SCEC-ERI Summer School on Earthquake Science
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Embassy Suites, Mandalay Beach Hotel, Oxnard, CA

INTEGRATED EARTHQUAKE SIMULATION
Program Architecture and Plugged-in Components

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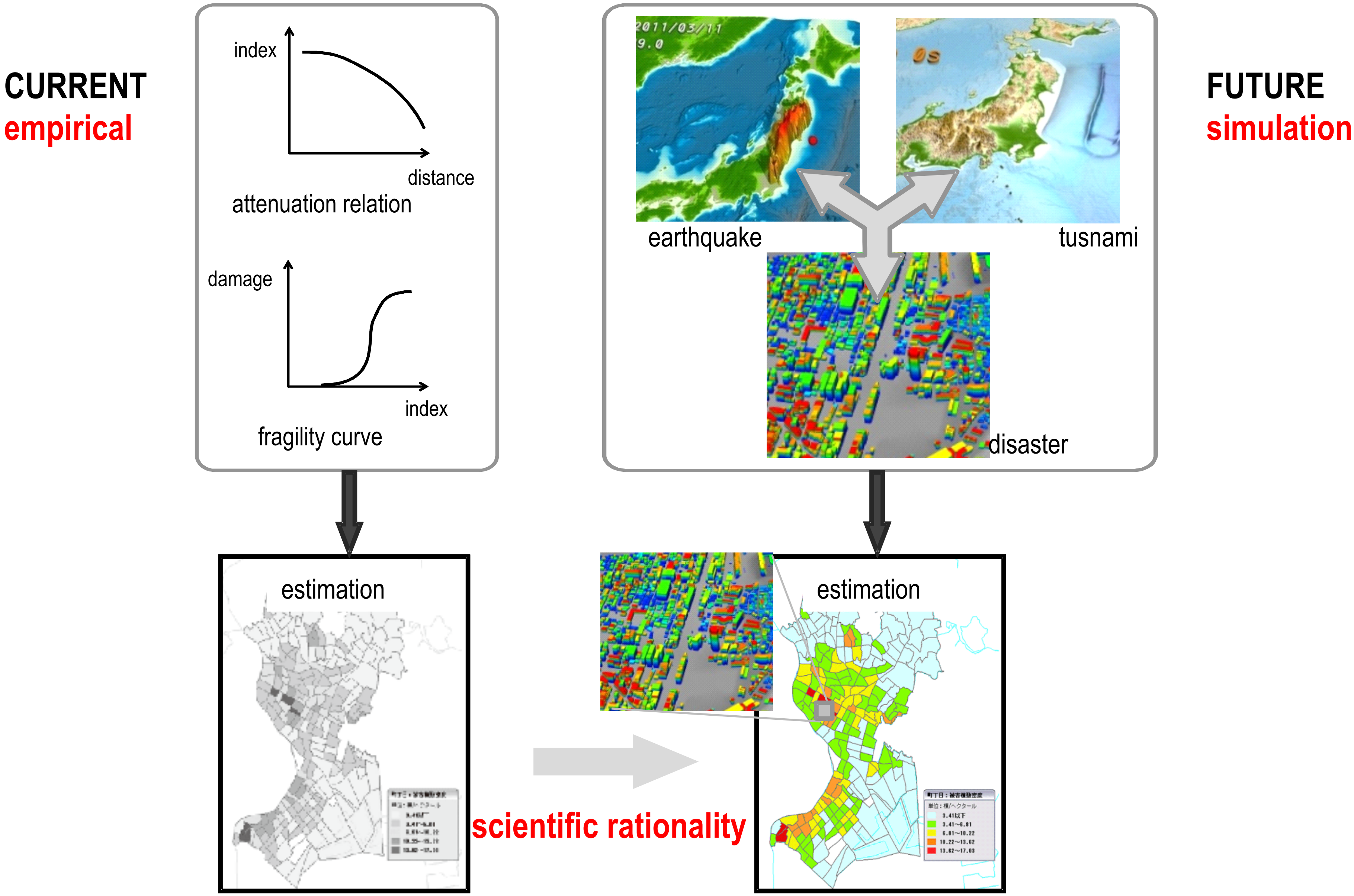
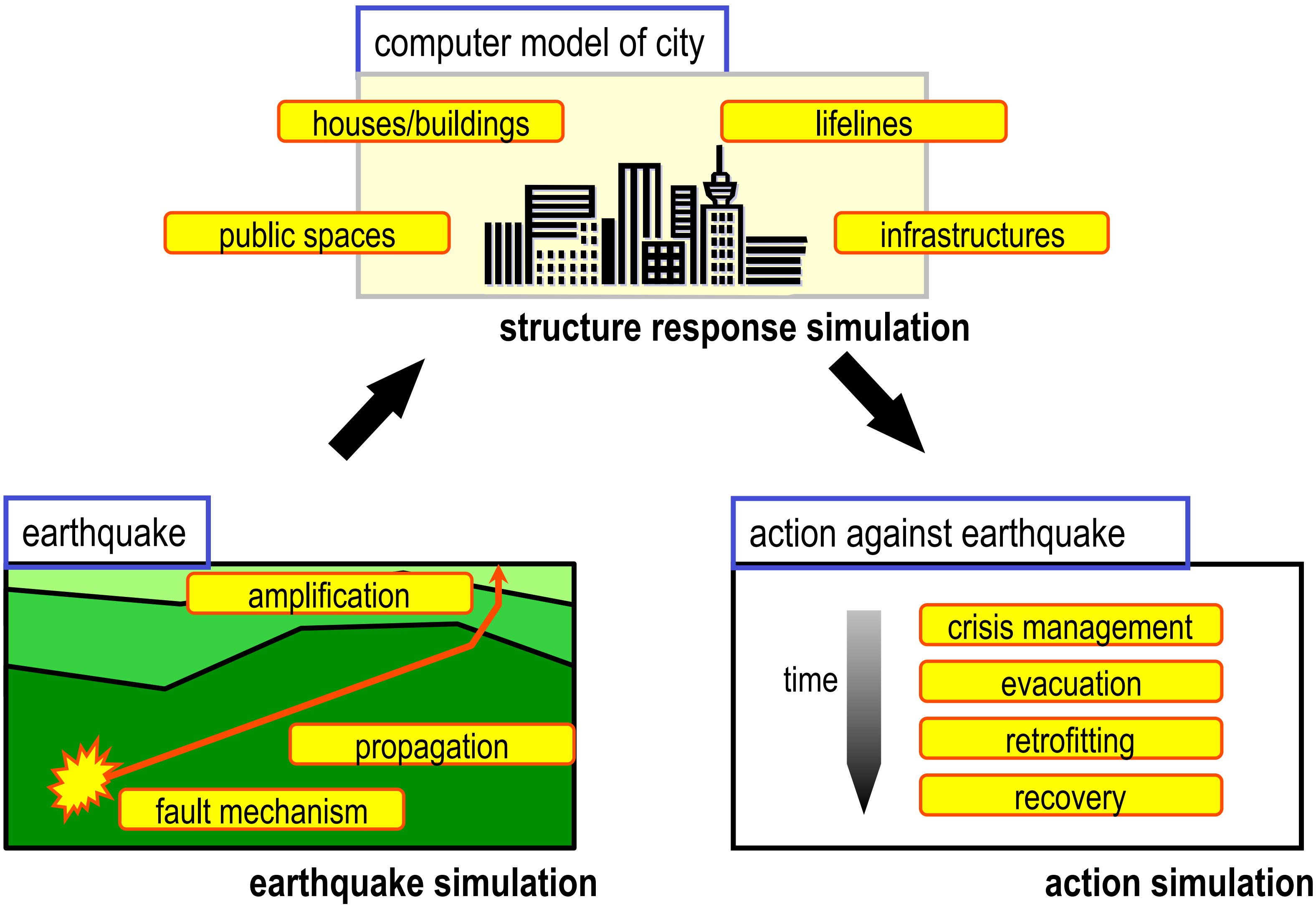
CONTENTS

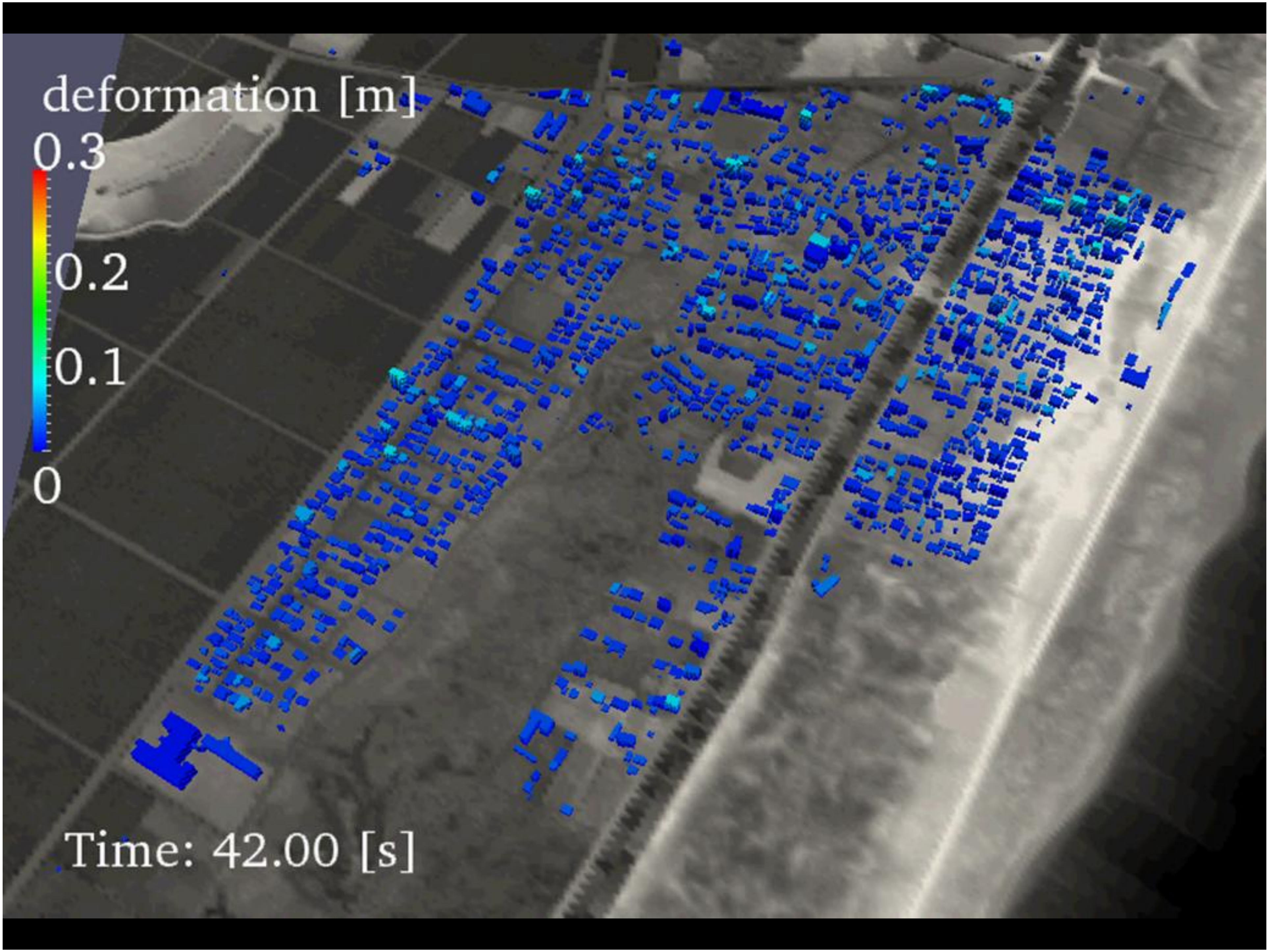
- Integrated Earthquake Simulation
  - Examples of seamless simulations
  - System computing that uses numerous components
- Plugged-in Components
  - FEM for ground motion analysis
  - SDOF for seismic structure response analysis
  - PDS for failure analysis
  - MAS for mass evacuation analysis

