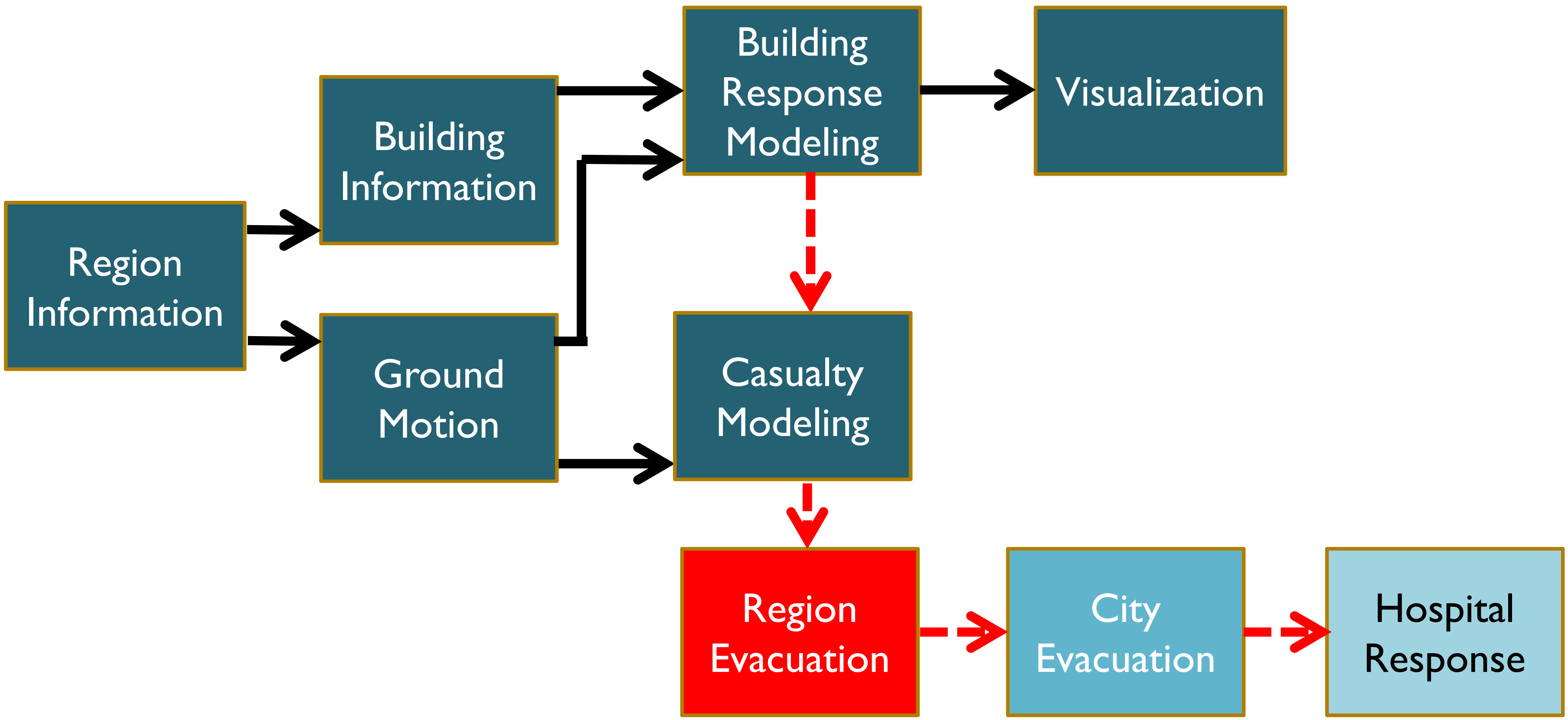
Assumptions and capabilities

- Each person tries to evacuate individually using shortest distance to exit.
- It is assumed that most of people know the shortest path to exit
- Some confused people are modeled
- Because the building is designed using high standards no injury or dead was assumed.
- People will never path walls, and avoid each other

