

مرکز پژوهشی پایداری و تاب‌آوری زیرساخت‌ها

Probabilistic Framework for Evaluating Urban Resilience under Natural Disasters

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Center for Infrastructure Sustainability and Resilience Research

I N S U R E R

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Multiple disciplines
collaborate to
analyze, assess,
protect, and recover
infrastructure systems
to facilitate meeting
the needs of the
present and sustainable
development, reducing
the adverse impacts,
developing software
tools, and the
implementation of
INSURER.

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resilience | ri-'zil-yən(t)s |

noun

the ability of a system to bounce back after a crisis:

'A disaster resilient community withstands an extreme event, natural or man made, with a tolerable level of losses, and recovers rapidly.'

sustainability | səstəmə'bilɪti |

noun

the ability to be maintained at a proper level:

'Sustainable urban development meets the needs of the present without compromising the ability of future generations to meet their own needs.'



Seismic Risk Communication System



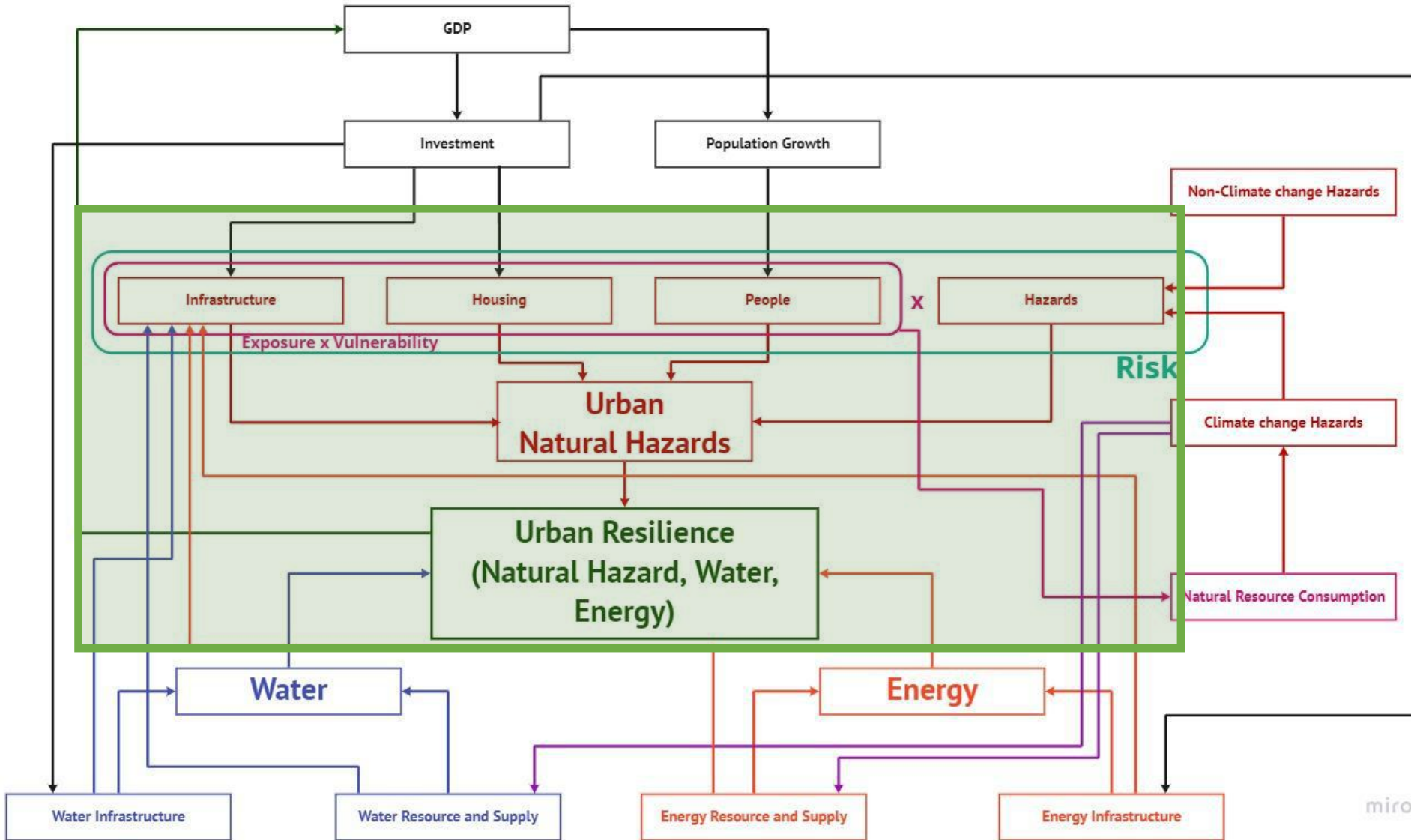
Evaluation and Optimization of Community Resilience

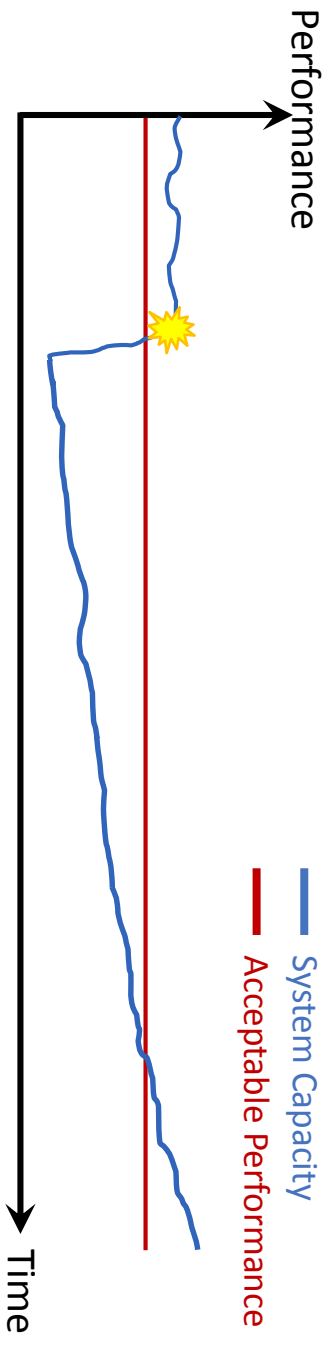
The primary objective of this megaproject is to design and develop a software platform, dubbed Rx, to evaluate and maximize the resilience of urban infrastructures. By simulating events starting from the occurrence of the hazard until the full recovery of infrastructure systems, this platform quantifies the community resilience. This simulation comprehensively models the hazard intensity, damage to infrastructure systems, and consequences. Example consequences are repair and replacement costs, casualties, reduction in life quality due to of ailment, amputation, or loss of a family member, reduction of hospital treatment capacity due to water and power outage, blockage of roads due to damage to bridges or debris, which subsequently interrupts the search-and-rescue operation, business interruption due to failure of lifelines, pandemics due to lack of clean water, and environmental impacts of reconstruction efforts. The simulation of consequences is followed by simulating the recovery process of infrastructure systems to