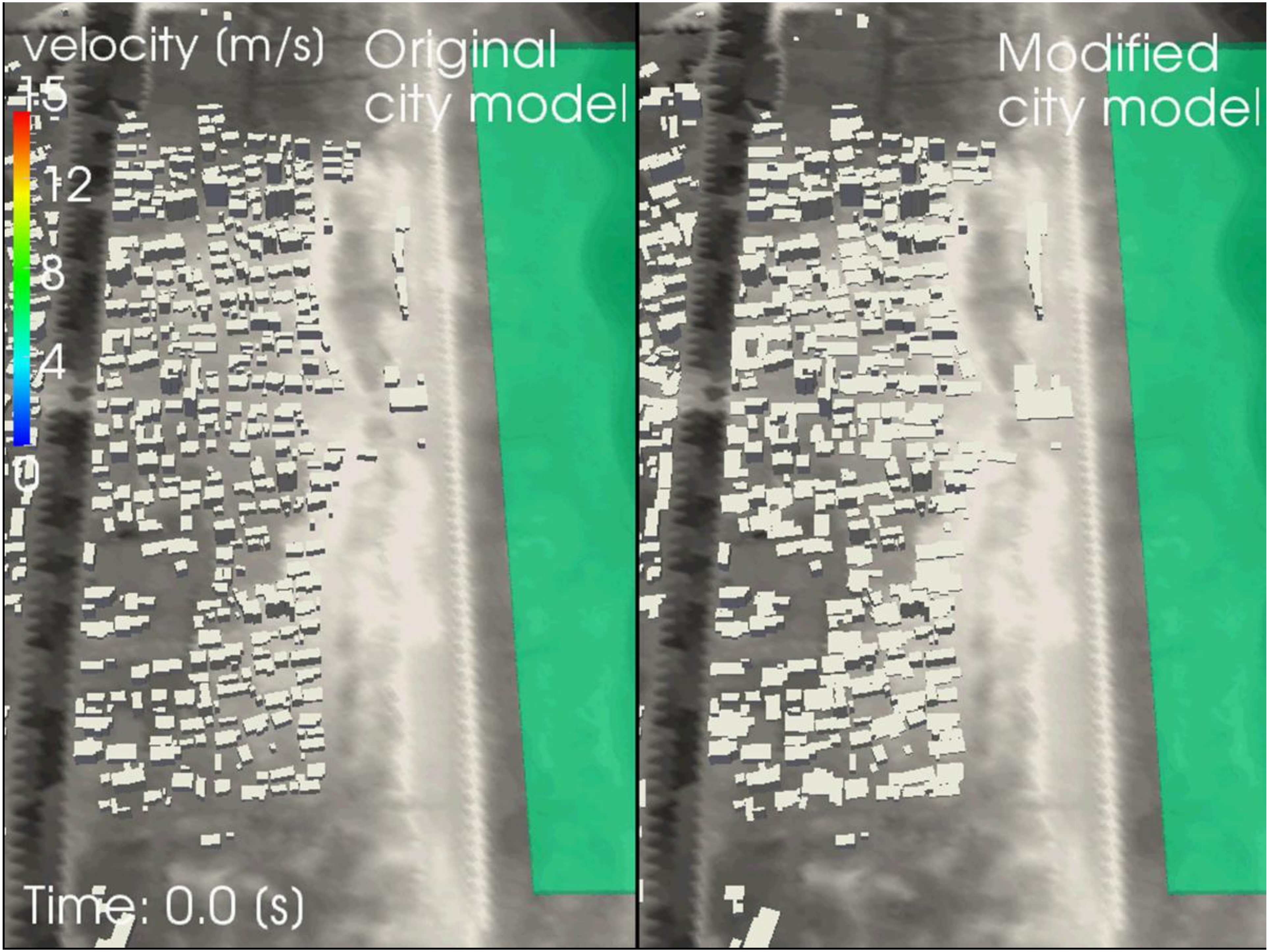
EARTHQUAKE DISASTER ASSESMENT



OVERVIEW OF IES

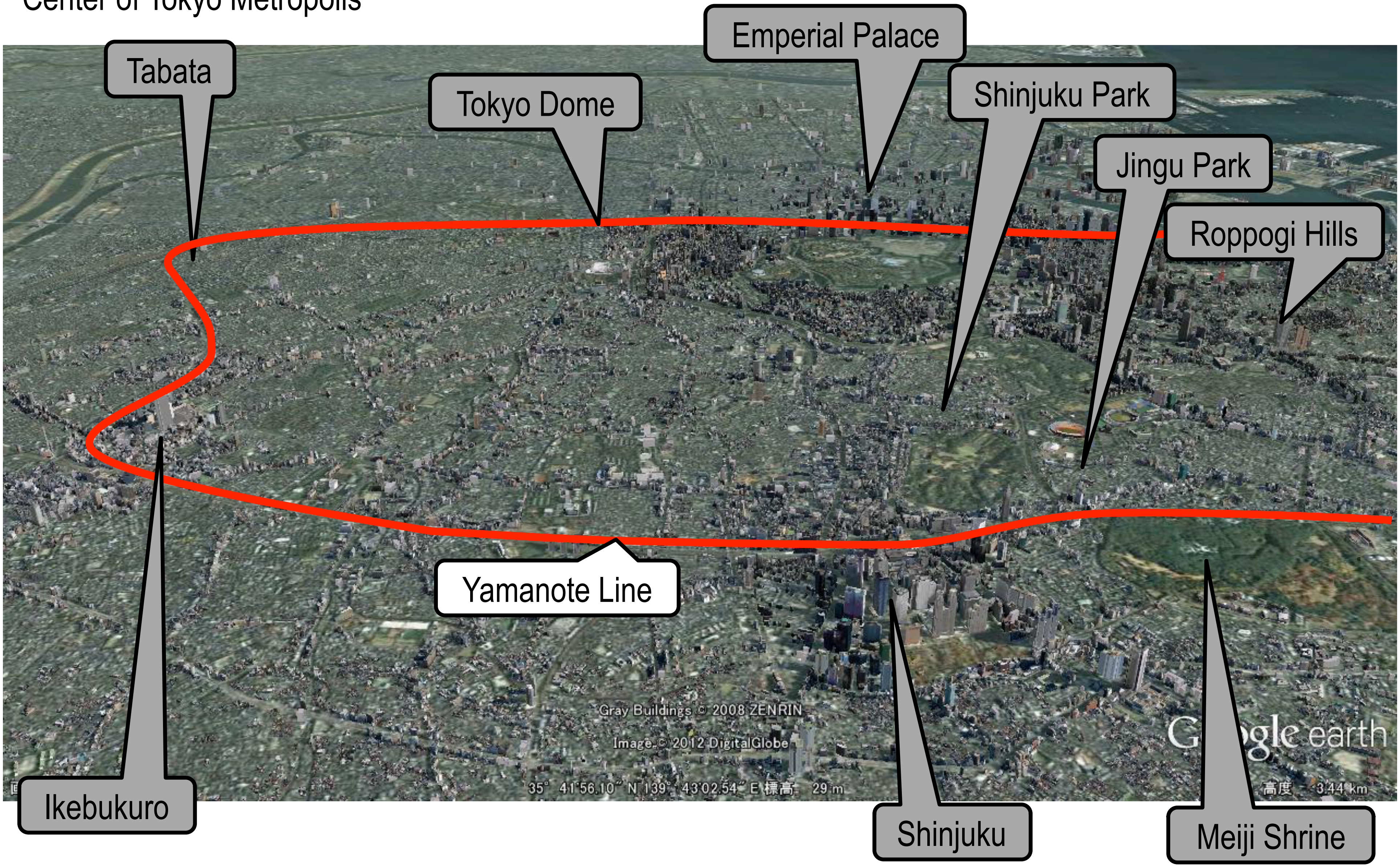


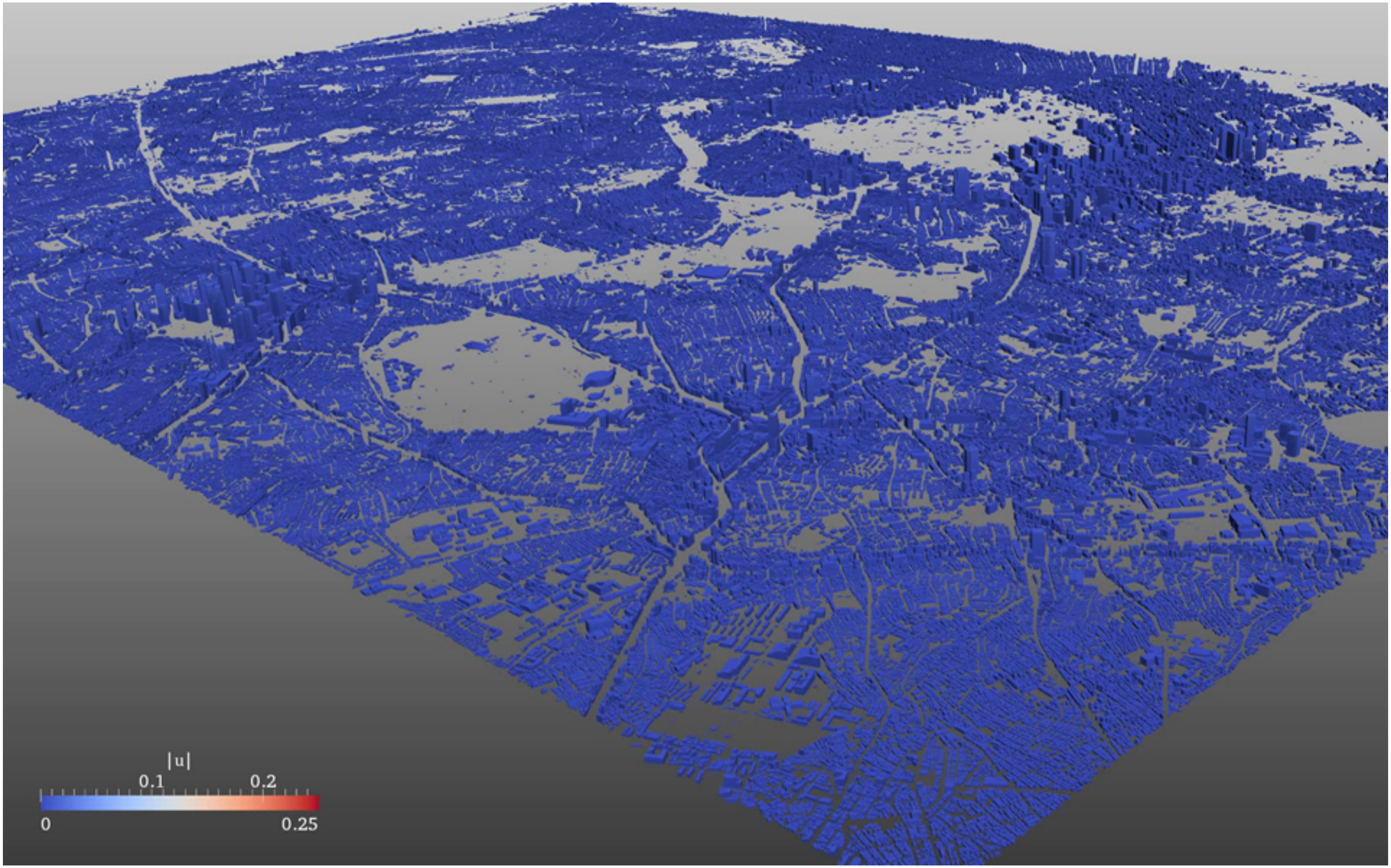

deformation [m]
0.3
0.2
0.1
0
Time: 42.00 [s]


velocity (m/s)
15
12
8
4
0
Original
city model
Modified
city model
Time: 0.0 (s)

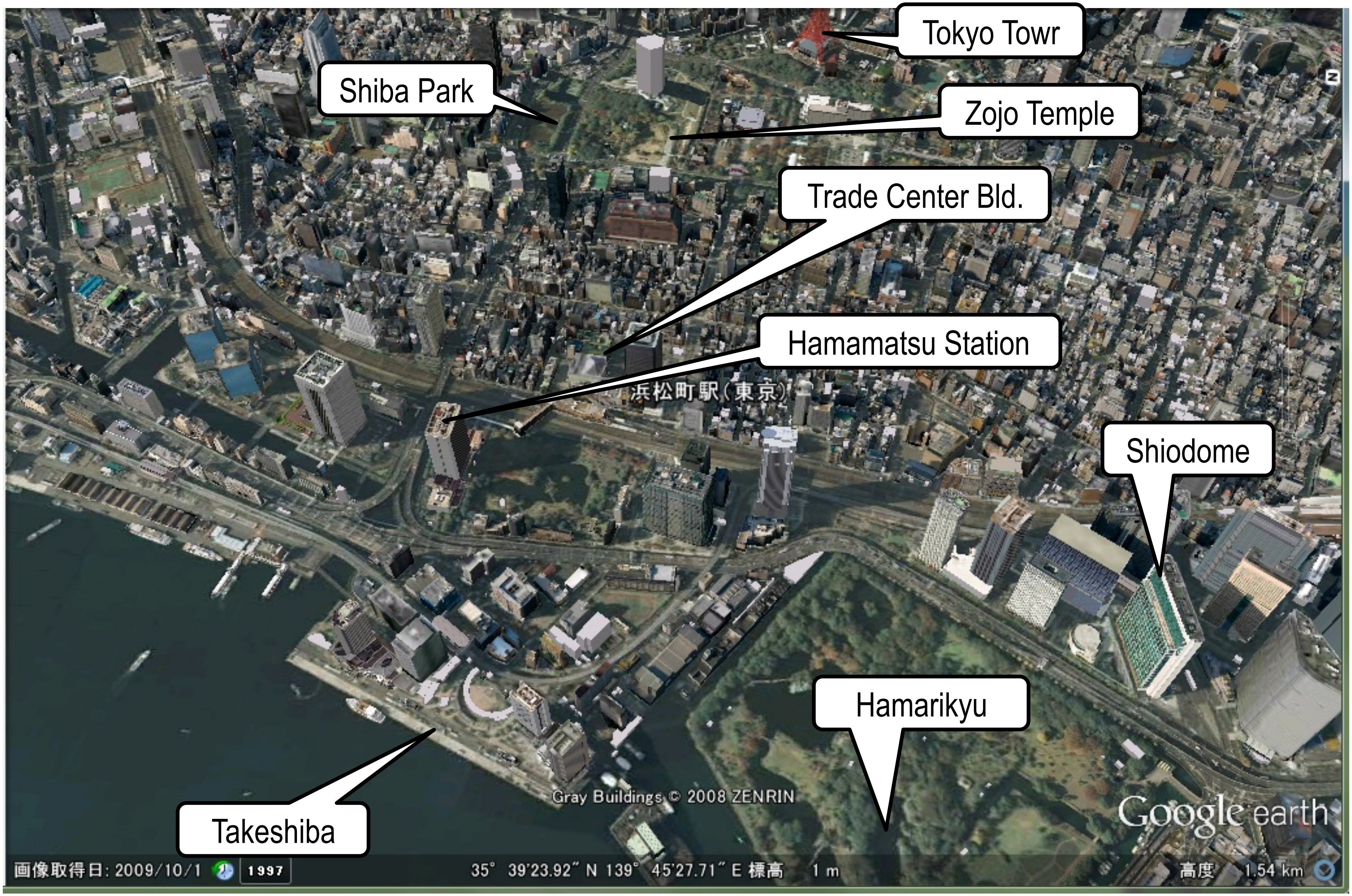