Evacuation of City block

Implement agent based modeling

Approach - City

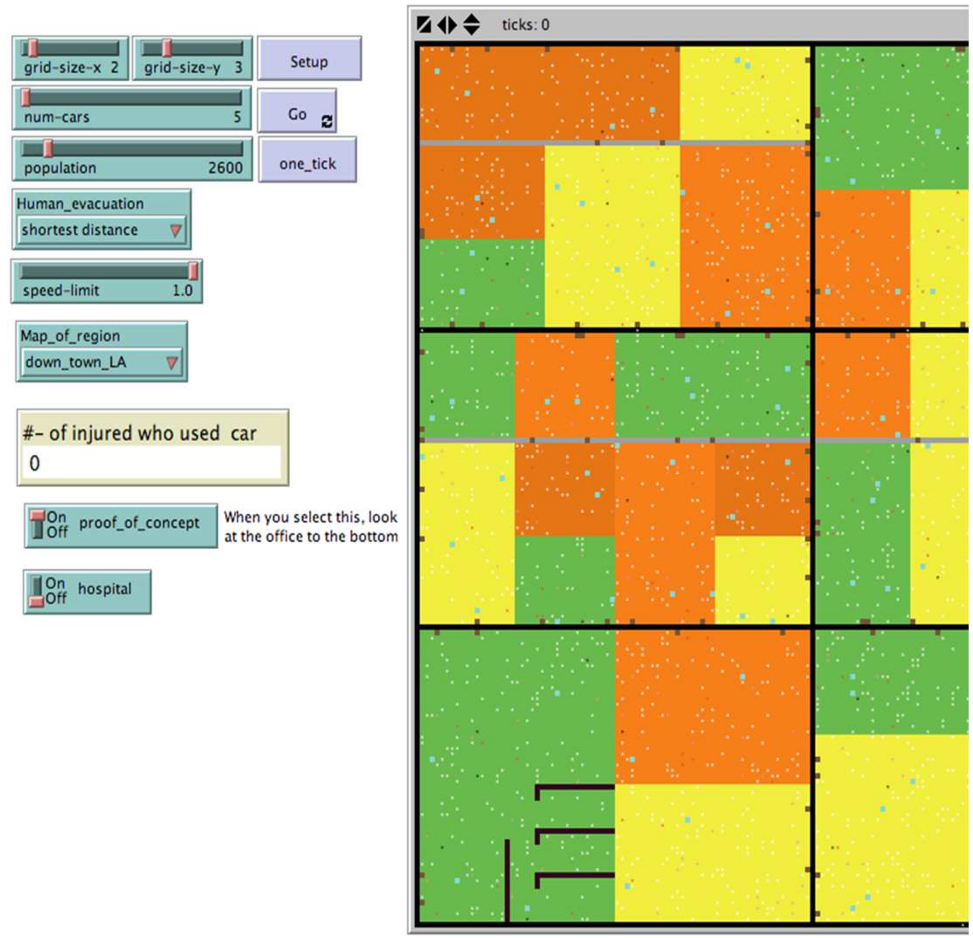


Partial map of region from ABM

Legend

City:
- Street
- Alley

- Building stock:
- One story
- Two stories
- Three story
- Four story

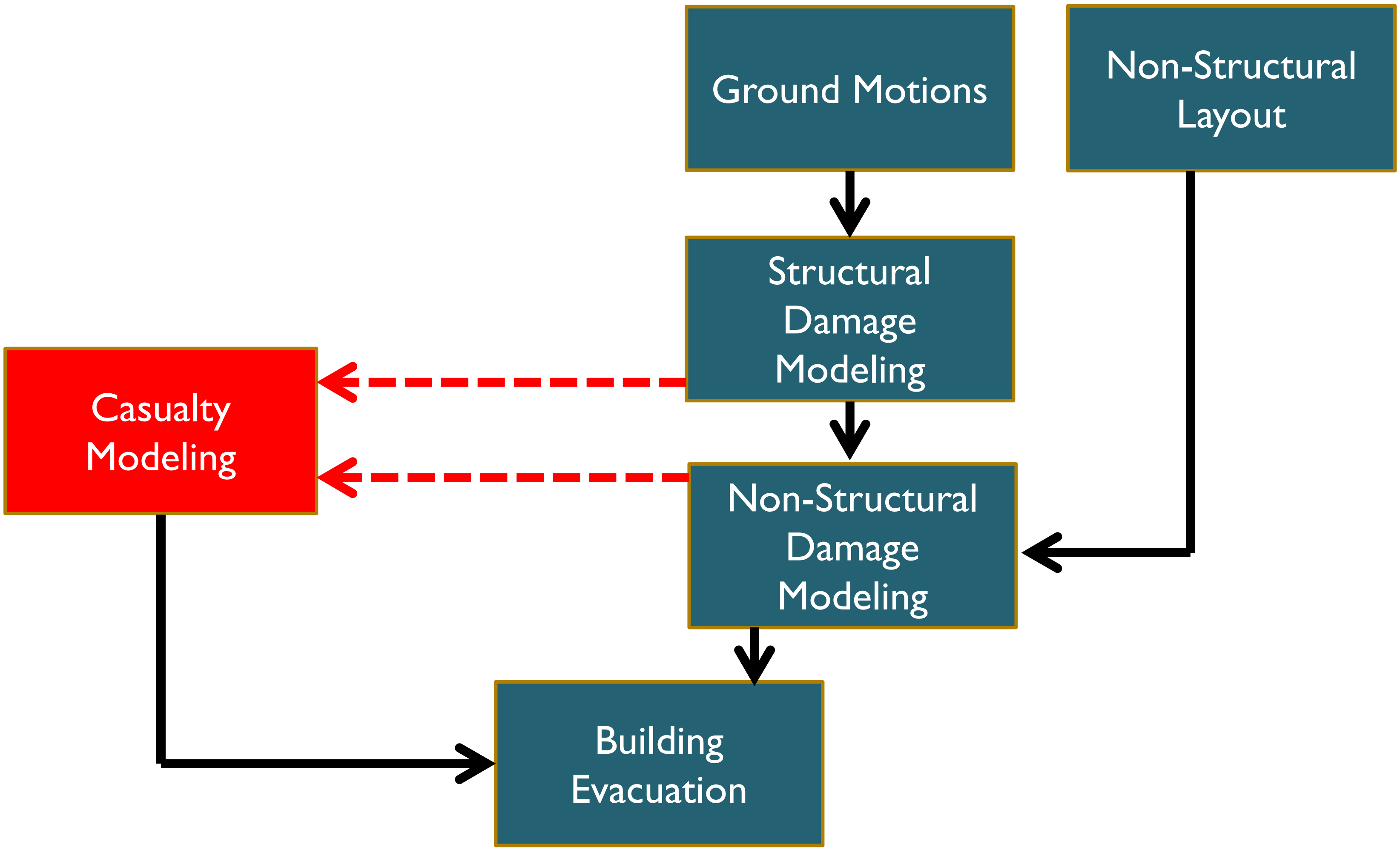


Model assumptions and capabilities

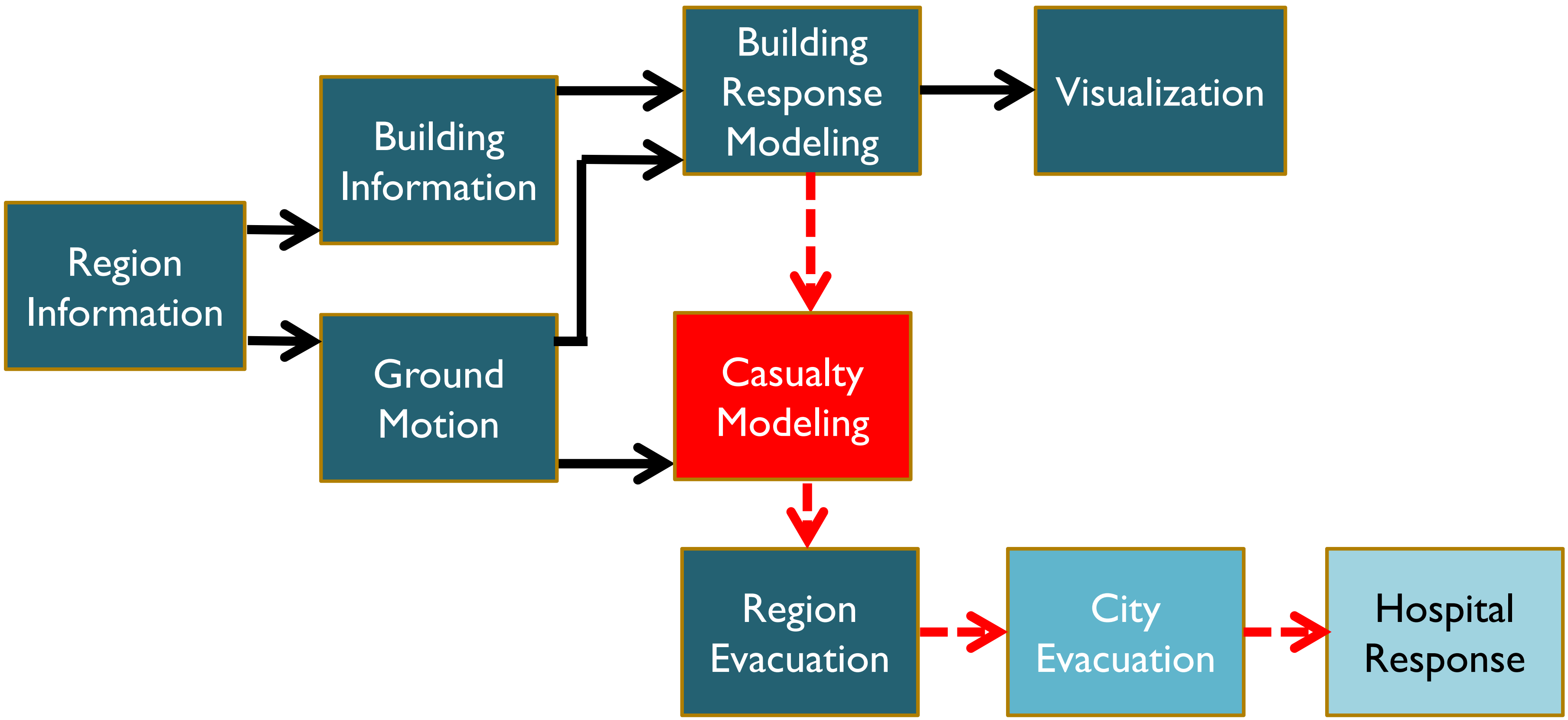
- Model is expandable to any city size and population
- Mapped the exact building stock in the model
- Exit and stair cases are approximately located
- Includes traffic flow, cars never run over people, two way streets
- People recognize each other and form queues at exits
- Walking speed is based on health status
- Some people use private cars to evacuate using two exit points provided
- Each injured individual if can make it to out of building will have a chance to get assisted by healthy persons near them