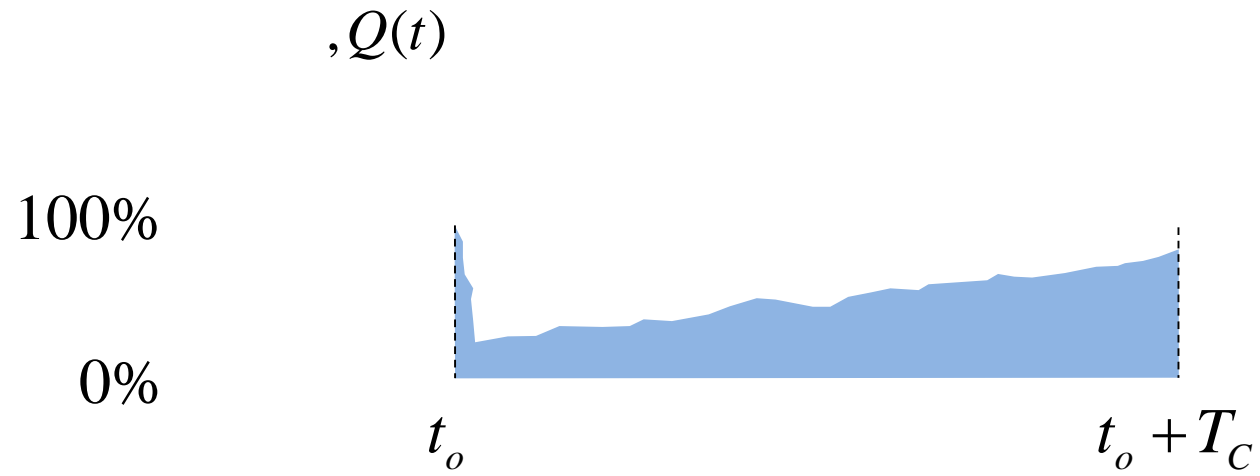
insurer.sharif.edu

System of Systems

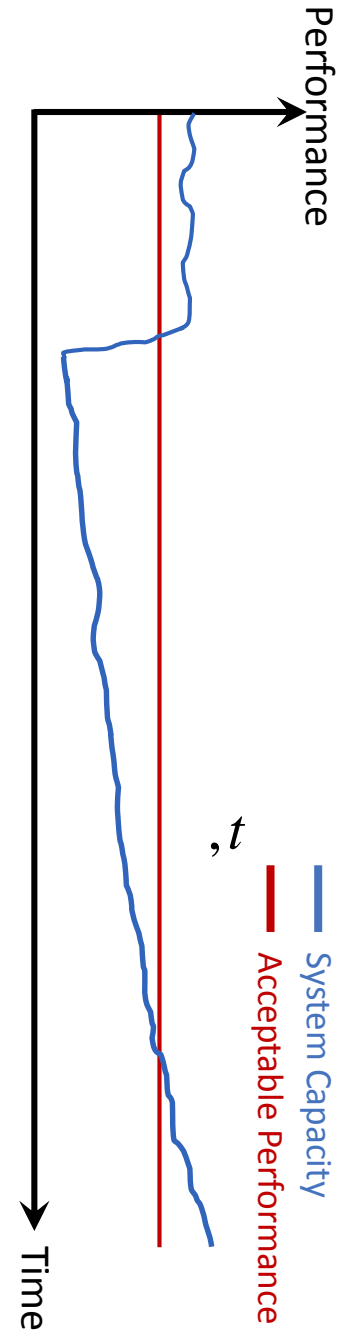




Resilience



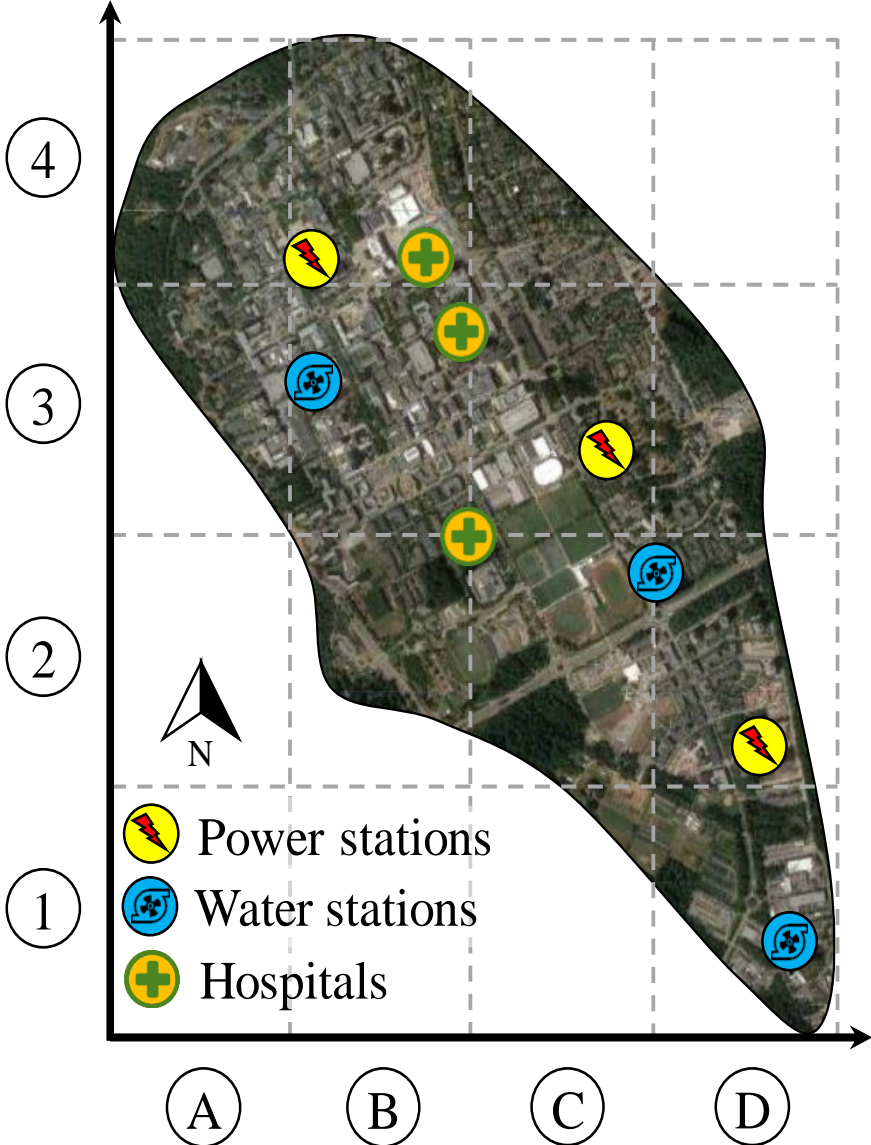
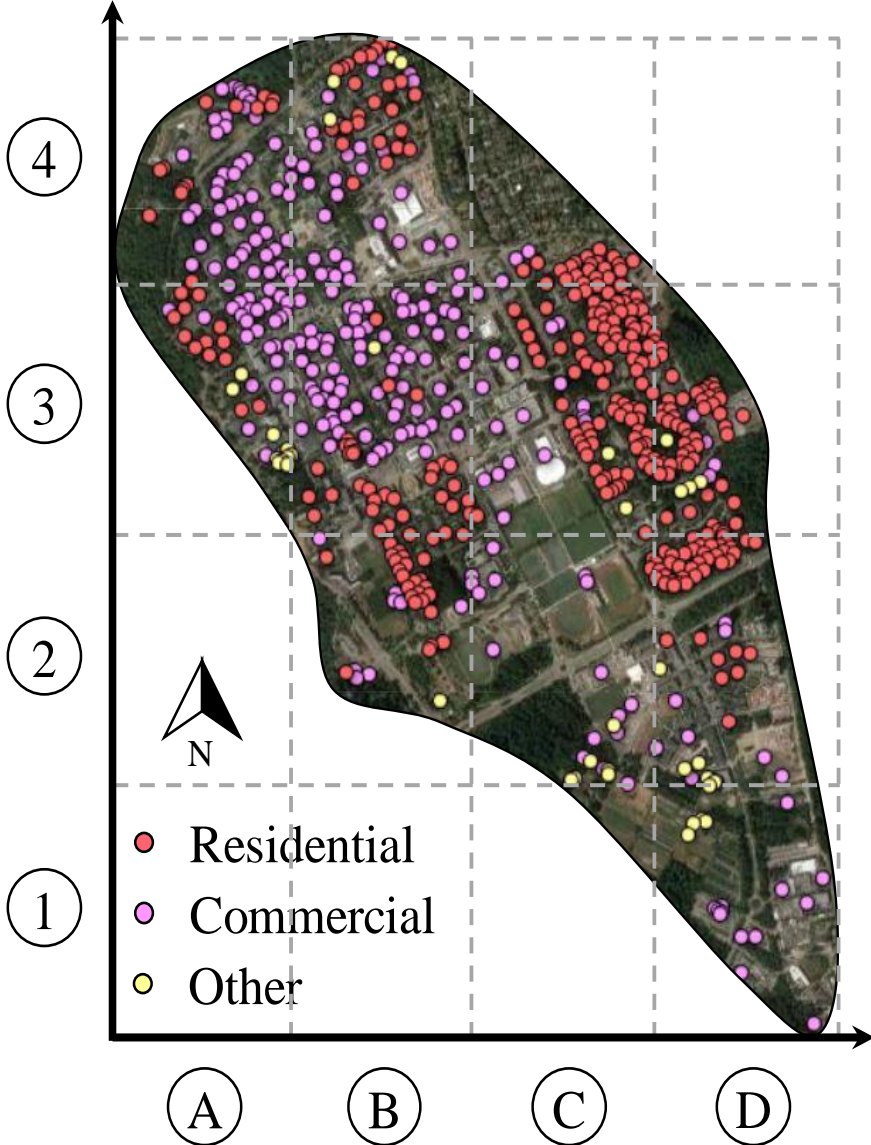
$$\square = \frac{1}{T_C} \int_{t_o}^{t_o + T_C} Q(t) dt$$