Target Area

Center of Tokyo Metropolis




|u|
0.1
0.2
0
0.25

Target Area



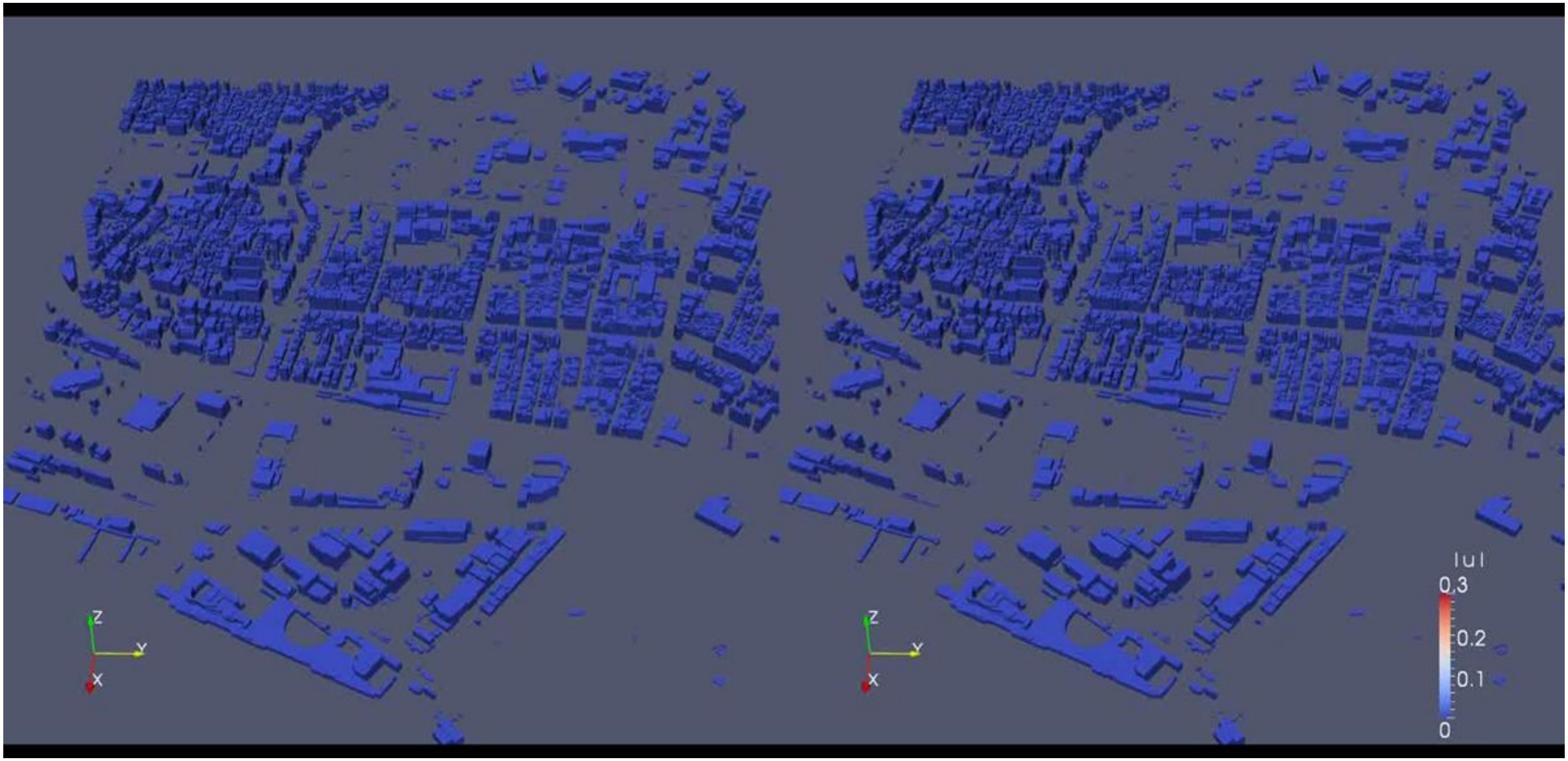
Tokyo Towr
Shiba Park
Zojo Temple
Trade Center Bld.
Hamamatsu Station
浜松町駅(東京)
Shiodome
Hamarikyu
Takeshiba
Gray Buildings © 2008 ZENRIN
Google earth
画像取得日: 2009/10/1
1997
35° 39'23.92" N 139° 45'27.71" E 標高 1 m
高度 1.54 km

