Joint Workshop organized by
the Institute of High Performance Computing and Kajima Corporation

Environmental Modelling &
Simulation for the Building Industry

Utilization of Air Flow Simulation in Construction Field

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Institute of High Performance Computing
A*STAR

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Supported by:

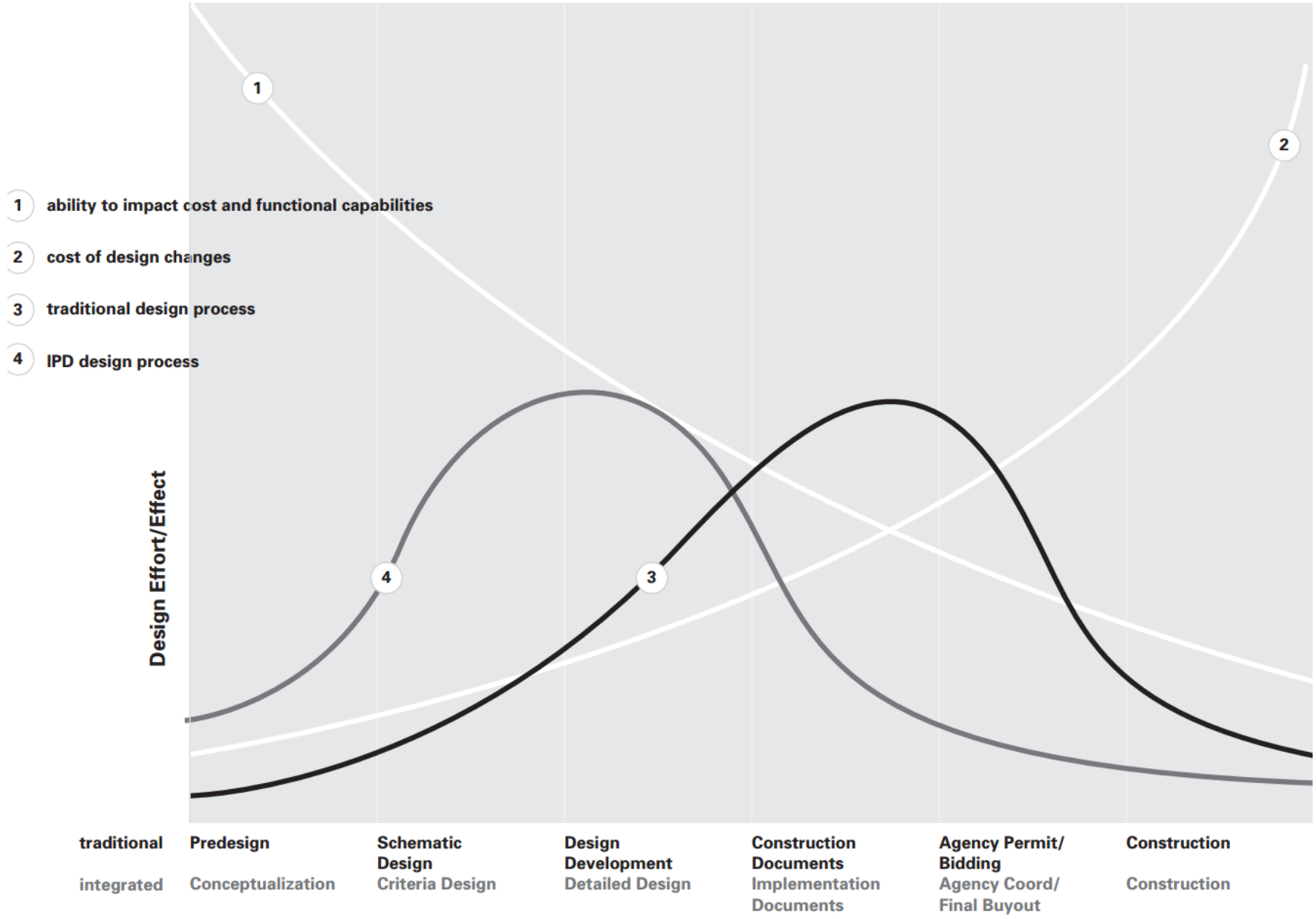
Building and Construction Authority

Outline

1. CFD in Building Design
   - BIM & Front Loading -
2. CFD Example of Environmental Evaluation
3. Development of Numerical Wind Tunnel for Wind Load Prediction
4. Conclusion