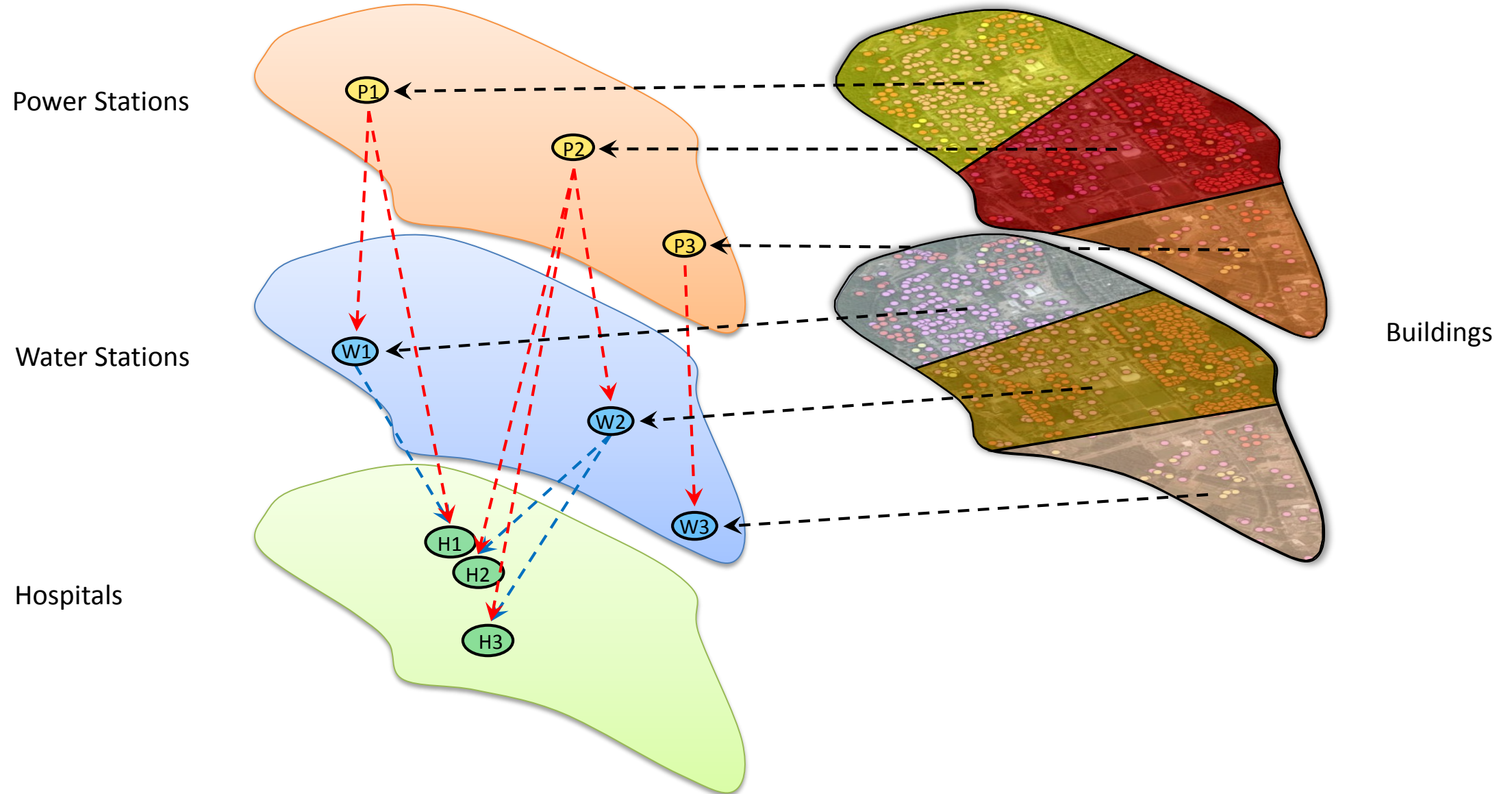
Hazard Sources

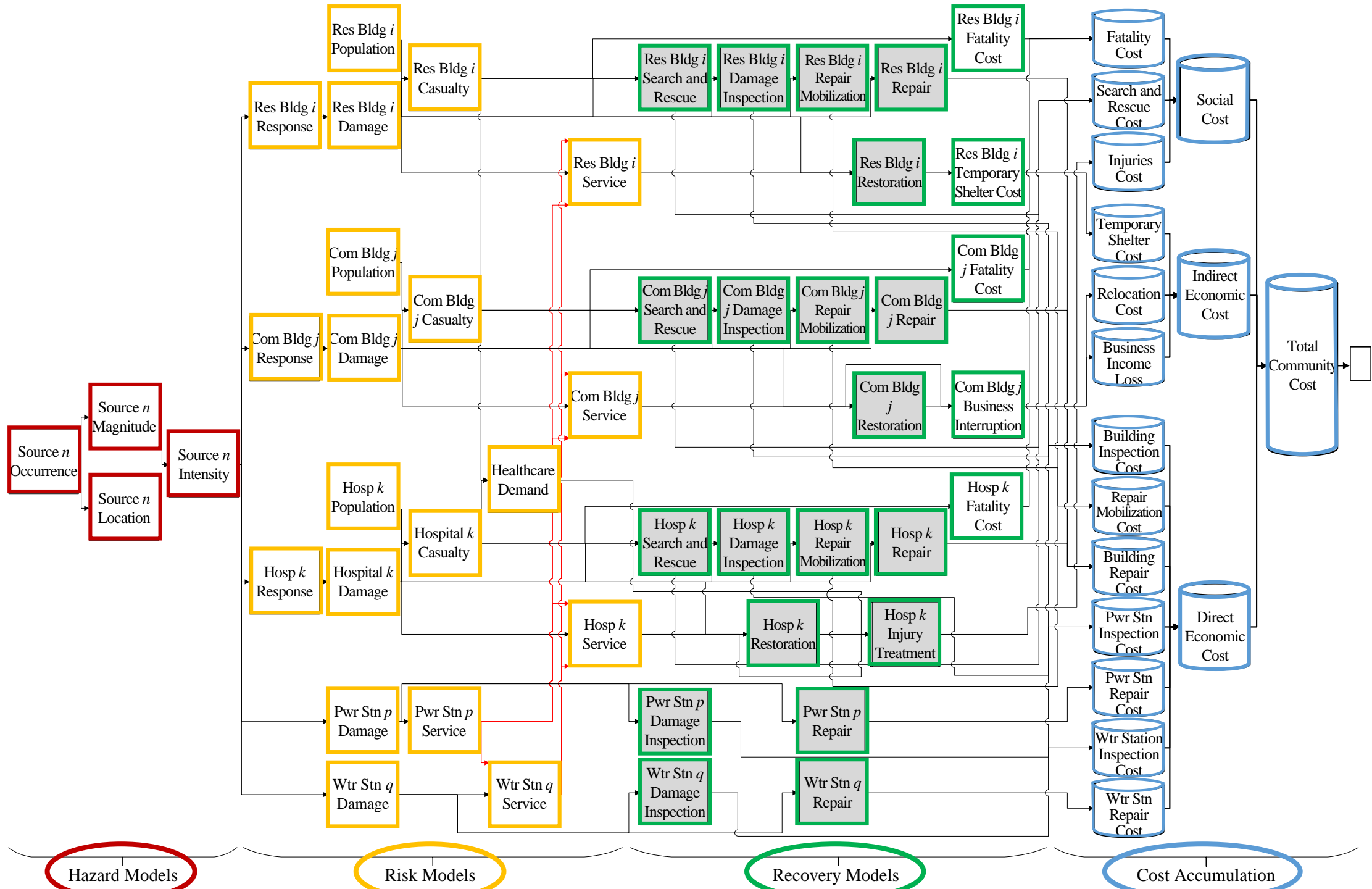


Infrastructure



Dependencies





Simulation Example

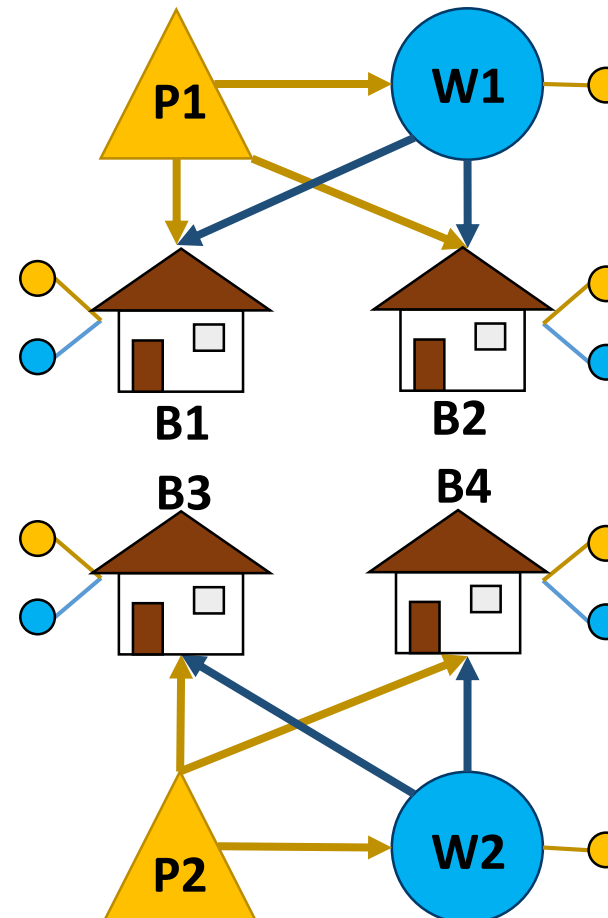
Information

Buildings: B1, B2, B3, B4
Building repair capacity: 2

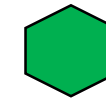
Water stations: W1, W2
W1 provides service for: B1, B2
W2 provides service for: B3, B4
Water station repair capacity: 1

Power stations: P1, P2
P1 provides service for: B1, B2, W1
P2 provides service for: B3, B4, W2
Power station repair capacity: 1

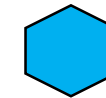
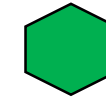
Community