Result

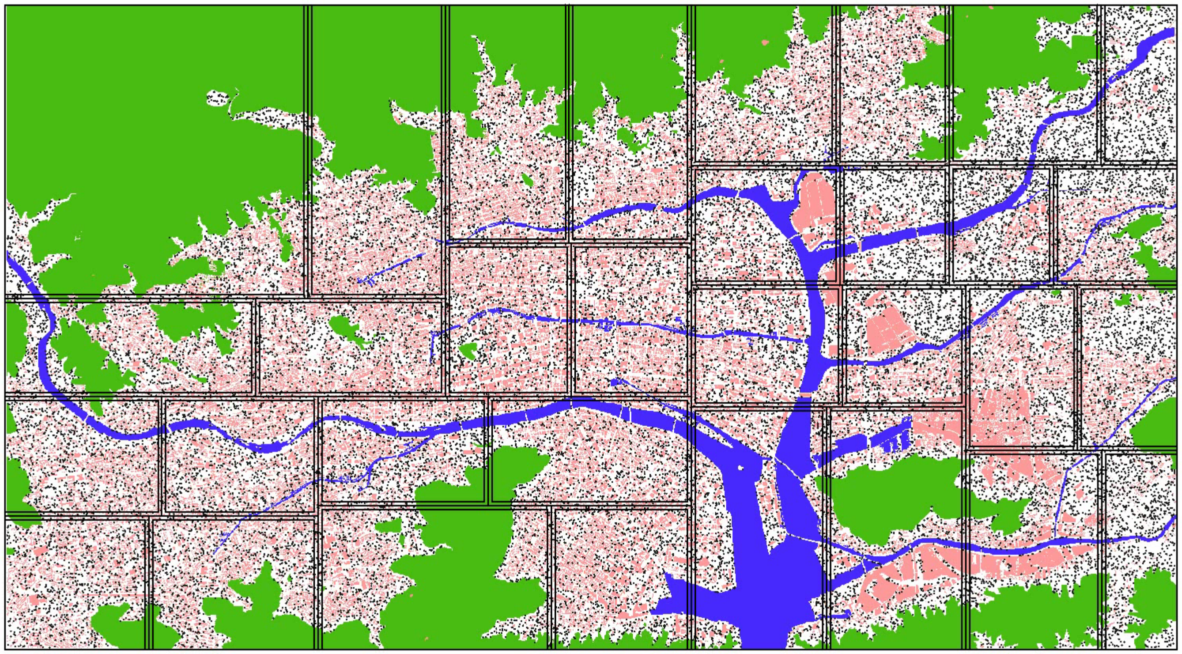
Fiber Model (high-rises are not included)

steel bar deterioration considered

steel bar deterioration not considered

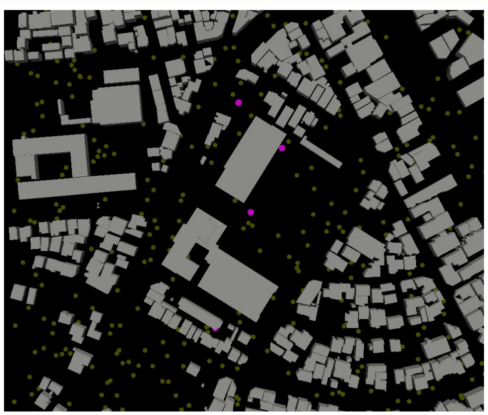


MASS EVACUATION



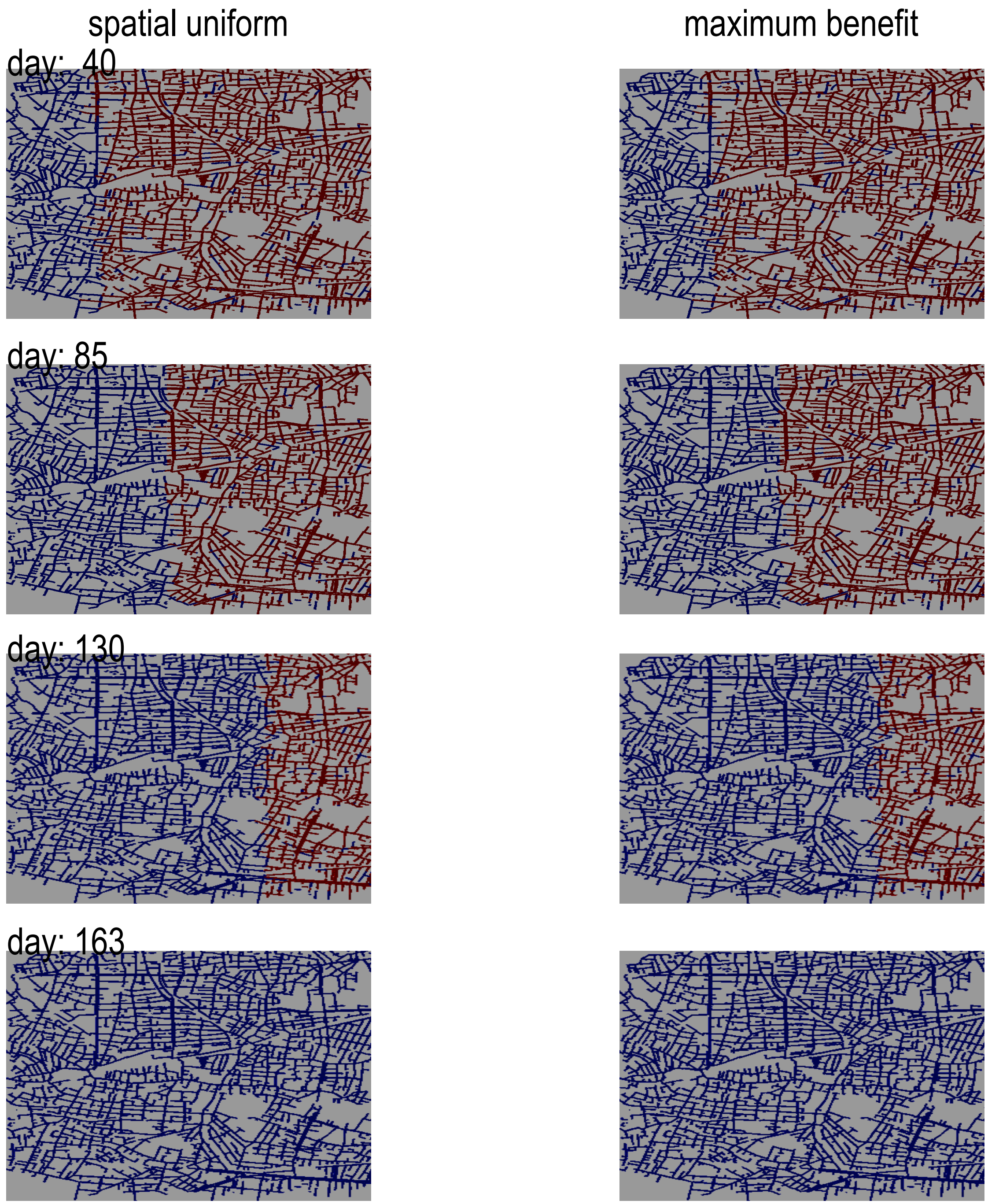
Kochi City
- large population
- road network and rivers
- visitors

Countermeasures for Tsunami
- tsunami shelter
- retrofitting infrastructures
- fast information delivery
- education



- official agent which forces evacuation
- agent which does not start evacuation
- agent which starts evacuation