1. CFD in Building Design
- BIM & Front Loading -

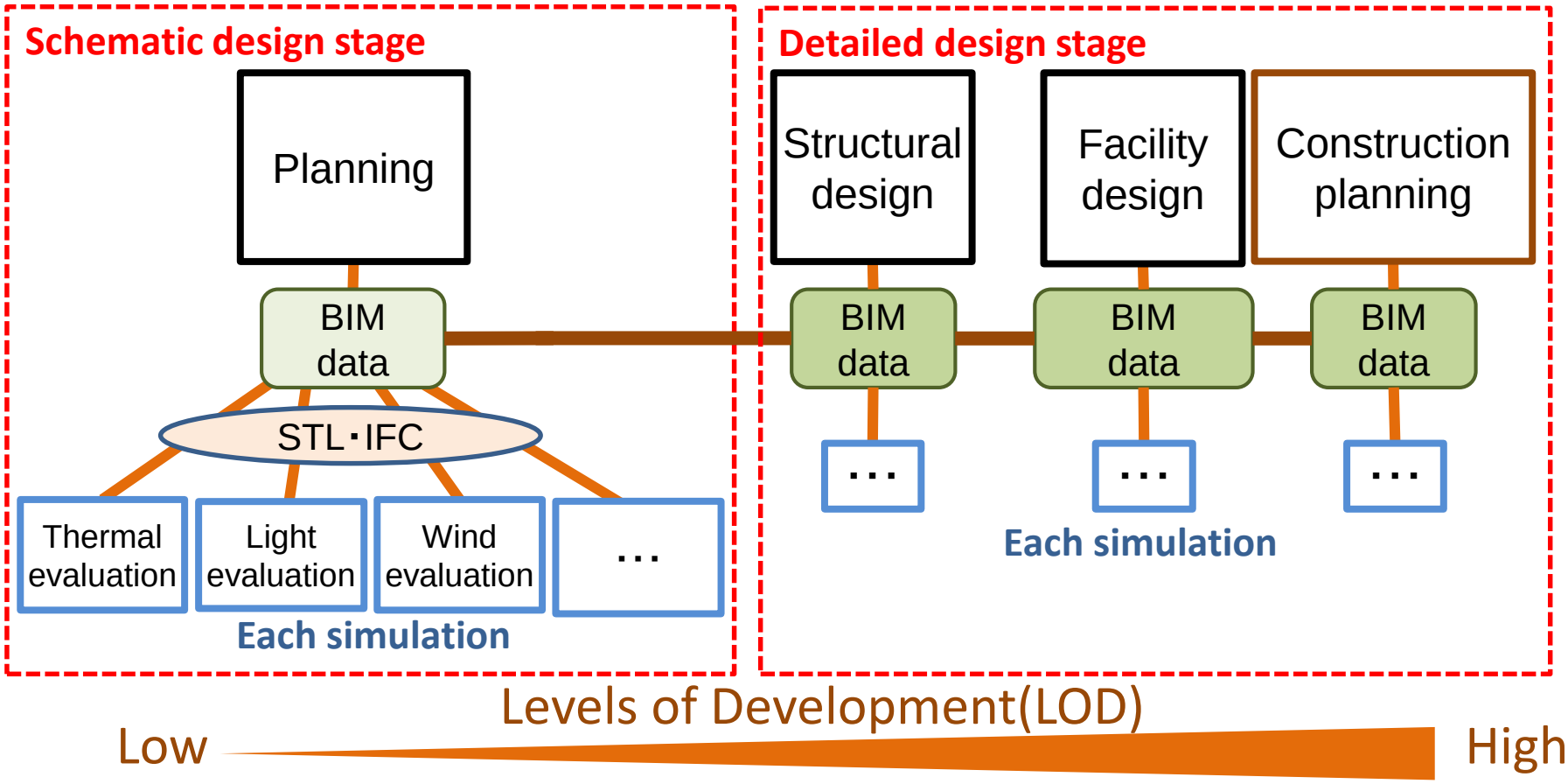
MacLeamy Curve



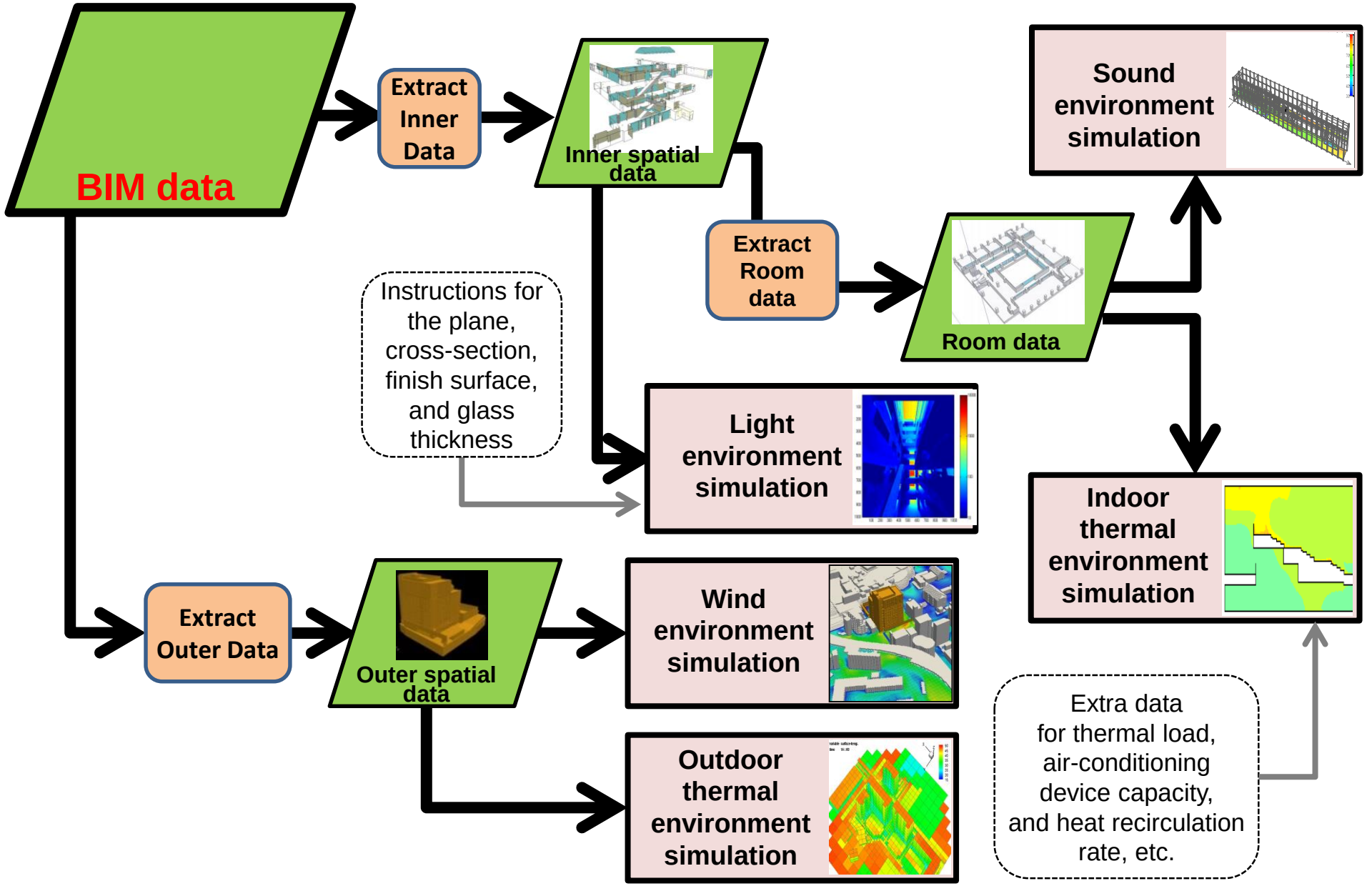
（The American Institute of Architects, Integrated Project Delivery: A Guide, 2007）

Using Simulation for Front Loading

- To determine one detail in schematic design stage, many assumptions of other details are needed.
- To determine these assumptions, simulation methods are very efficient tools.