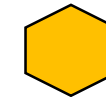
Repair Capacity



Buildings Agent



Water System Agent



Power System Agent

Risk

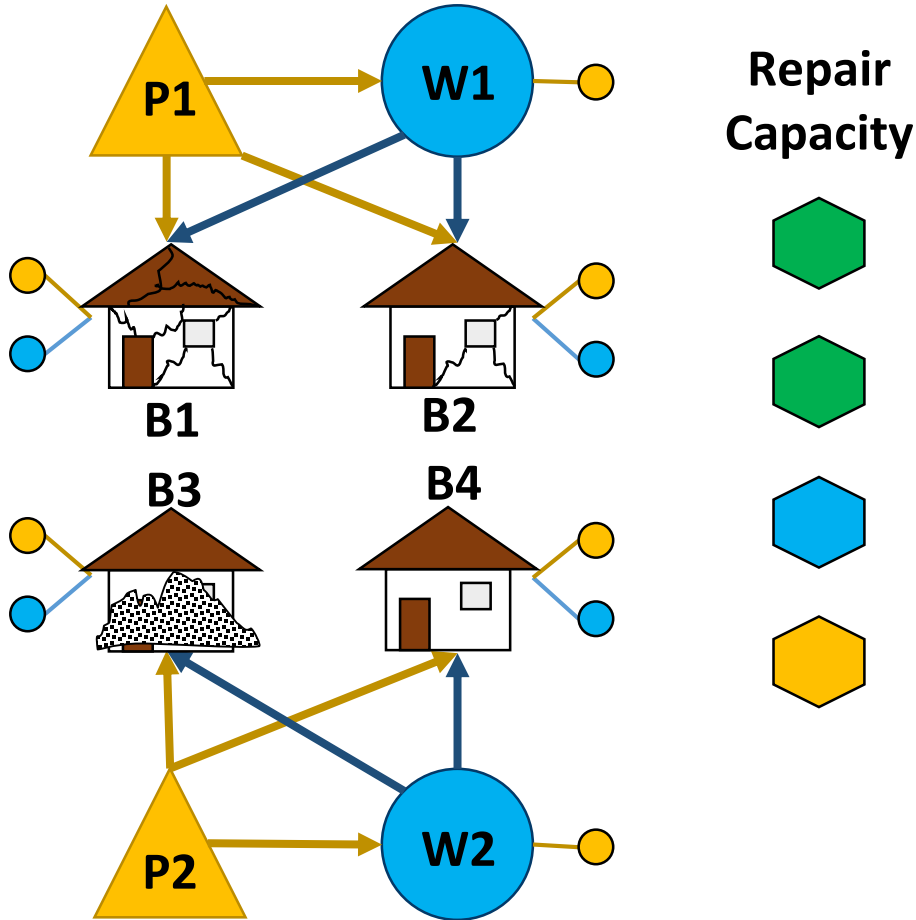
Post-hazard Status

B1: Moderate damage
B2: Slight damage
B3: Complete damage
B4: No damage

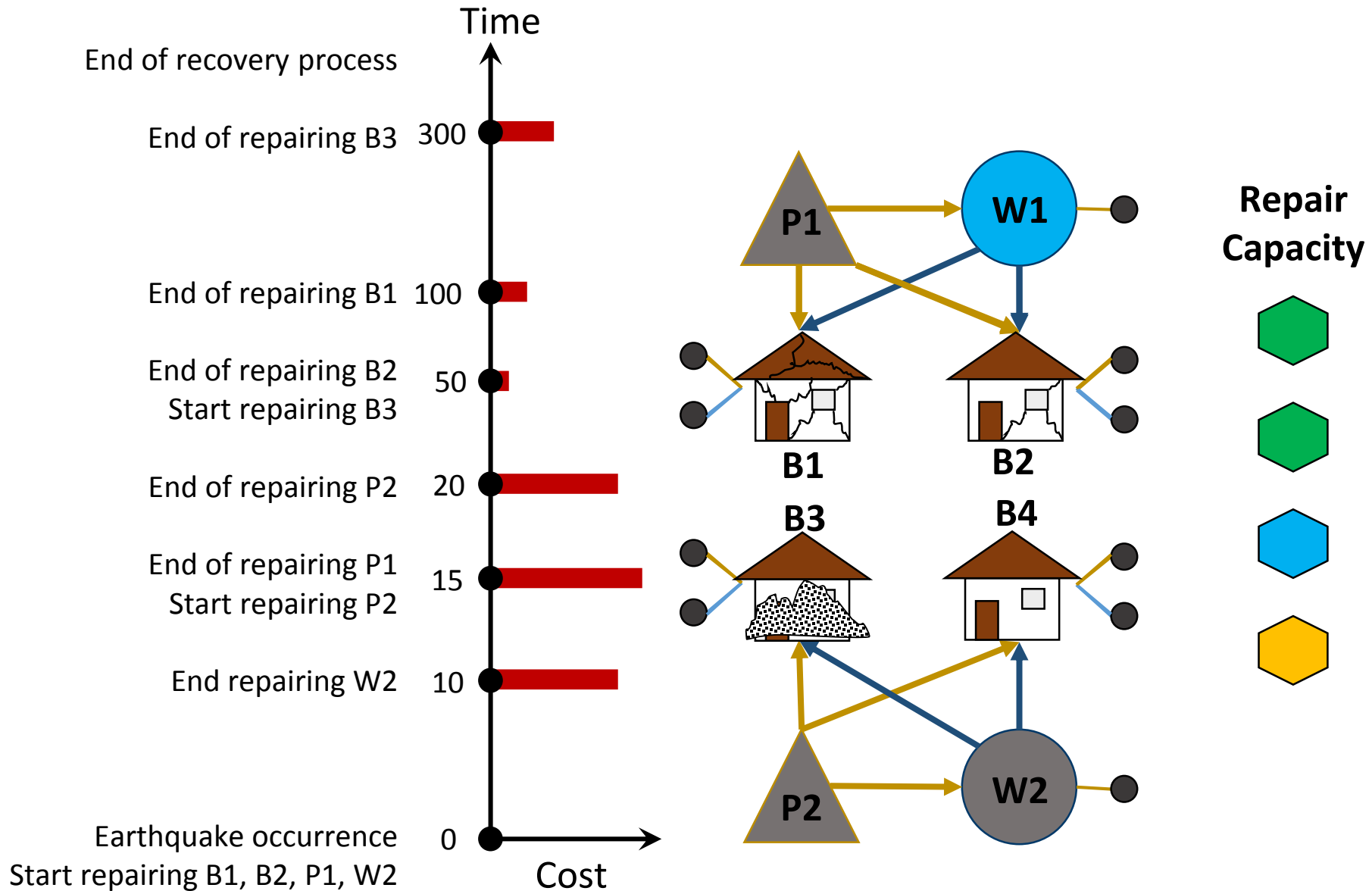
P1: Damaged
P2: Damaged

W1: Undamaged
W2: Damaged

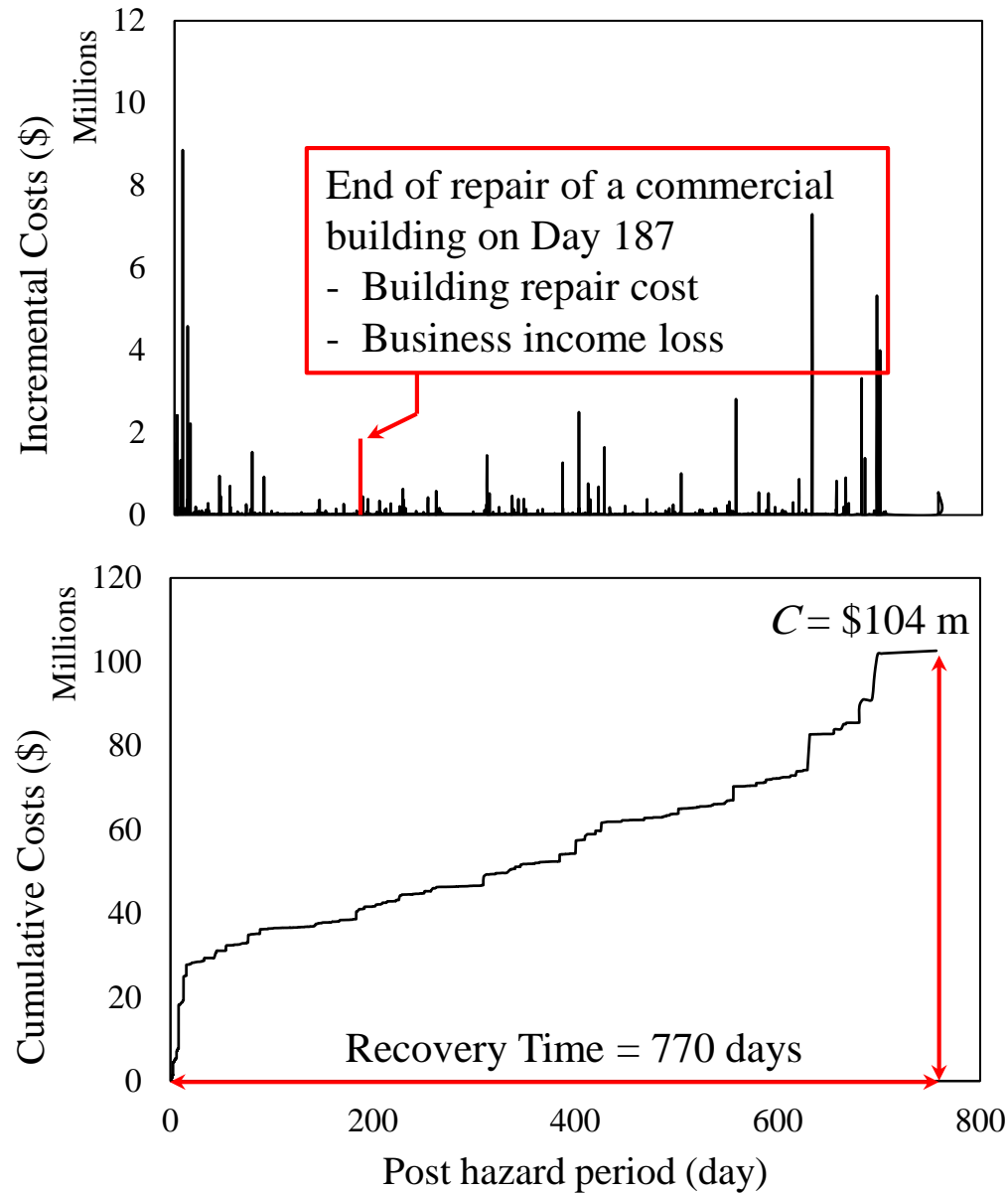
Community



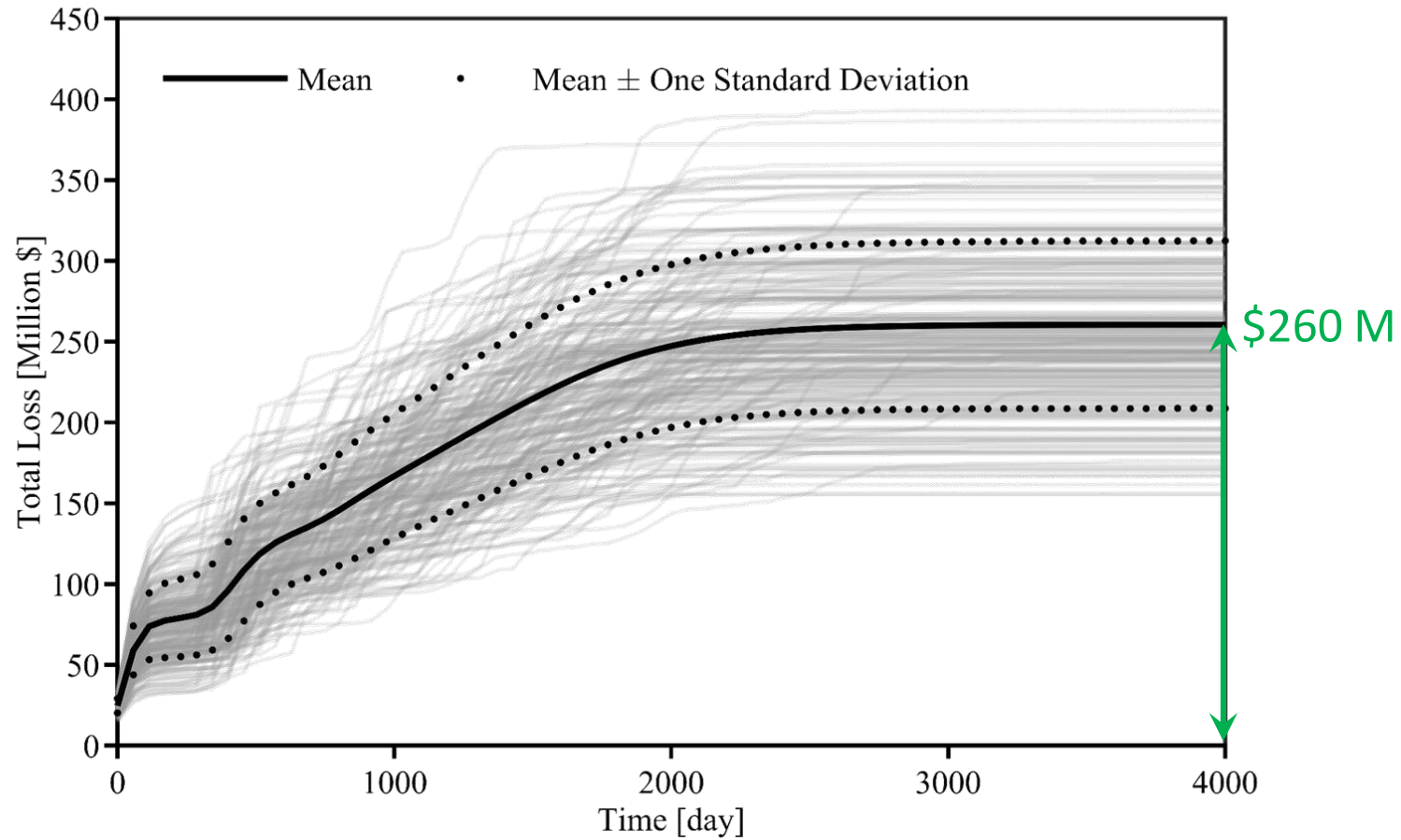
Agent-based Simulation



Simulation Output



Community Resilience Measure



$$\bar{\square} = 1 - \frac{\mu_C}{\text{GRP}} = 15\%$$

Decision Making

Decisions

Description

Decision A: Retrofit Power Station P2

Decision B: Retrofit Water Station W2

Cost of Implementation

Decision A: $C_A = \$0.5 \text{ m}$

Decision B: $C_B = \$0.1 \text{ m}$

Benefit of Implementation

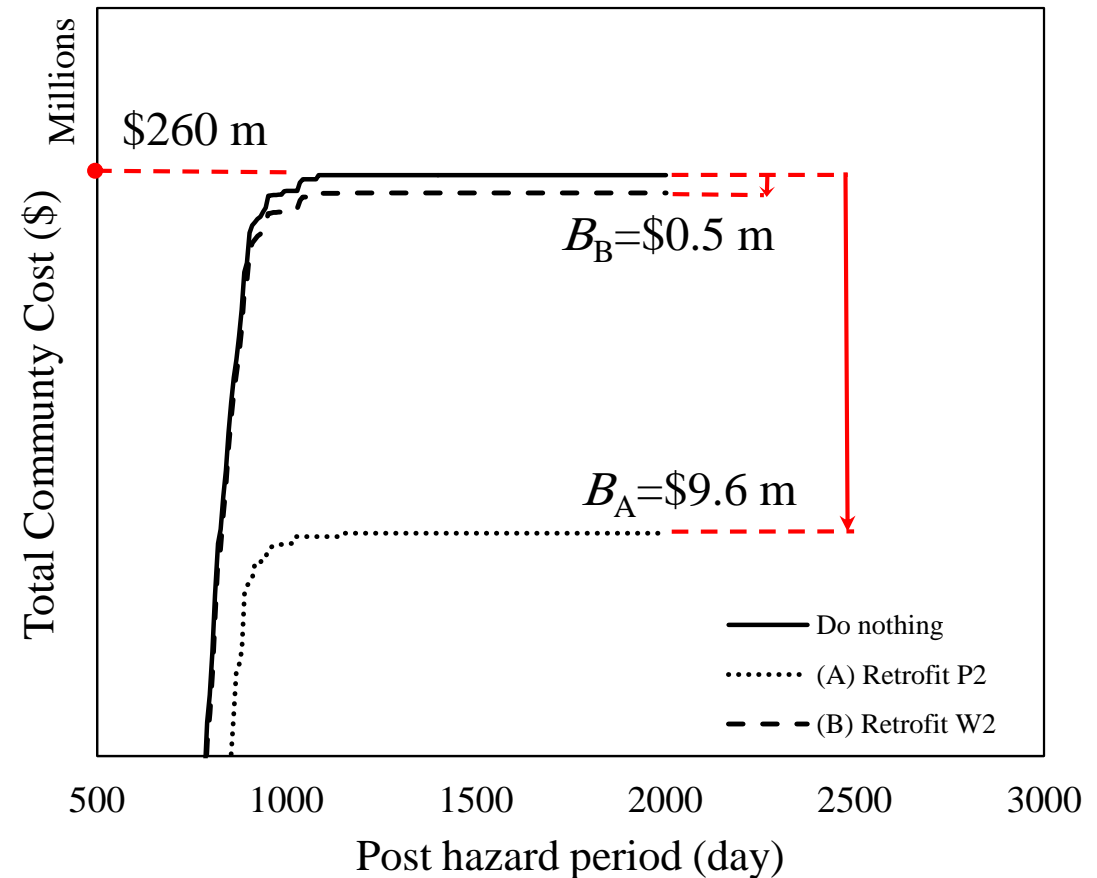
Decision A: $B_A = \$9.6 \text{ m}$

Decision B: $B_B = \$0.5 \text{ m}$

Evaluation Criterion: B/C

Decision A: $B_A/C_A = 19.2$

Decision B: $B_B/C_B = 5.0$





Rtx
File Edit View Analysis Window Help
Clear All Open Save Recent Files Delete Output View Map Toggle Panes Toggle Toolbars Select As Default Zoom In Run Analysis Run Parametric Analysis Variable Inference Model Inference Set Number of Threads Tile Windows Help

Models
Parameter
Random Variable
Decision Variable
Constant
Response
Correlation
Location
Time
Function
TotalLoss
Model
Occurrence
Poisson Pulse Process
Event
Hazard
Earthquake
Magnitude
Moment Magnitude
Bounded Exponential Magnitude
MagnitudeModel
Location
Intensity
Wind
Snow
Infrastructure
St
Building
Commercial
Power
Water
Healthcare
Consequence
Economic
Environmental
Social
External Software
Matlab
OpenSees
ANSYS
Abaqus
SAP2000
USFOS
EMME
Generic
Algebraic Expression
Random Variable With Random Parameters
Root Finding
Script