Evacuation guiding/forcing
- <u>official agent</u> that finds agents which do not start evacuation and lets/makes it start evacuation
- determination of guiding/forcing official number, considering local road network and composition of resident characteristic


spatial uniform
maximum benefit
day: 40
day: 85
day: 130
day: 163

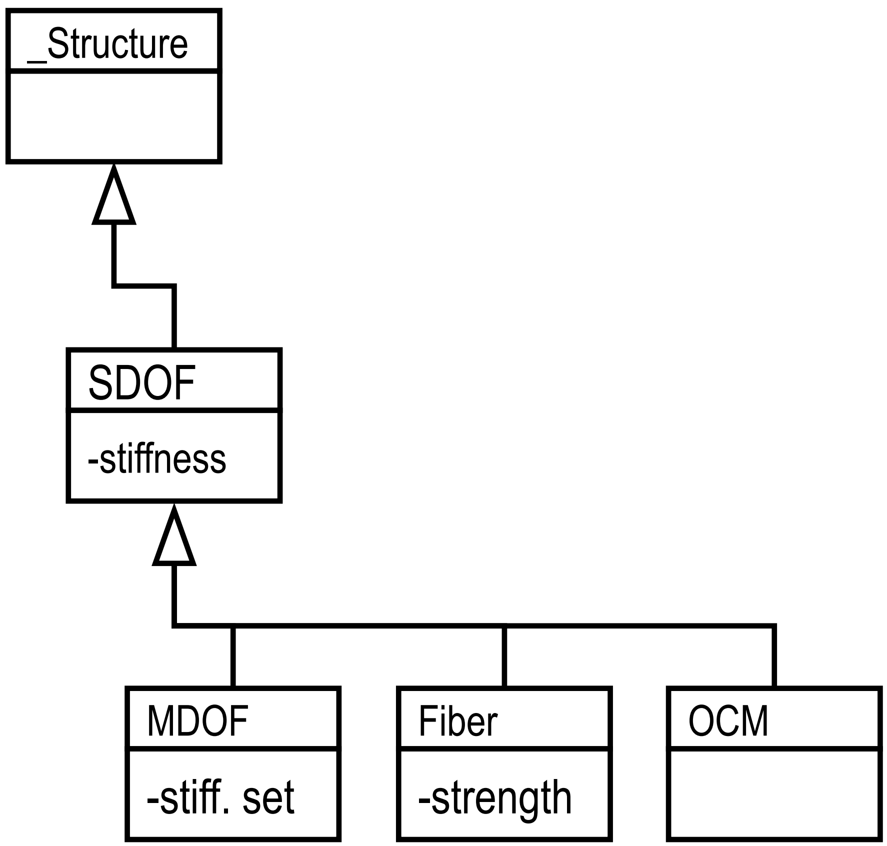
SYSTEM COMPUTING

- Software Engineering
  - One generous programmer vs system engineer group
  - Quality control/guarantee of software: V & V

- Integrated System
  - Transparency for developers of generations
  - Robustness error minimization
  - Extention-ability reuse of modules

IES employs *object-oriented programming* that uses object hierarchy and *aspect-oriented programming* that uses template.

IES



object hierarchy

```
template class<S> void Analyze( S &x )
{
  double acc=x, vel=0.;
  while( … ) vel += x dt;
  …
}
```

- algorithm -

```
template<class C1, class C2>
class X : public C1, public C2
{
  public:
  void Analyze( … );
}
```

- class -

template

FINITE ELEMENT METHOD

- Standard Numerical Method for Engineering
  - Linear/non-linear PDF in domain of complicated configuration
  - Utilization of smaller grain modules
  - Development of good commercial packages

- Research on New Features
  - Dynamic problems
  - Failure problems: 2D to 3D
  - Materials of complicated constitutive relations

SEISMIC STRUCTURE RESPONSE

- Lagrangian Formulation

$$L[\boldsymbol{v},\boldsymbol{\varepsilon}]=\int \tfrac{1}{2}\rho\boldsymbol{v}\cdot\boldsymbol{v}-\tfrac{1}{2}\boldsymbol{\varepsilon}:\boldsymbol{c}:\boldsymbol{\varepsilon}\,\mathrm{d}v \qquad (\boldsymbol{v},\boldsymbol{\varepsilon})=(\boldsymbol{u},\mathrm{sym}\{\boldsymbol{\nabla}\boldsymbol{u}\})$$

- Rigid-body Motion and Response

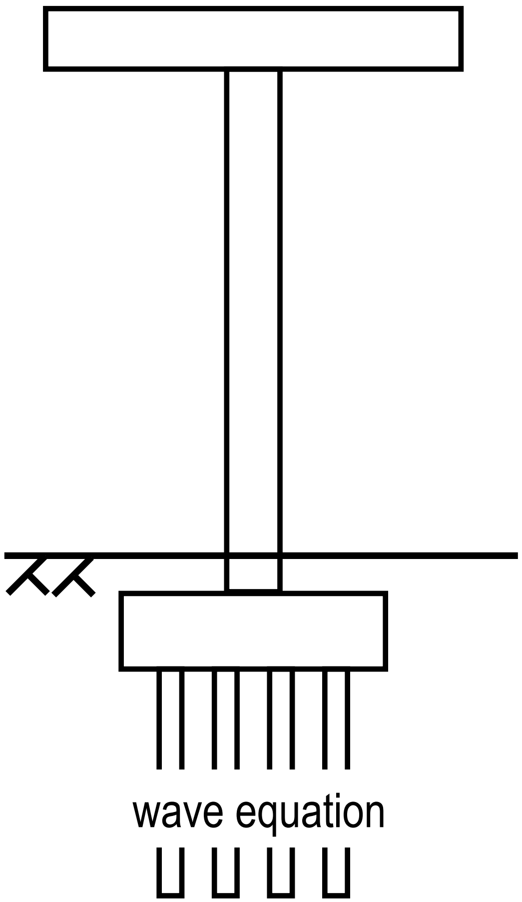
$$\boldsymbol{u}(\boldsymbol{x},t)=\boldsymbol{g}(\boldsymbol{t})+\boldsymbol{u}^{r}(\boldsymbol{x},t)$$

- Smart Approximation

$$\boldsymbol{u}^{r}(\boldsymbol{x},t)=U(t)\boldsymbol{A}(\boldsymbol{x})$$

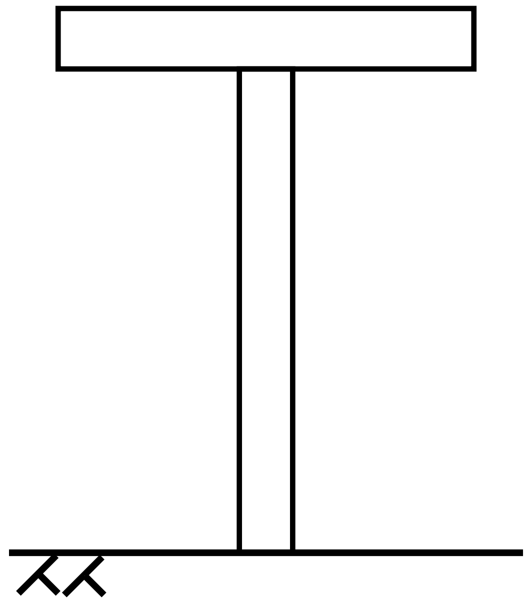
$$L=\tfrac{1}{2}MU^{2}-\tfrac{1}{2}KU^{2}+GU \qquad (M,K)=\left(\int \tfrac{1}{2}\rho\boldsymbol{A}\cdot\boldsymbol{A}\,\mathrm{d}v,\int \tfrac{1}{2}\boldsymbol{\nabla}\boldsymbol{A}:\boldsymbol{c}:\boldsymbol{\nabla}\boldsymbol{A}\,\mathrm{d}v\right)$$