Casualty Modeling

Approach – Test Structure



Approach - City



Methodology

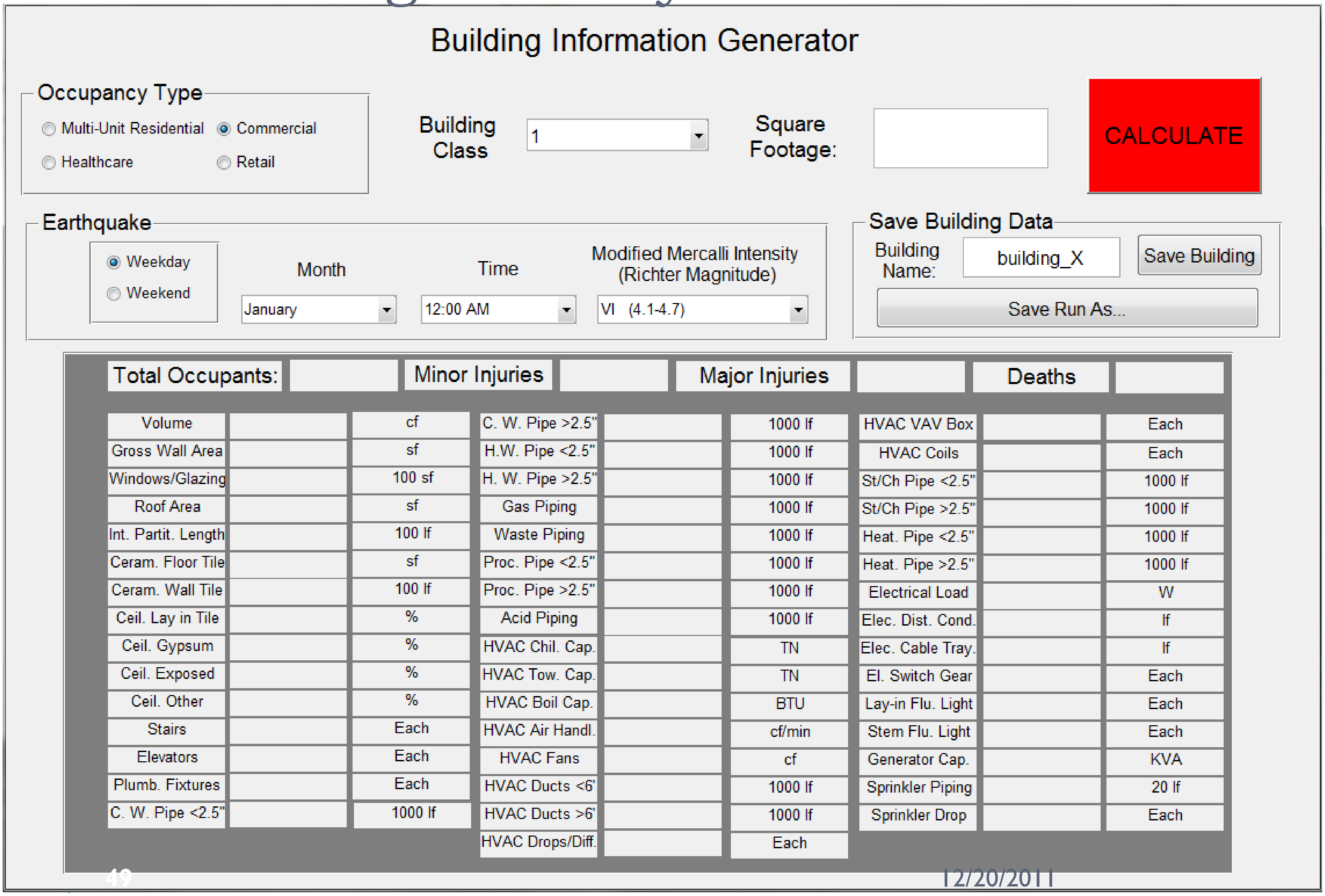
1. Visually assess structure load bearing system
2. Based on ATC 13, estimate central damage factor.