3D Display of theStExampleBuilding
Node19, Node20, Node17, Node15, Node18, Node16, Node12, Node13, Node14, Node9, Node7, Node10, Node8, Node11, Node4, Node5, Node6, Node1, Node2, Node3

TotalLoss Model Flowchart
LocationModel, MagnitudeModel, IntensityModel, Building4_DamageModel, Building5_DamageModel, Building1_DamageModel, Building6_DamageModel, Building8_DamageModel, Building3_DamageModel, Building2_DamageModel, Building7_DamageModel, Building9_DamageModel, Building4_LossModel, Building5_LossModel, Building1_LossModel, Building6_LossModel, Building8_LossModel, Building3_LossModel, Building2_LossModel, Building7_LossModel, Building9_LossModel, TotalLoss

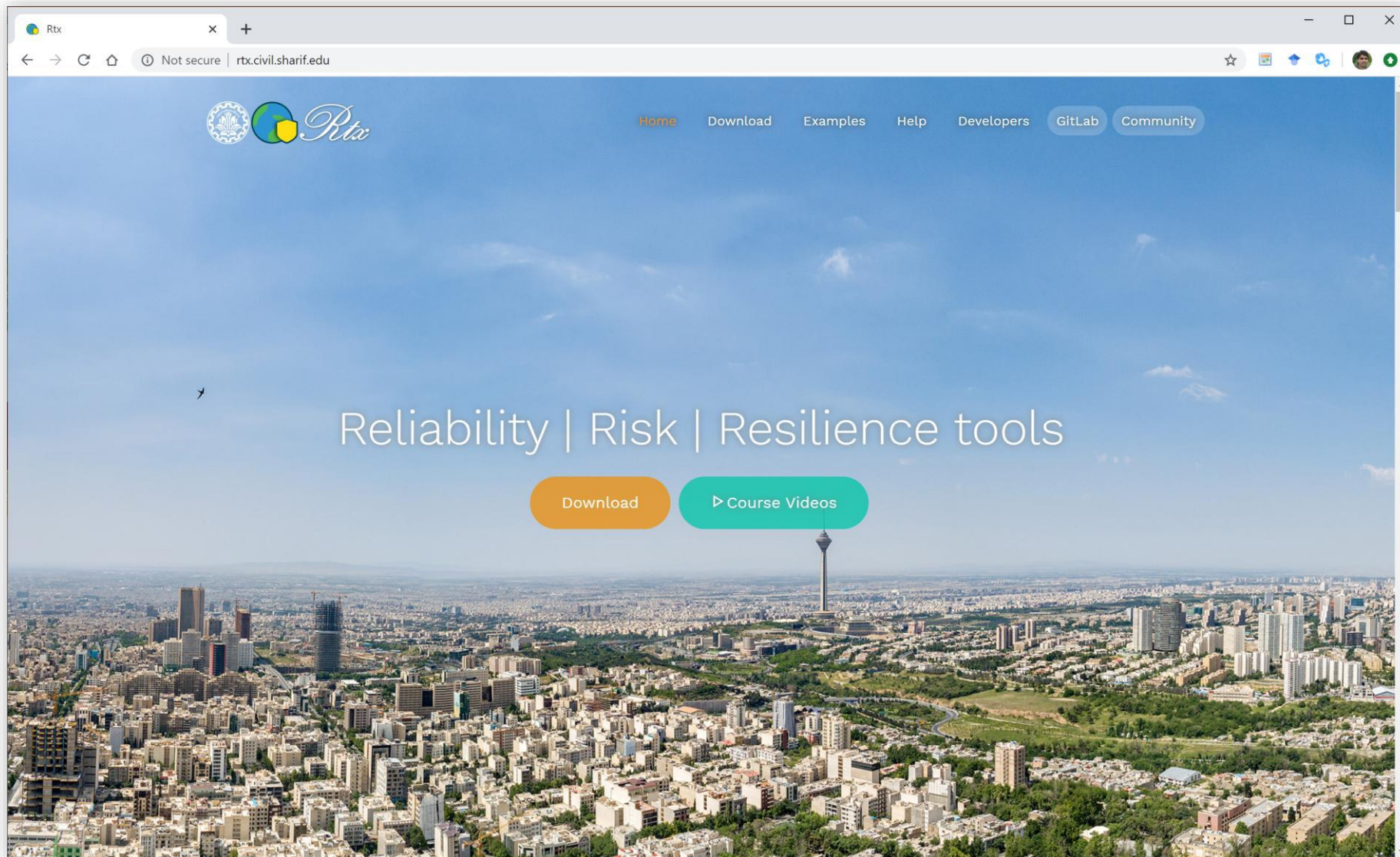
myHistogramAccumulator Plot of the Function g
PDF, CDF or CDF, Function Value

Map
Map Satellite, Tehran, Sargan, Lavasan, Saeeadabad, Khomeini, National Park, Qods, Shahrivar, Baghestan, Eslamshahr, Khavar Shahr

Properties
Property Value
1 Object Name MagnitudeModel
2 Display Output false
3 Minimum Magnitude EyvanekeyMmin
4 Maximum Magnitude EyvanekeyMmax
5 Beta EyvanekeyMagModelBeta
6 Theta EyvanekeyMagModelTheta

Output
1960.48
5.29511
sample 100000
Function "g" = 0.352207
current point in original space, x:
600.242
2607.83
4.73975
Histogram sampling analysis is complete.
Function "g": Mean = 0.333309 Standard Deviation = 0.159964
The total number of samples = 100000
SAMPLING ANALYSIS DONE IN 45.541 SECONDS.

Rtx Website



rtx.civil.sharif.edu

The image displays the RTX software interface, which is used for modeling and simulation. The interface is divided into several panes:

- Left Pane (Models):** A hierarchical tree view showing the model structure. It includes categories like Parameter, Function, Model, Occurrence, Event, Hazard, and Consequence. The 'MagnitudeModel' is currently selected.
- Top-Left Pane (3D Display of theStExampleBuilding):** A 3D visualization of a building structure with nodes labeled Node1 through Node20.
- Top-Right Pane (TotalLoss Model Flowchart):** A flowchart showing the relationships between different building damage models (e.g., Building1_DamageModel, Building1_LossModel) and their corresponding loss models.
- Bottom-Left Pane (my-HistogramAccumulator Plot of the Function g):** A plot showing the Probability Density Function (PDF) and Cumulative Distribution Function (CDF) of a function 'g'. The x-axis is 'Function Value' and the y-axis is 'PDF'.
- Bottom-Right Pane (Map):** A map of Tehran, Iran, showing the location of the building. The map is color-coded by district.
- Bottom-Center Pane (Properties):** A table listing the properties of the selected 'MagnitudeModel'.
- Bottom-Right Pane (Output):** A text area showing the results of a histogram sampling analysis, including the mean and standard deviation of the function 'g'.

The Properties table is as follows:

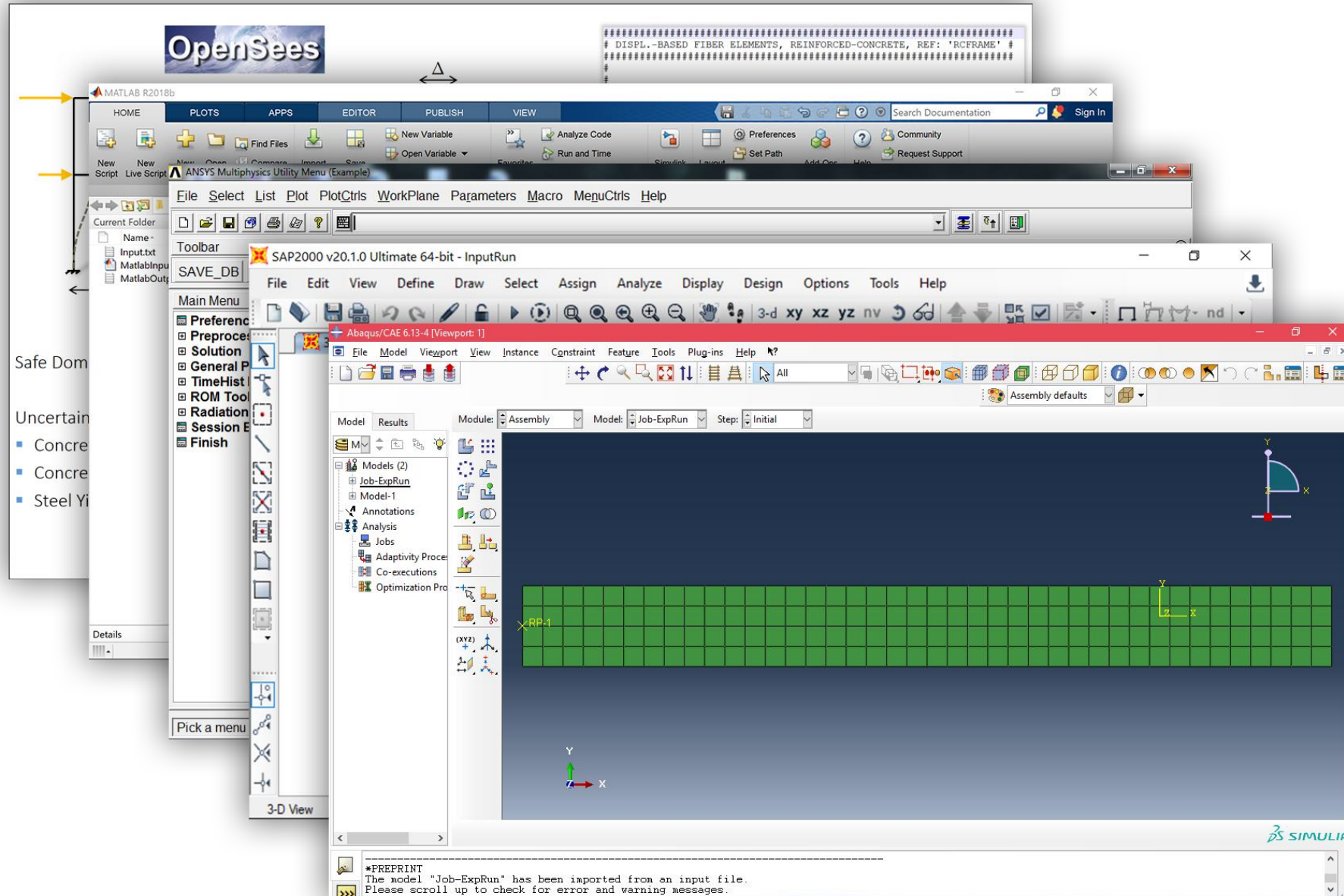
Object Name	Property	Value
1	Display Output	false
2	Minimum Magnitude	EyvanekeyMmin
3	Maximum Magnitude	EyvanekeyMmax
4	Beta	EyvanekeyMagModelBeta
5	Theta	EyvanekeyMagModelTheta

The Output pane shows the following results:

```

Sample 100000
Function "g" = 0.312249
Current point in original space, x:
  488.146
 2462.28
  4.94972
Histogram sampling analysis is complete.
Function "g" :      Mean = 0.333389      Standard Deviation = 0.159964
The total number of samples = 100000
  