SMART SOLUTION



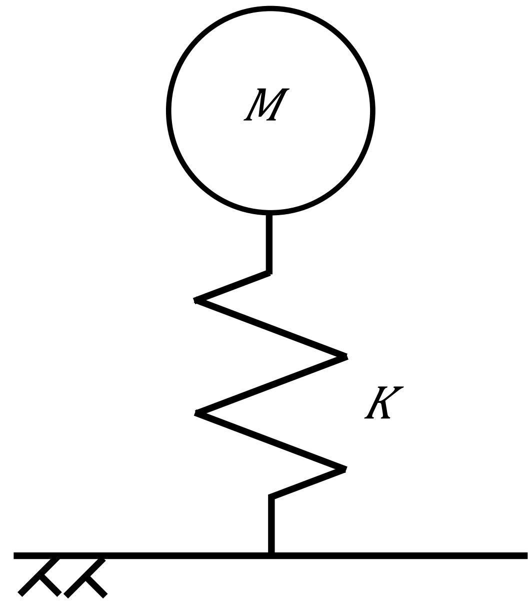
wave equation

$L[\boldsymbol{v},\boldsymbol{\varepsilon}]$



rigid-body motion
response as relative deformation

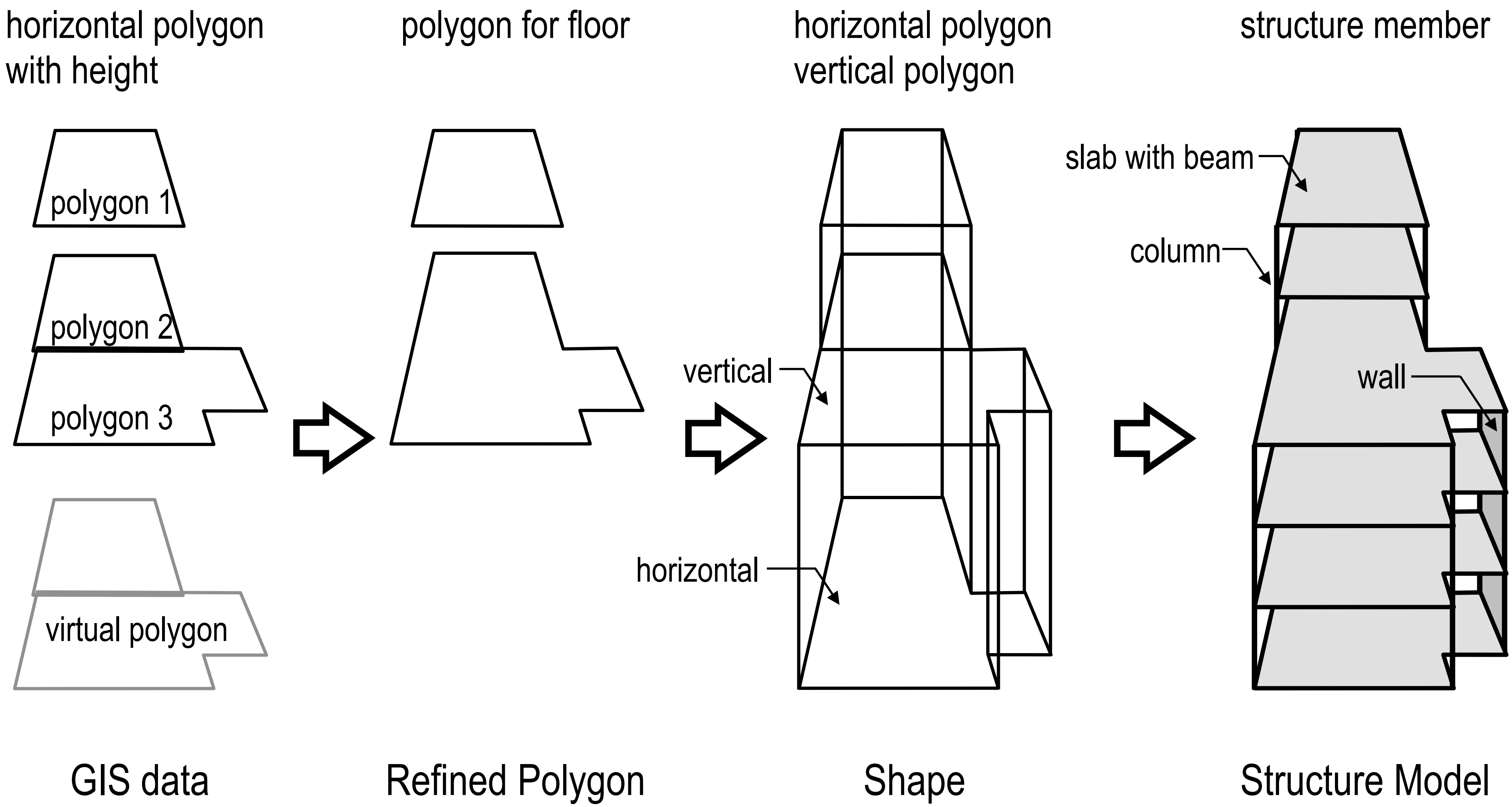
$L[\boldsymbol{g}+\boldsymbol{u}\uparrow r\ ,\ \boldsymbol{\varepsilon}\uparrow r\ ]$



smart approximation

$L[\boldsymbol{g}+U\boldsymbol{A}\ ,U\boldsymbol{\nabla}\boldsymbol{A}\ ]$

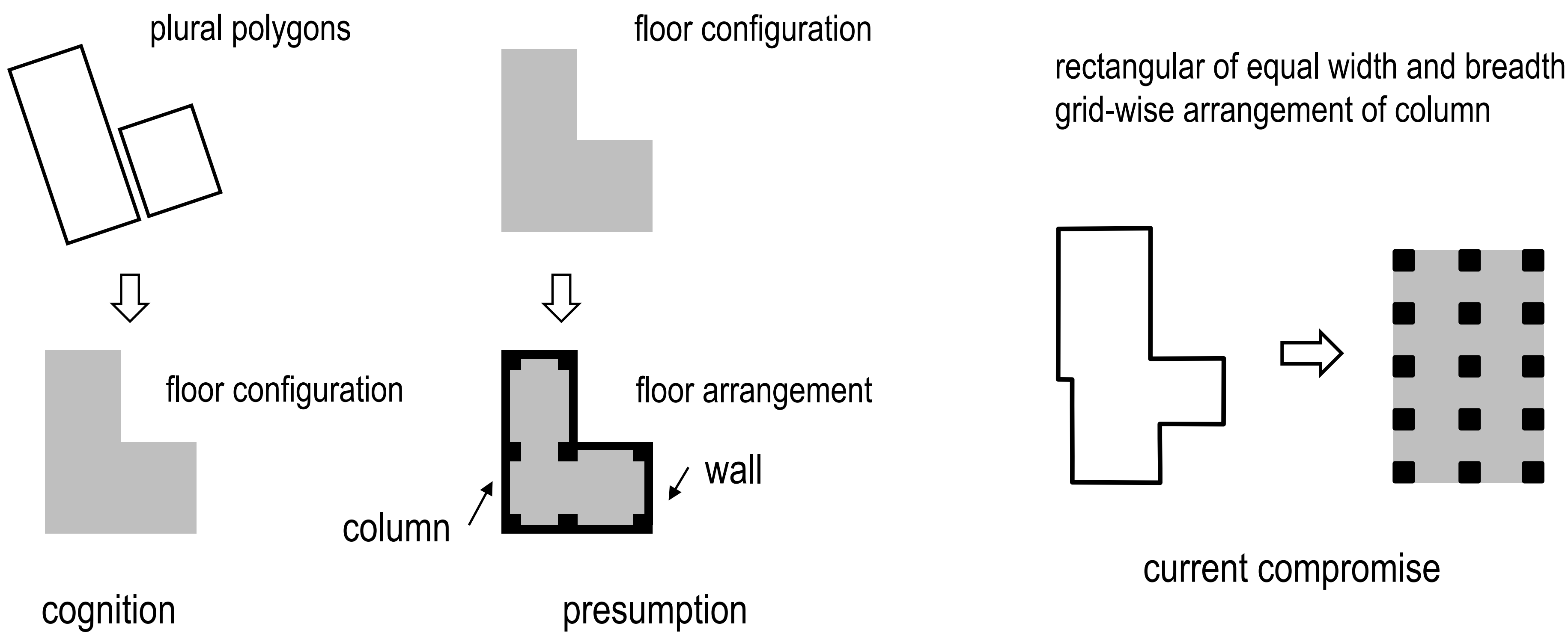
URBAN AREA MODEL



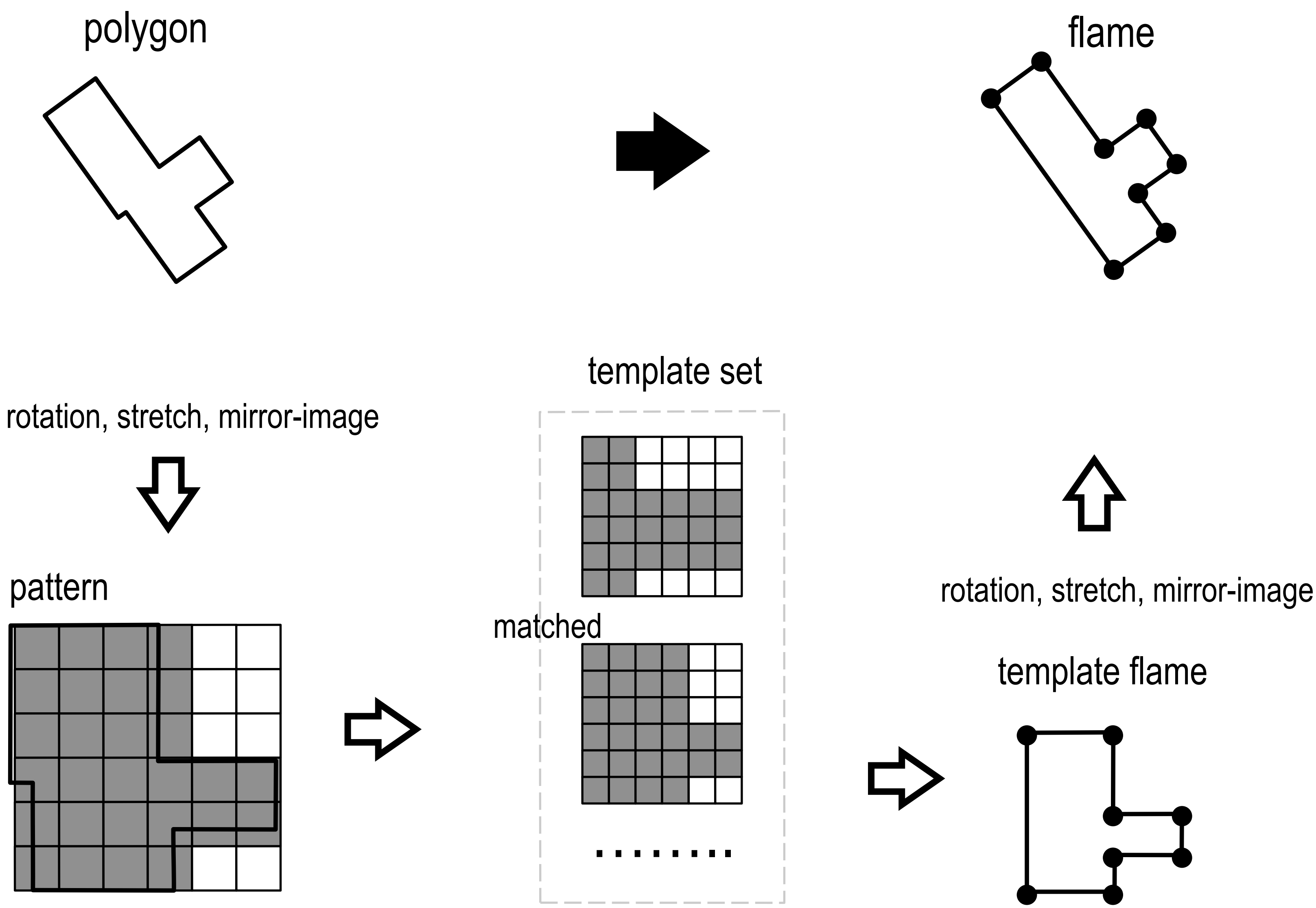
AUTOMATED MODEL CONSTRUCTION

Two Major Difficulties

- Cognition of floor configuration using plural polygons
- Presumption of floor arrangement using floor configuration