$$0 \leq cdf \leq 100$$

1. Below table is the mapping between people and building

CDF	Different types of Building							Minor injury	Serious injury	Dead
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00003	0.000004	0.000001
5	1.90	0.50	0.00	0.00	0.00	0.00	0.00	0.0003	0.00004	0.00001
20	85.10	60.20	0.10	0.00	6.60	3.60	3.90	0.003	0.0004	0.0001
45	13.00	39.30	10.10	5.30	78.80	70.00	57.80	0.03	0.004	0.001
80	0.00	0.00	83.10	80.00	14.60	26.40	38.30	0.3	0.04	0.01
100	0.00	0.00	6.70	14.70	0.00	0.00	0.00	0.4	0.4	0.2
P[Minor]	0.65	1.36	27.91	30.04	6.76	10.03	13.24			
p[Seroius]	0.18	6.04	9.10	0.90	1.34	1.76	0.17			
P[Dead]	2.18	3.75	0.23	0.33	0.44	0.08	0.08			

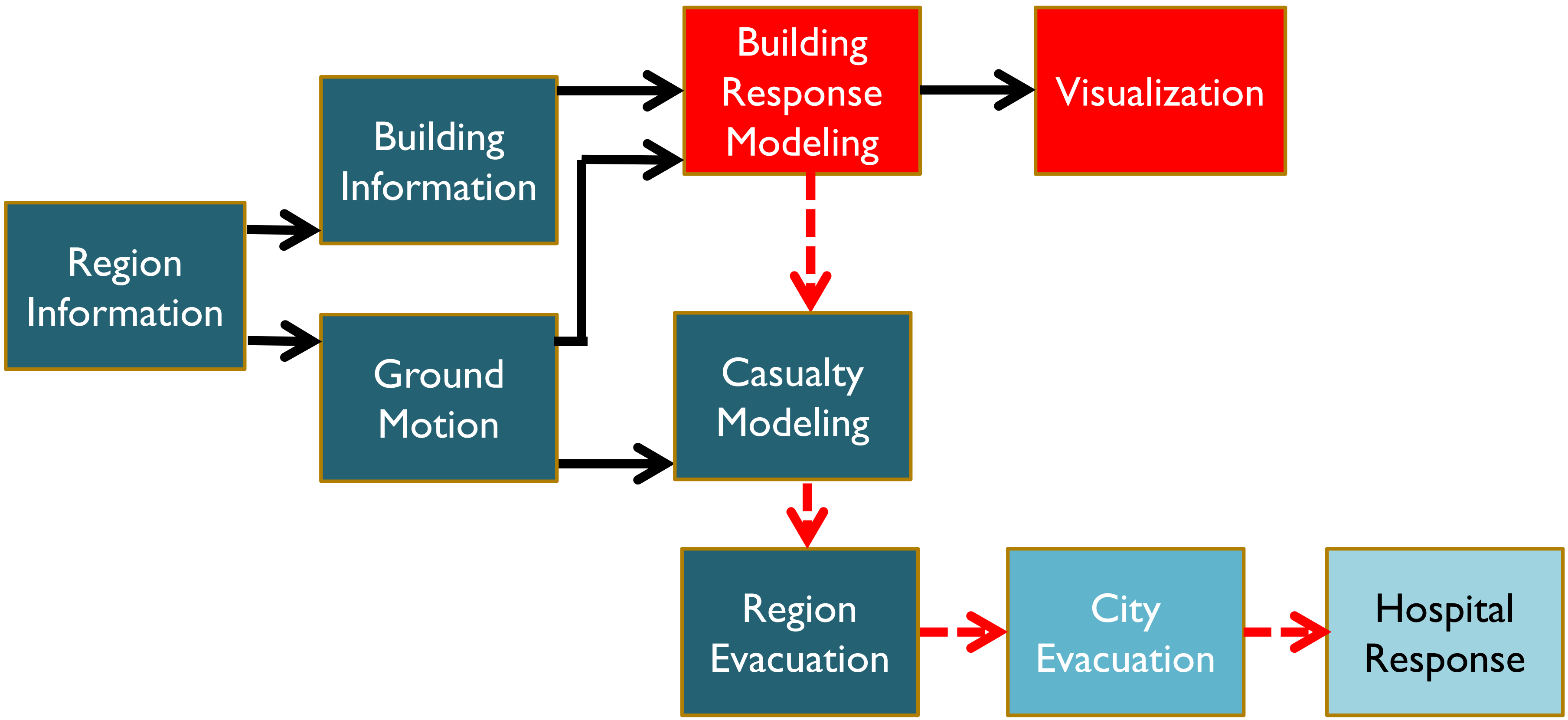
Automating Casualty Calculation



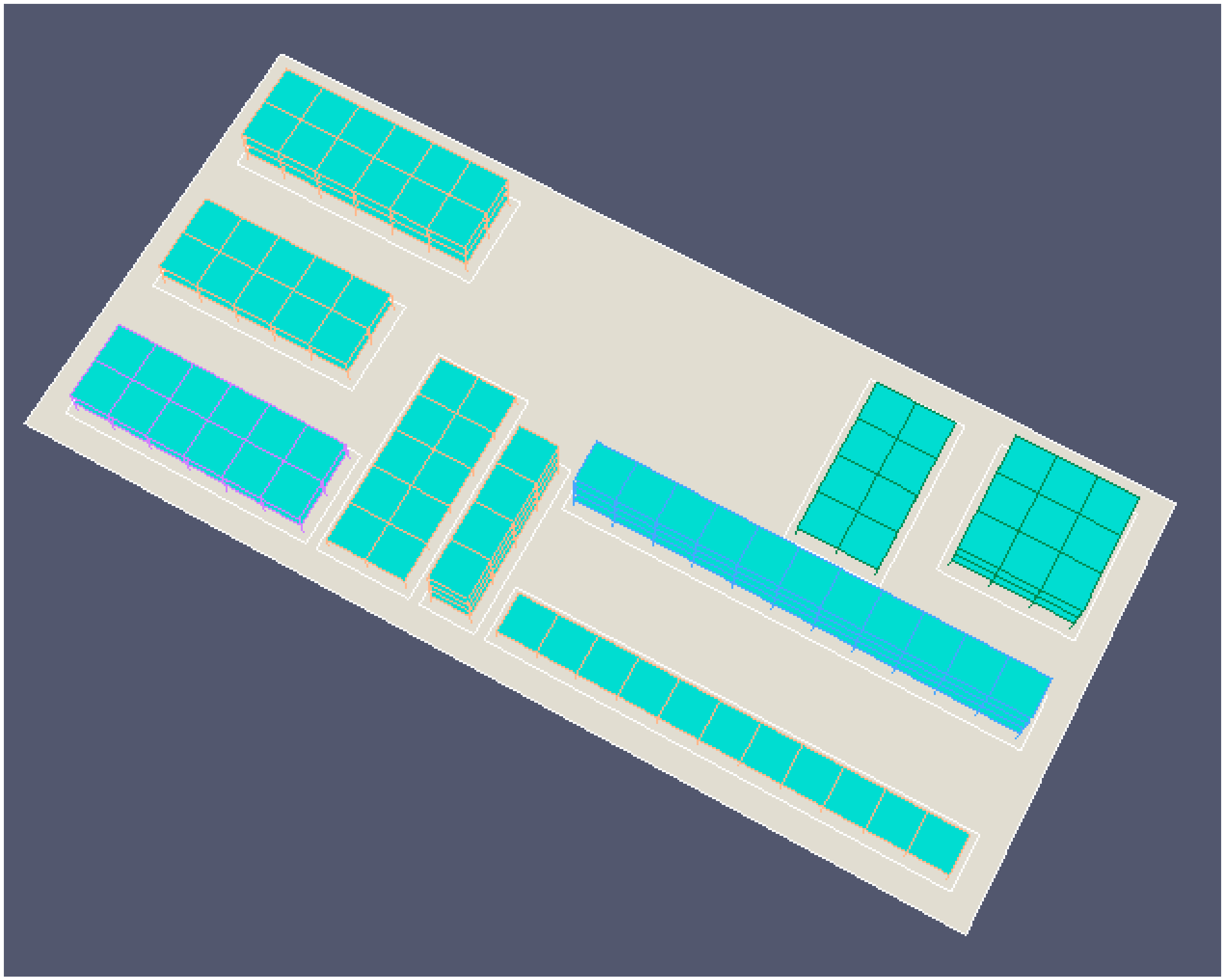
Regional Modeling and Animation

Single degree of freedom

Approach - City



Example (Single Block)