```

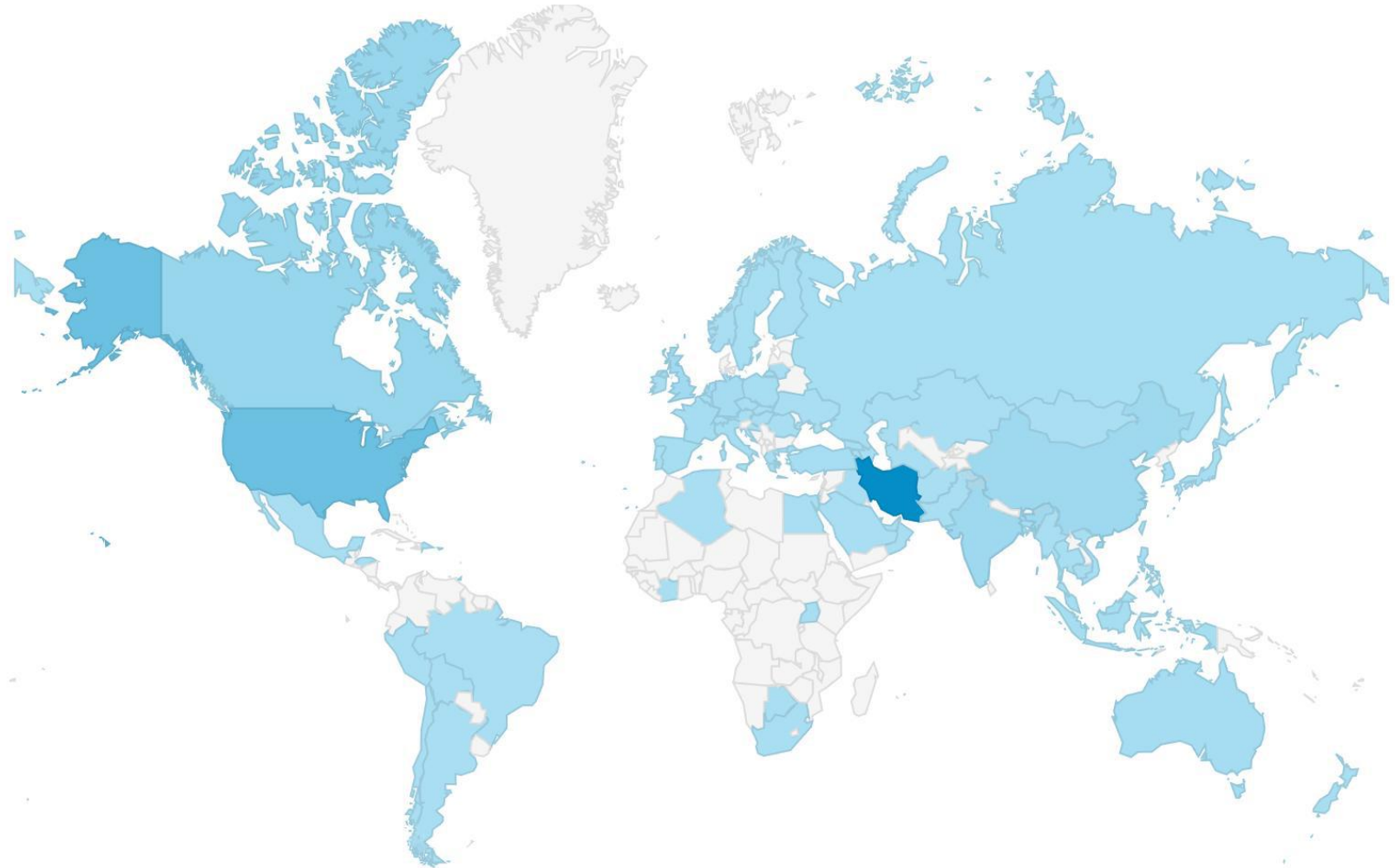
External Software



Safe Dom
Uncertain
■ Concre
■ Concre
■ Steel Y

Ptsc Users Worldwide

1.  Iran
2.  United States
3.  Canada
4.  India
5.  China
6.  United Kingdom
7.  Germany
8.  Netherlands
9.  Australia
10.  France



Analysis of Large Systems



Sharif High Performance Computing Center

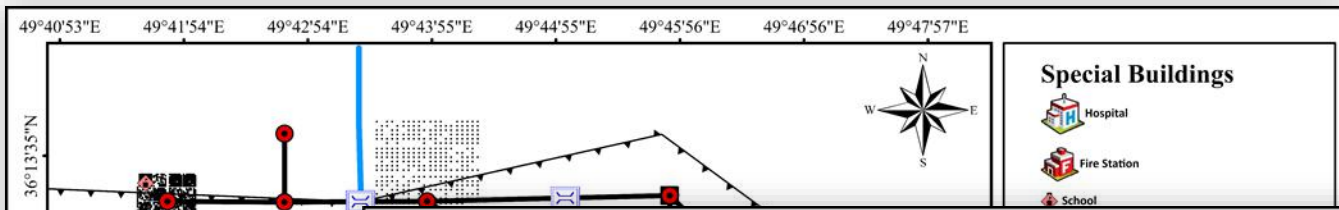
Sharif high-performance computing center provides computational power for scientific researches. This center allows scientists and engineers to solve their complex problems with the supported computational power. This center provides a cluster based on linux operating systems. All users must register to use the services provided by this center.



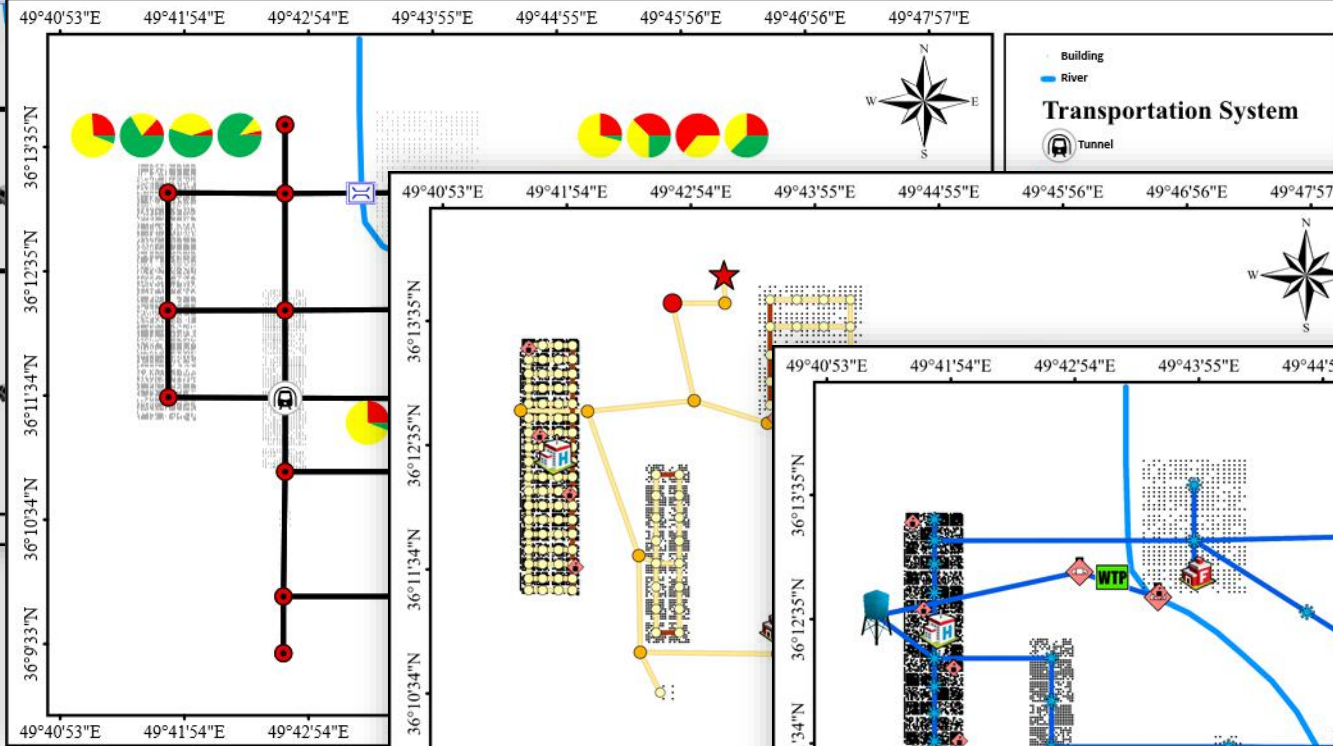
[SIGNIN AND REGISTER](#)

[SUPPORT SYSTEM](#)

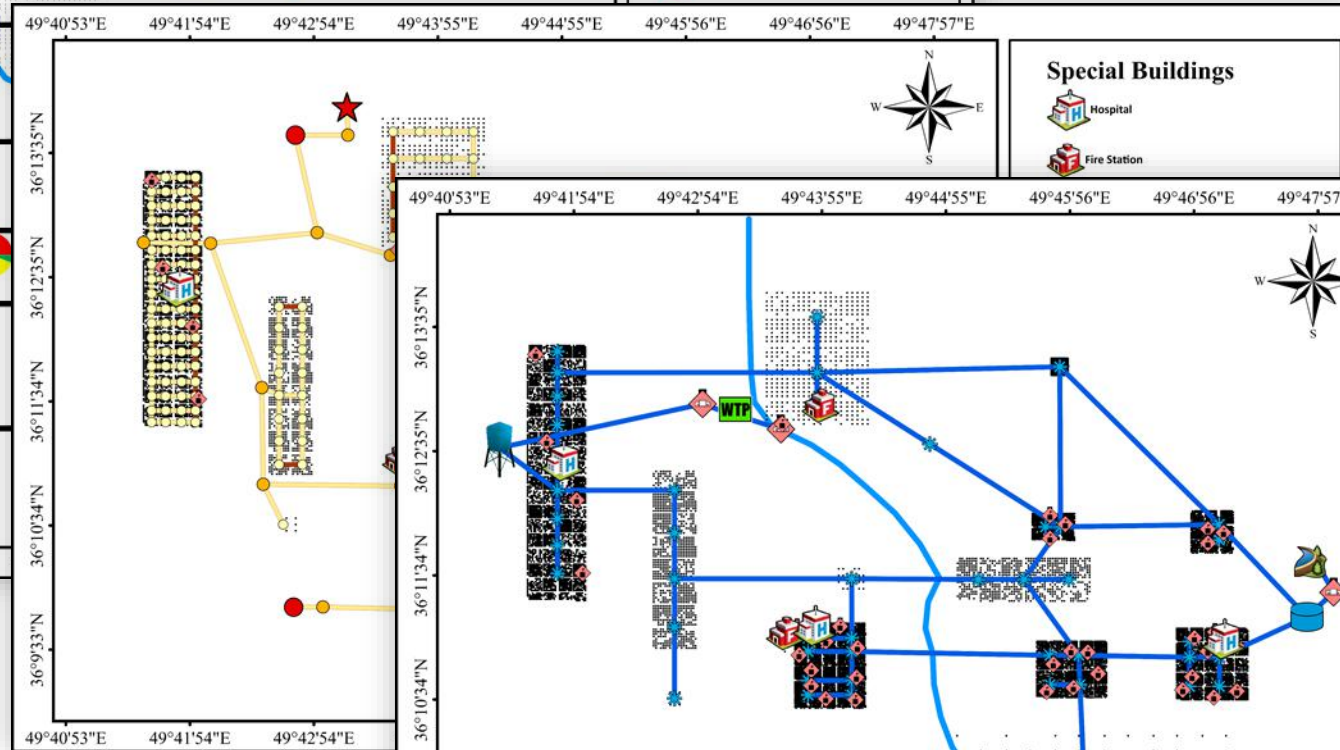
[HELPS AND DOCUMENT](#)