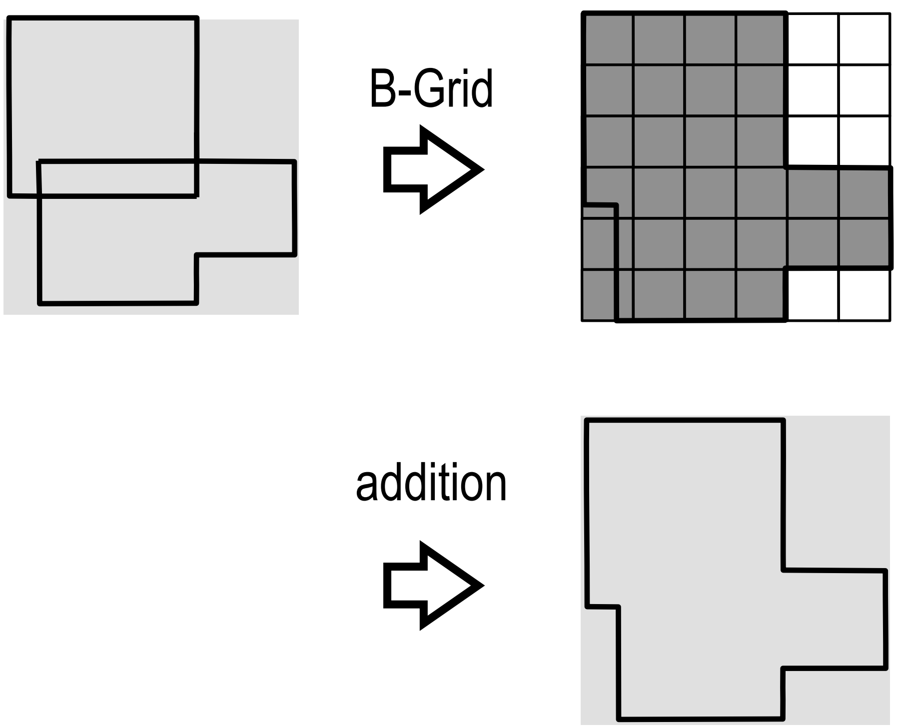


TEMPLATE FITTING



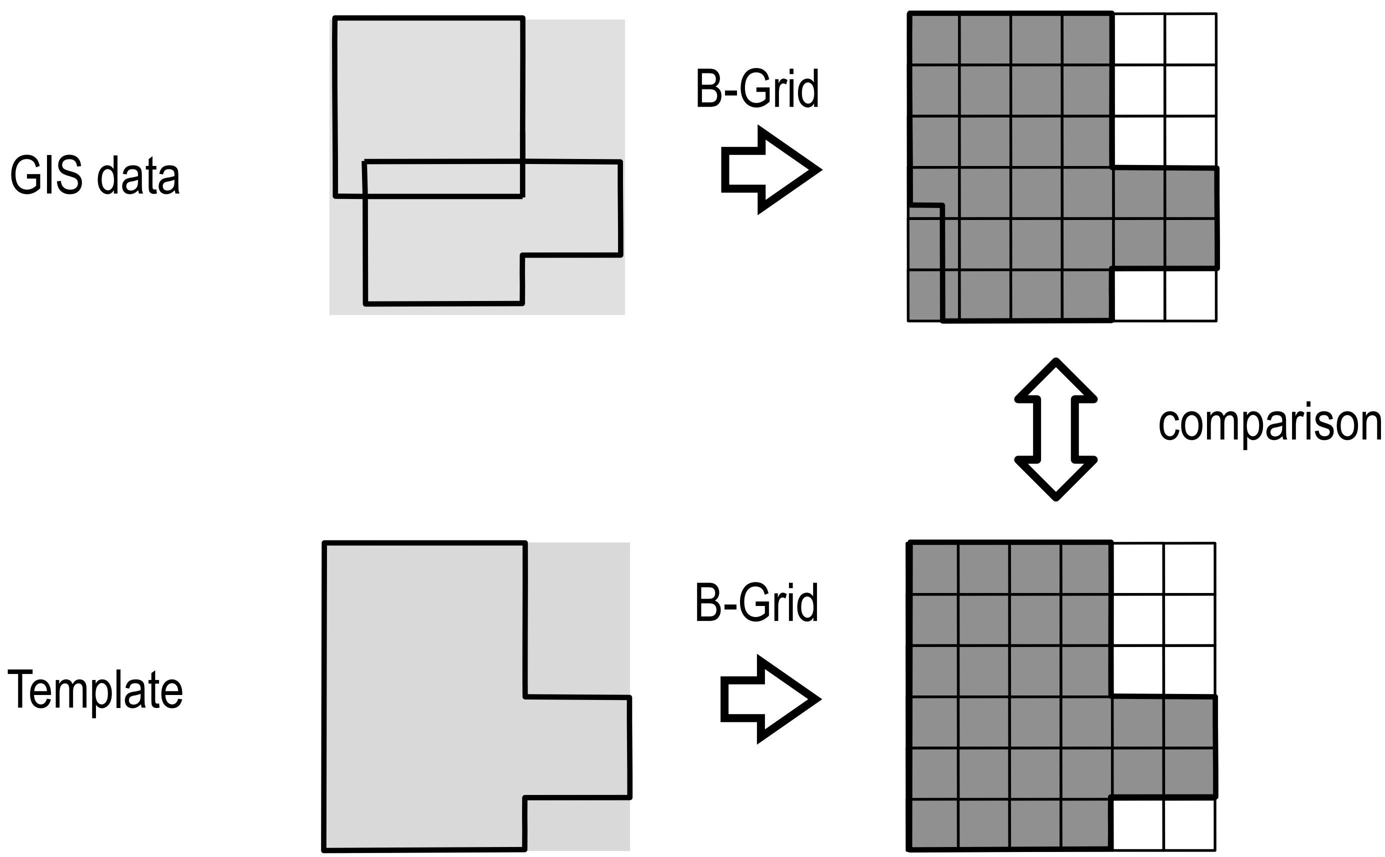
COGNITION OF PLURAL POLYGONS

- Two methodologies
  - B-GRID cast polygon into Boolean grid
  - Polygon Algebra manipulate polygons' configuration



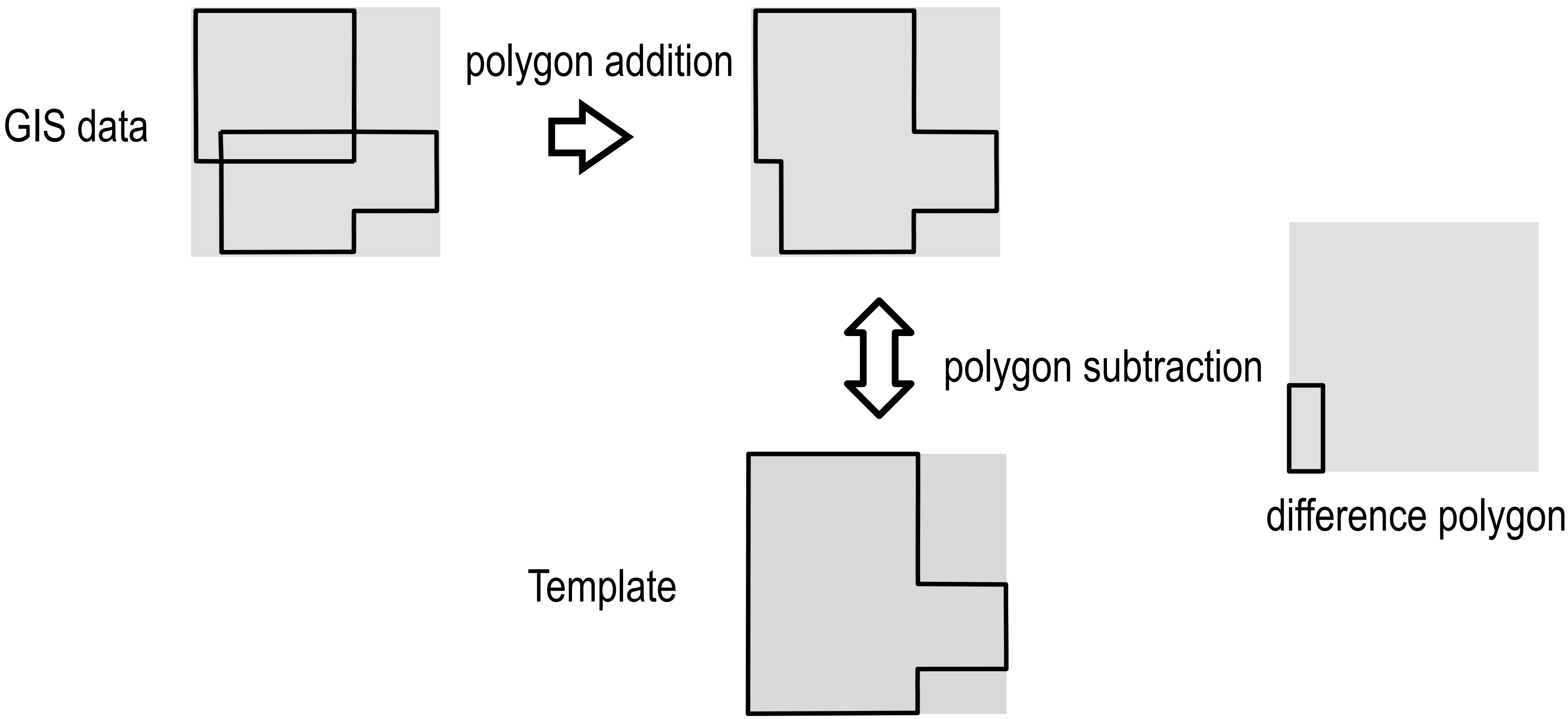
	B-GRID	POLYGON ALGBRA
coding	easy	difficult
robustness	high	low
error	grid size dependence	principally zero
computation time	long	short