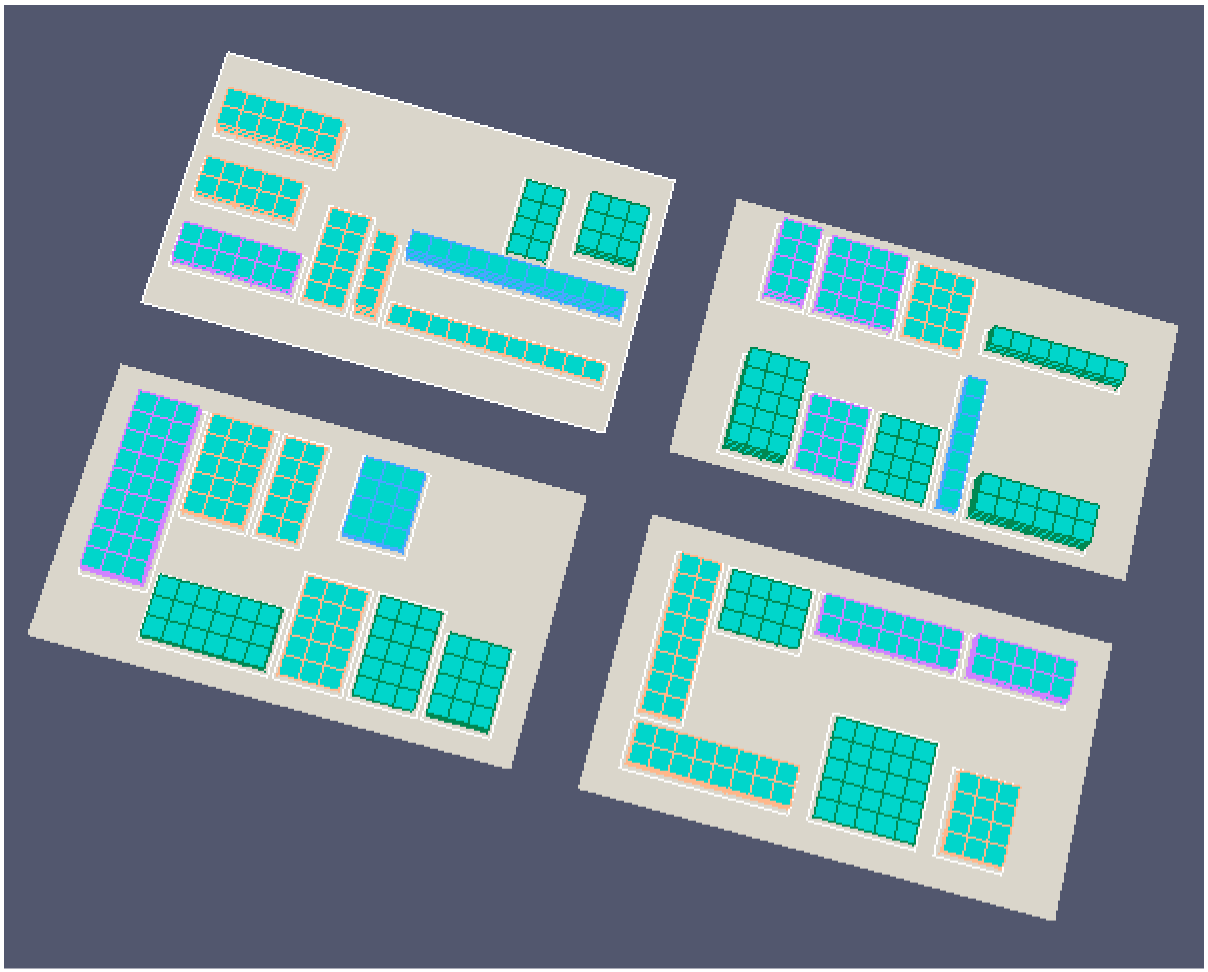
Steel moment frame

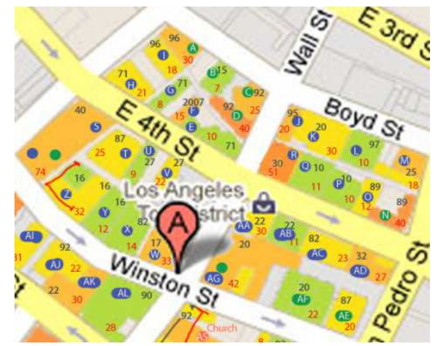
Eccentrically braced steel frame

Concrete moment frame

Others

Example (Multi Blocks)





Steel moment frame

Eccentrically braced steel frame

Concrete moment frame

Others

Future Work

Needed Connections and Modules

Connections:

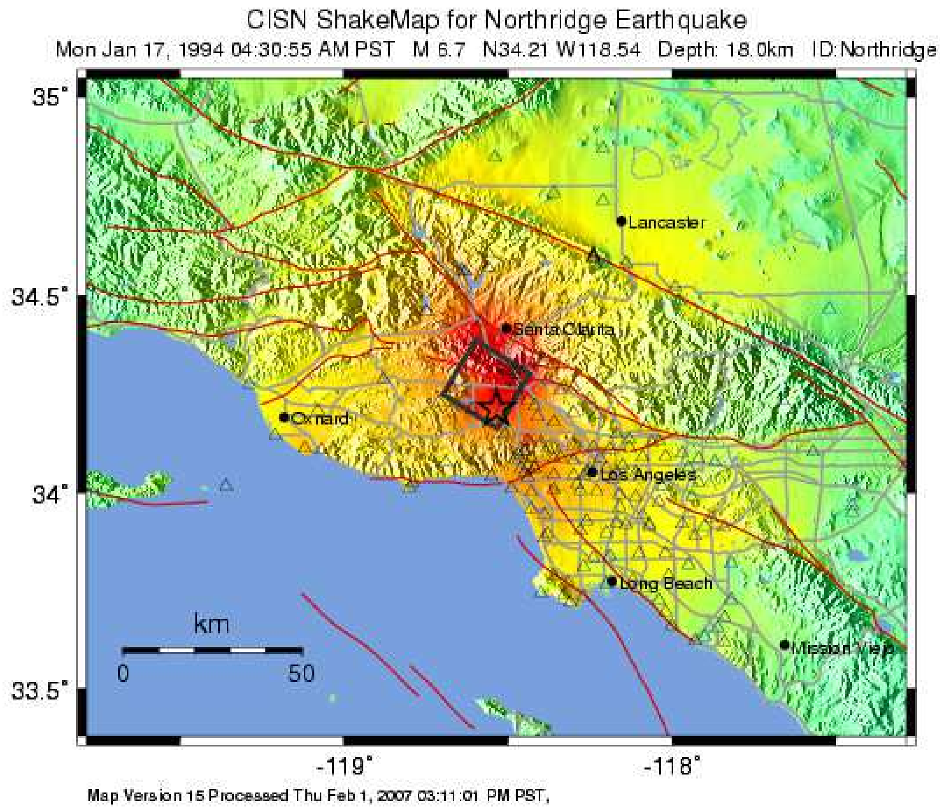
- From building response to casualties
- From casualties to regional agent-based models
- From region to city
- From city to hospital

Modules

- Whole city response
- Hospital response

Other Avenues of Exploration

- Traffic and transportation
  - Greater literature review needed
  - Estimated flow of cars
- Cooperative/competitive evacuation
- Incorporation of GIS into Netlogo
- Ambulances and health responders


CISN ShakeMap for Northridge Earthquake
Mon Jan 17, 1994 04:30:55 AM PST M 6.7 N34.21 W118.54 Depth: 18.0km ID:Northridge
35˚
34.5˚
34˚
33.5˚
-119˚
-118˚
Lancaster
Santa Clarita
Oxnard
Los Angeles
Long Beach
Mission Viejo
km
0
50
Map Version 15 Processed Thu Feb 1, 2007 03:11:01 PM PST,

Questions?