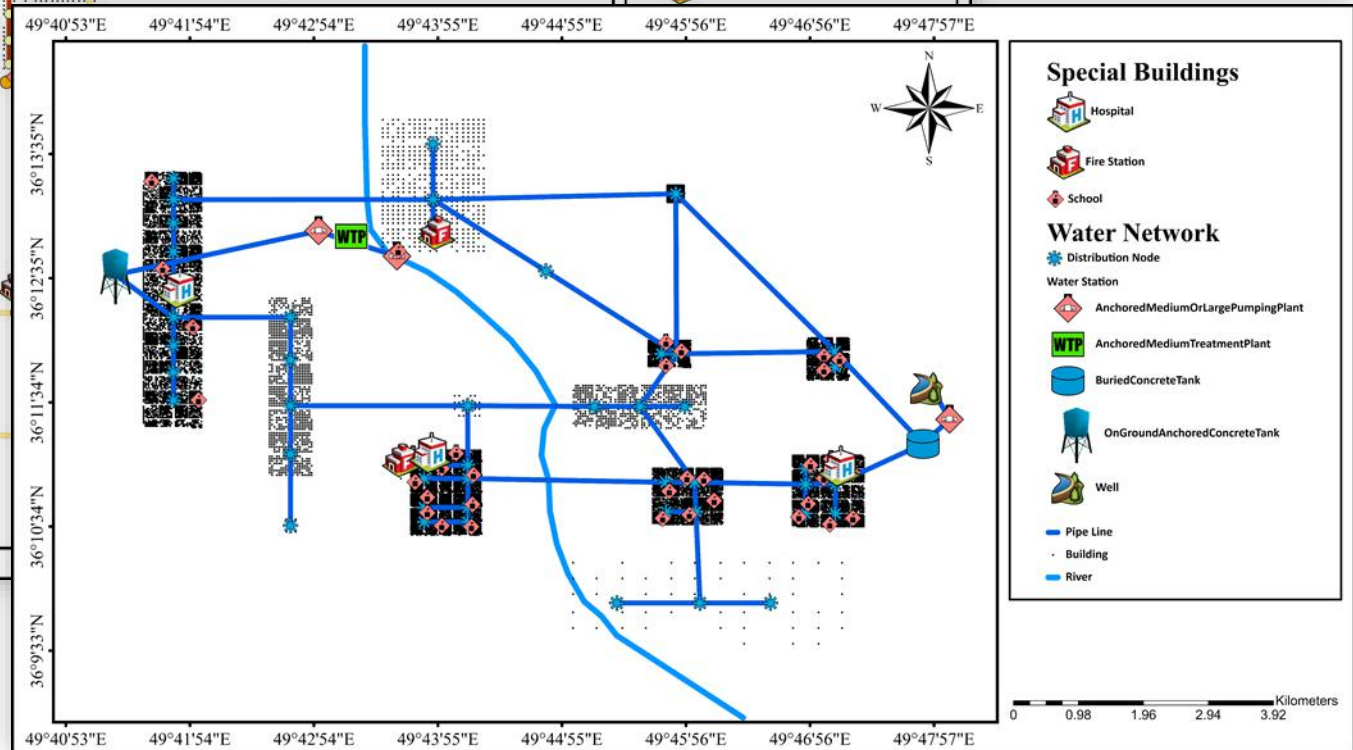
Building Stock and Transportation System