COGNITION: B-GRID



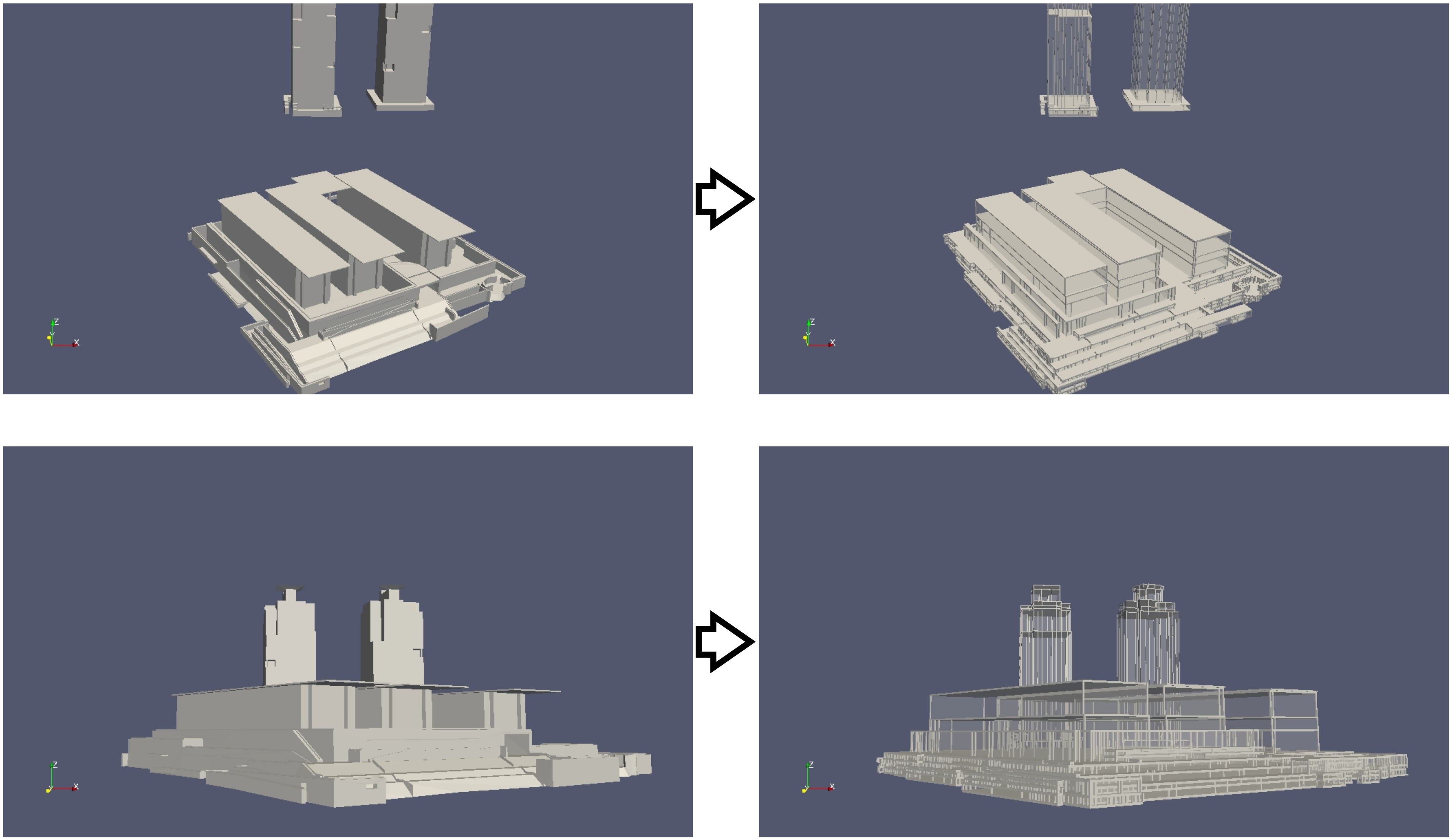
(relative difference) = (number of different cells) / (number of cells)

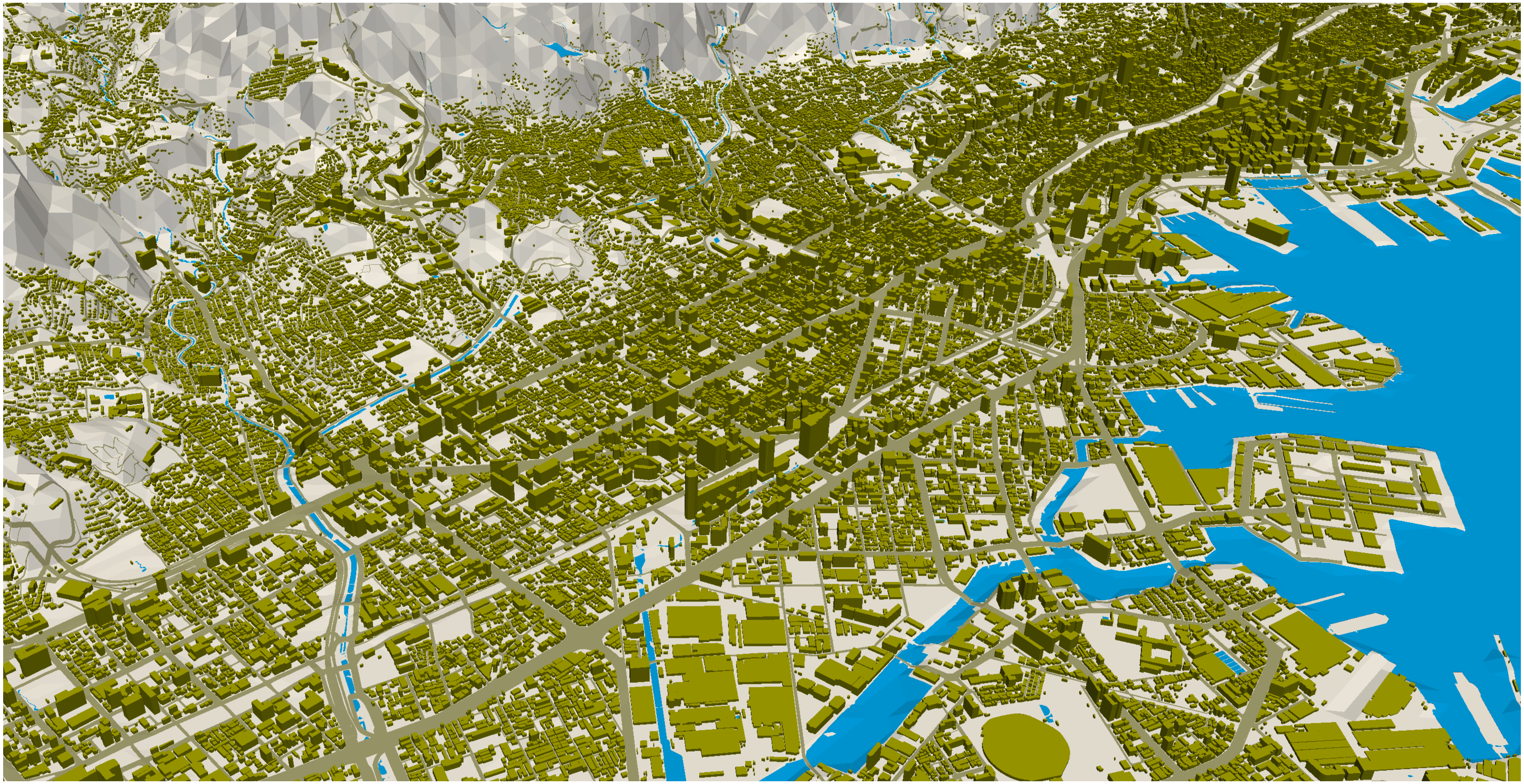
COGNITION: POLYGON ALGEBRA



(relative difference) = (area of difference polygons) / (area of template)

SEQUENTIAL TEMPLATE GENERATION



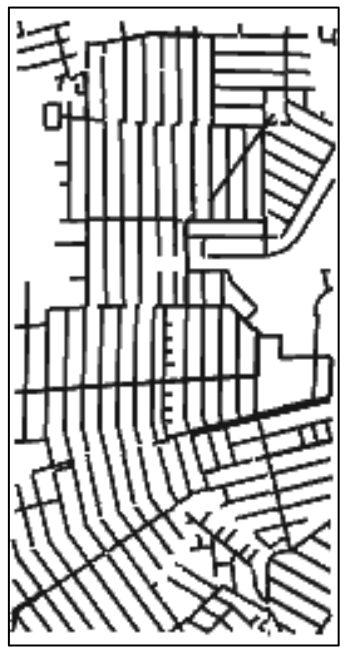


LIFELINE MODEL

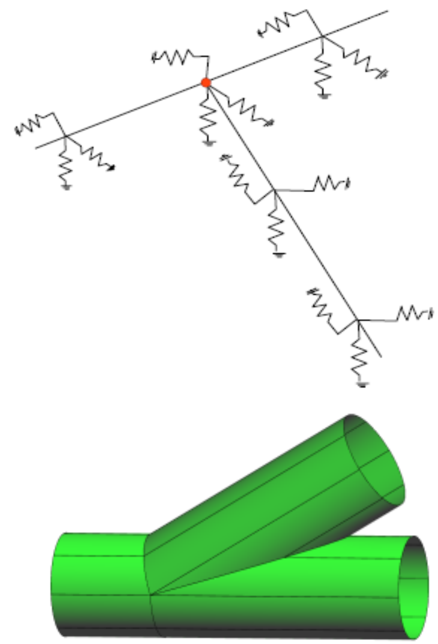
GIS Data Conversion　　　Model Data Conversion

Control Data	Company ID
	Assessment ID
	...
Attribute	Radius
	Thickness
	Construction Date
	...
Coordinate sets	(x_1, y_1, z_1)
	(x_2, y_2, z_2)
	...
	(x_n, y_n, z_n)

GIS



converted GIS



structure model

SEWEGE PIPELINE NETWORK

CONCLUDING REMARKS

- Integration of Many Data Sets and Analysis Methods
  - Earth science simulation   wave propagation analysis
  - Engineering simulation   seismic response analysis
  - Social science simulation   mass evacuation analysis

- Collaboration of Computer/Computational Science
  - Capability computing for large-scale simulation
  - Capacity computing for multi-scenario simulation
  - Software engineering aspects in developing IES