Population Demographic

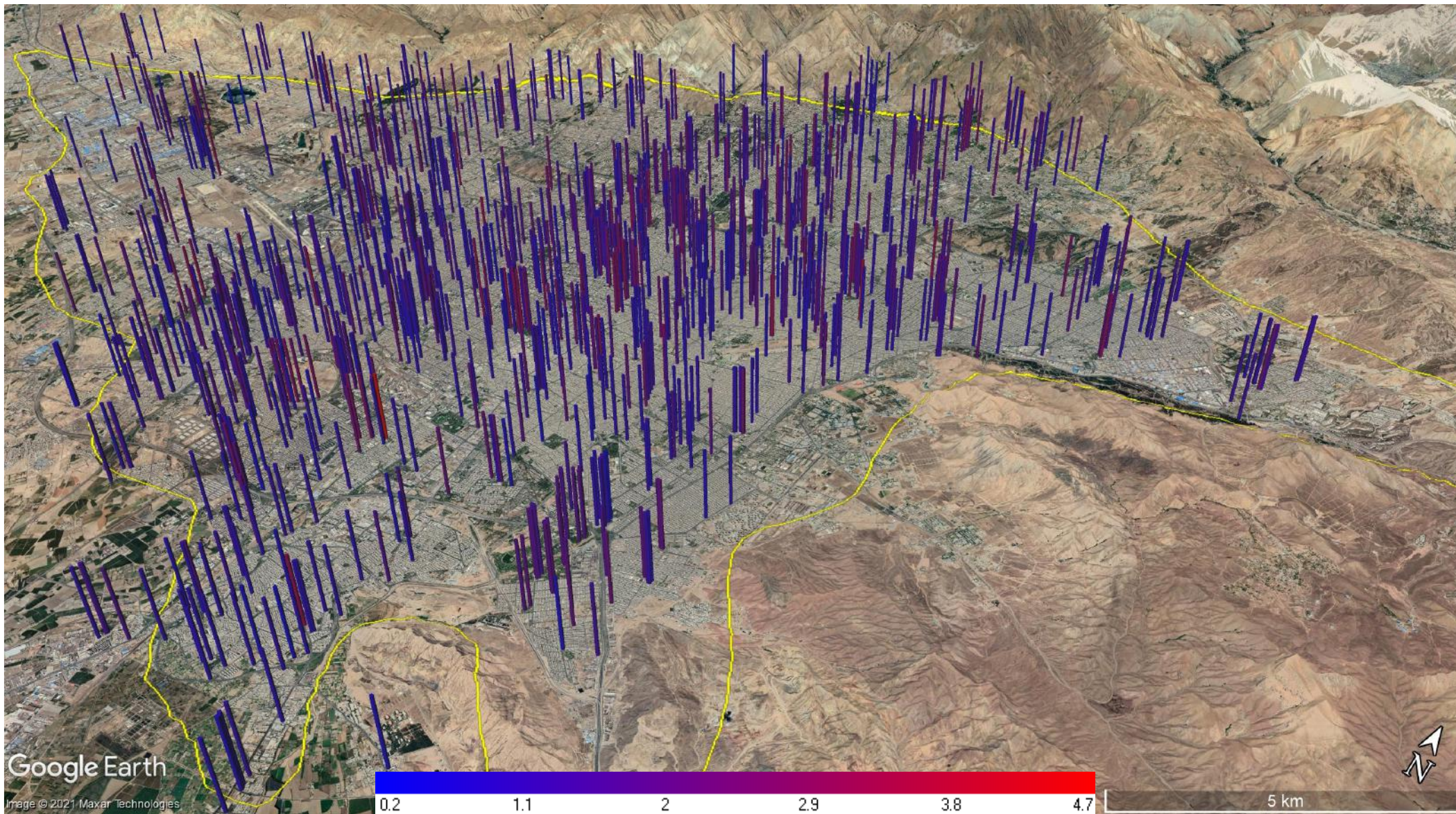


Power Network

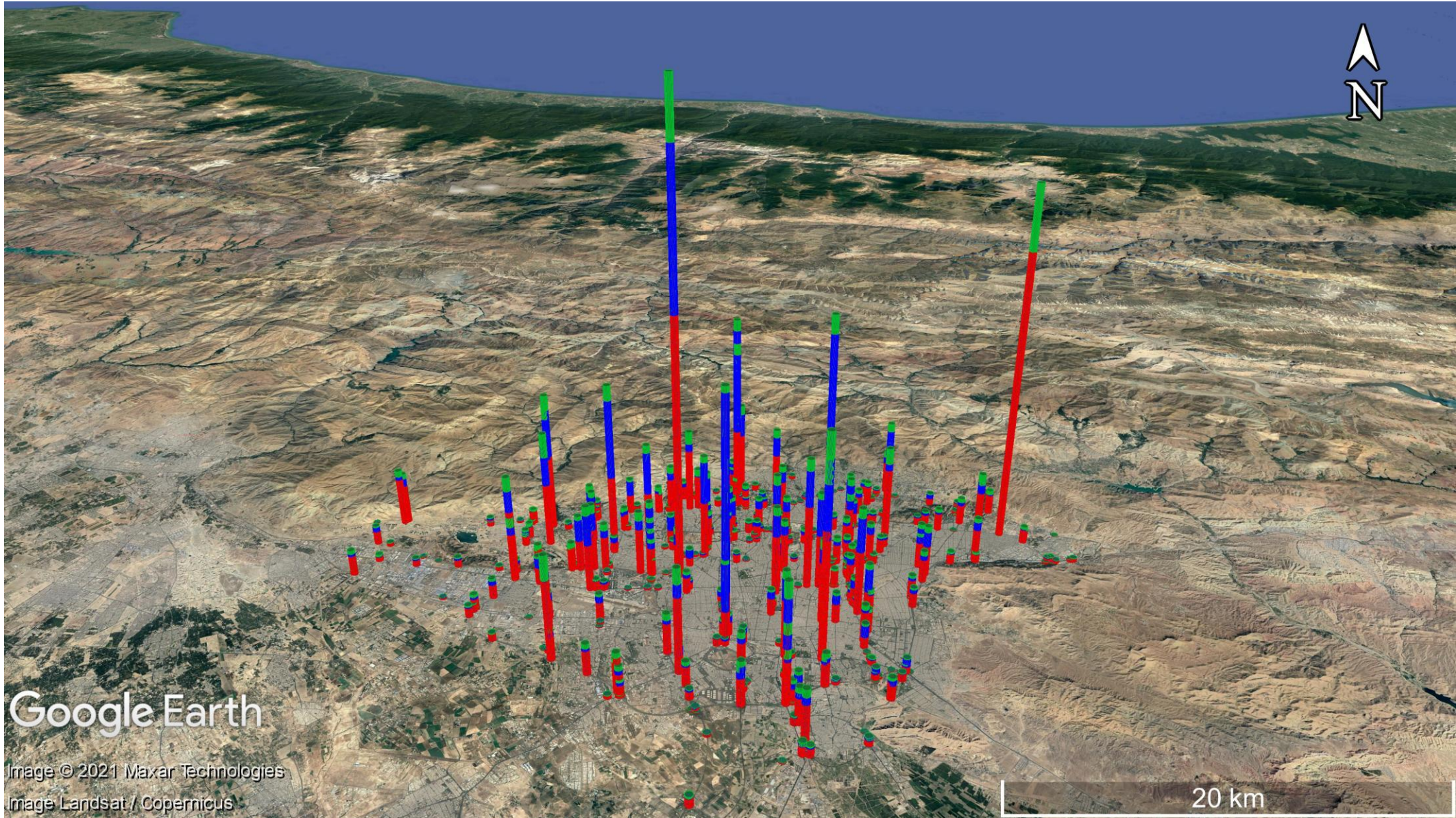


Water Network

Tehran Municipality Buildings



Tehran Bridge Network



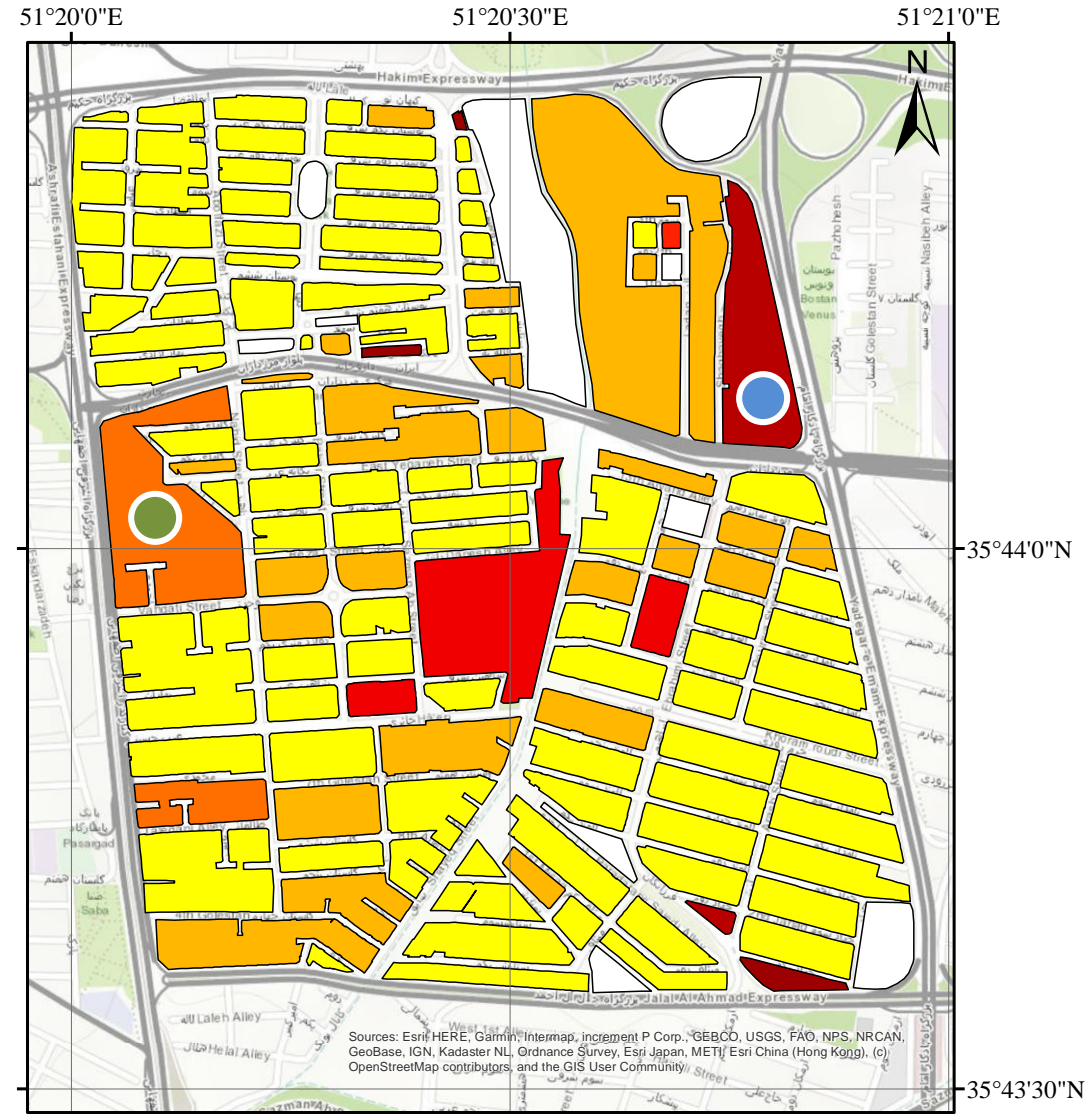
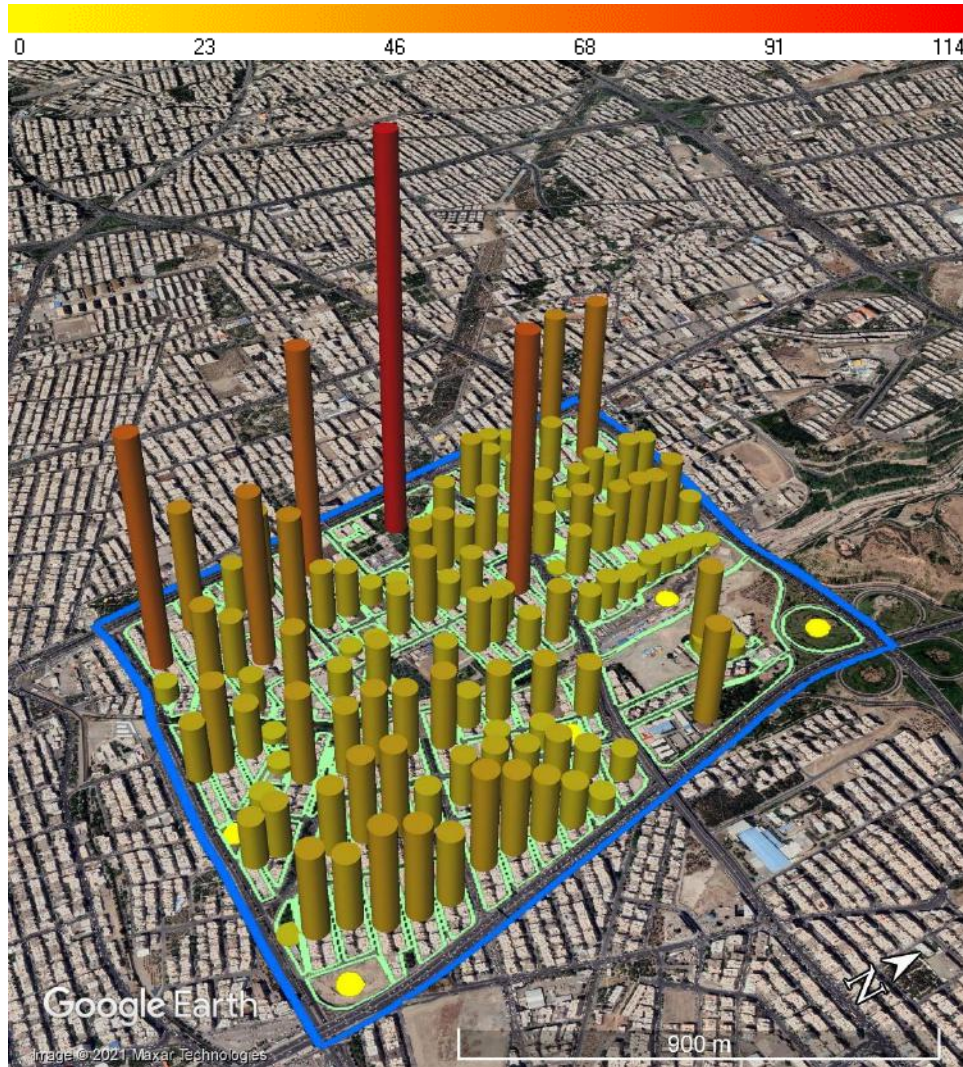
Google Earth

Image © 2021 Maxar Technologies
Image Landsat / Copernicus

20 km

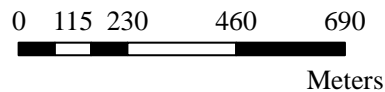
Risk Model of Tehran

50-Year Repair Cost (BT)

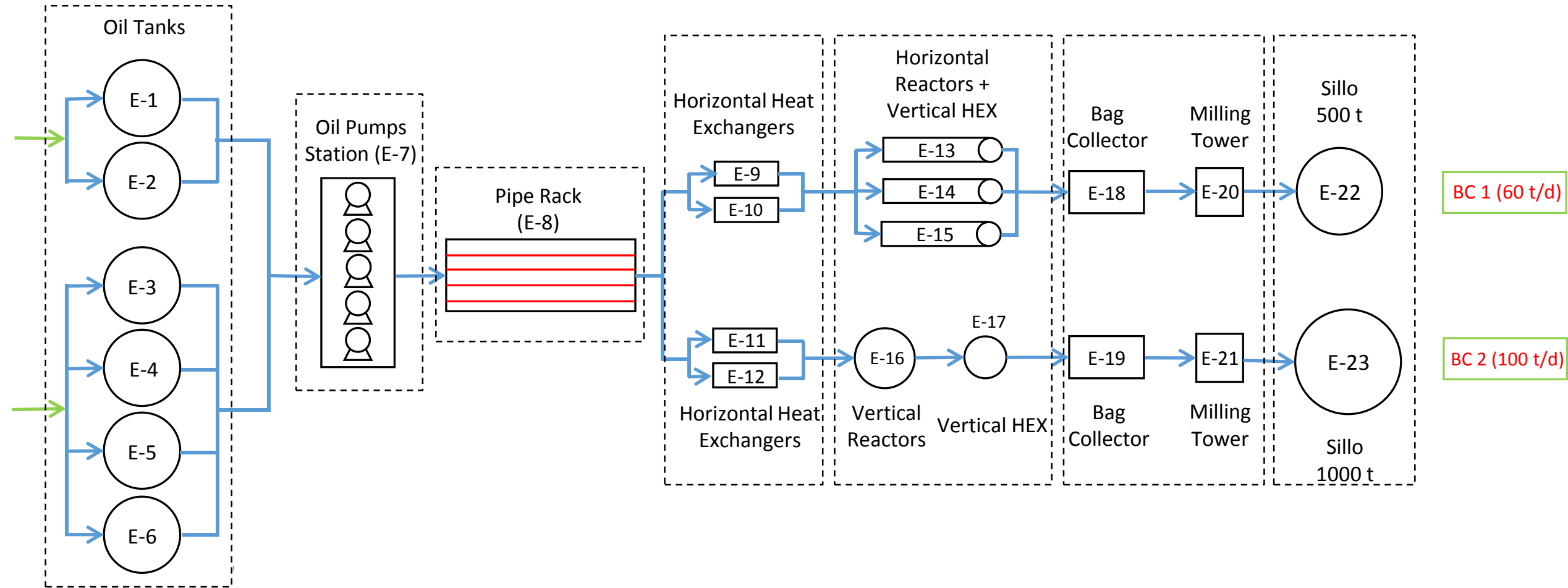


50-Year Repair Cost: Ratio (%)

0 - 8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
20 - 22
N/A



Oil Infrastructure



Further Information



ASCE

Probabilistic Framework for Evaluating Community Resilience: Integration of Risk Models and Agent-Based Simulation

Hossein Nasrazadani, S.M.ASCE¹ and Mojtaba Mahsuli, A.M.ASCE²

Abstract: This paper proposes a novel probabilistic framework to quantitatively evaluate the resilience of communities comprising buildings and various interdependent infrastructure systems. To this aim, the proposed framework seamlessly integrates risk models and agent-based simulation in a Monte Carlo sampling scheme. The risk module includes models that evaluate the initial posthazard state of the community by probabilistic simulation of the hazard event, the structural response and damage of buildings and infrastructure systems, and cascading consequences that arise from interdependencies. Subsequently, the agent-based module simulates the recovery of the community from those consequences in which decentralized autonomous decision-making entities called “agents” undertake recovery operations. The agents prioritize buildings and infrastructure components for recovery and schedule operations as discrete events with uncertain duration and cost. Consequently, the probability distribution of the total cost incurred by the community and the total recovery time is evaluated. A resilience measure is then proposed as a function of the total community cost, which represents demand, and the gross regional product of the community, which represents the capacity to cope with that demand. The framework is showcased by a comprehensive application to a community comprising a portfolio of residential and commercial buildings, an electric power system, a water system, and a healthcare system subject to seismic hazard. DOI: [10.1061/\(ASCE\)ST.1943-541X.0002810](https://doi.org/10.1061/(ASCE)ST.1943-541X.0002810). © 2020 American Society of Civil Engineers.

Author keywords: Community resilience; Risk analysis; Recovery analysis; Agent-based simulation; Infrastructure systems; Interdependency; Cost.





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