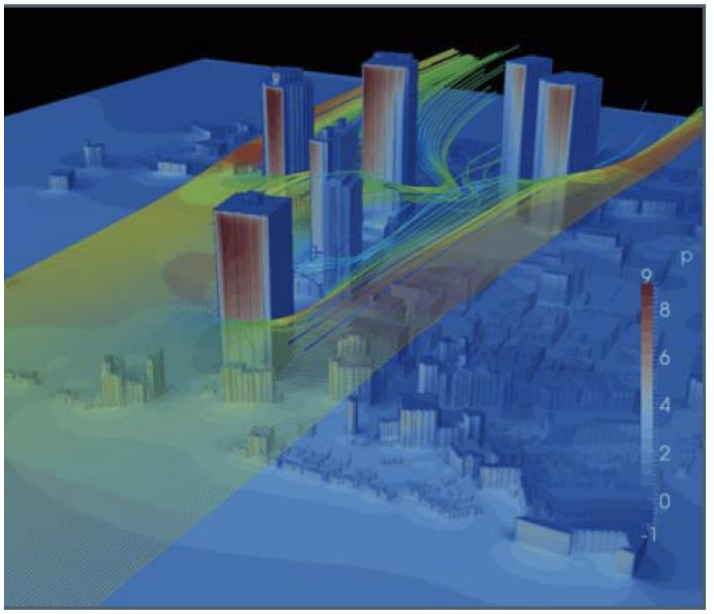


Environmental Simulation Process by BIM



What is “CFD” ?

- **Computational Fluid Dynamics**
  - Flow field prediction method by numerical integral operation based on partial difference equations for momentum.
- **Very useful simulation for construction related work**
  - Evaluation for air quality, natural ventilation, thermal comfort, wind environment, wind load, severe disaster prevention and so on.



Wind simulation example

- **Tow types of CFD**
  - RANS: moderate accuracy & middle computational cost.
  - LES: high accuracy but high computational cost. But, gradually reasonable by the advancement of computer.

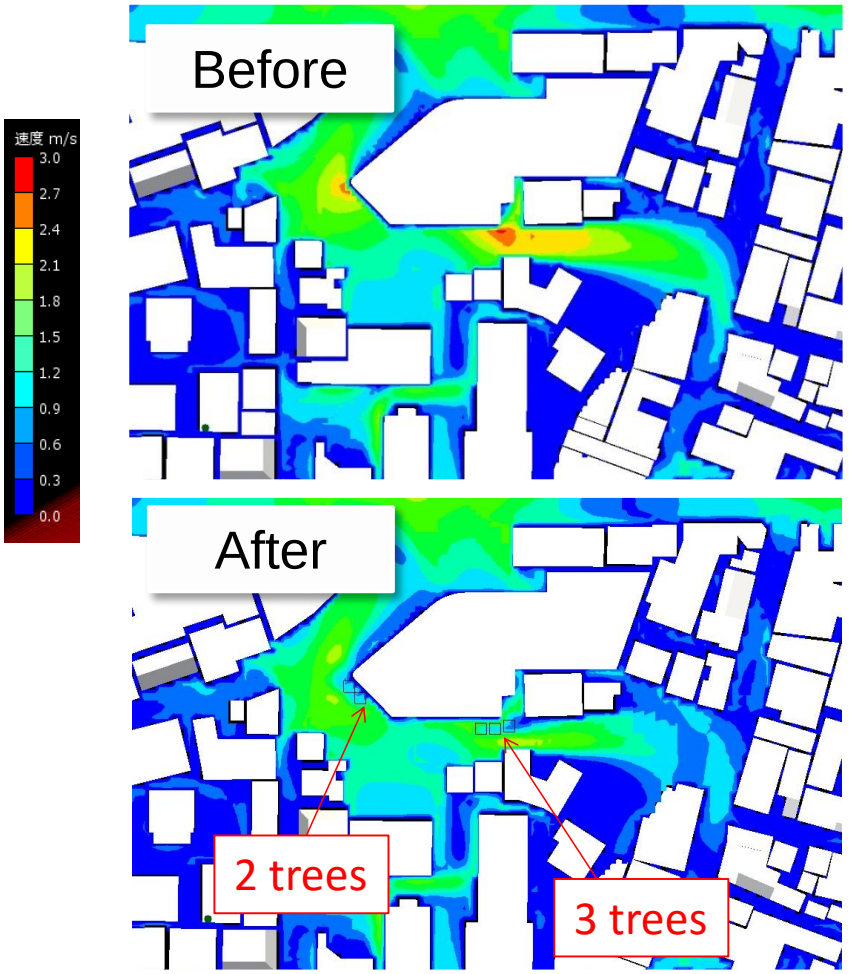
2. CFD Example of Environmental Evaluation

Wind Environment

SW



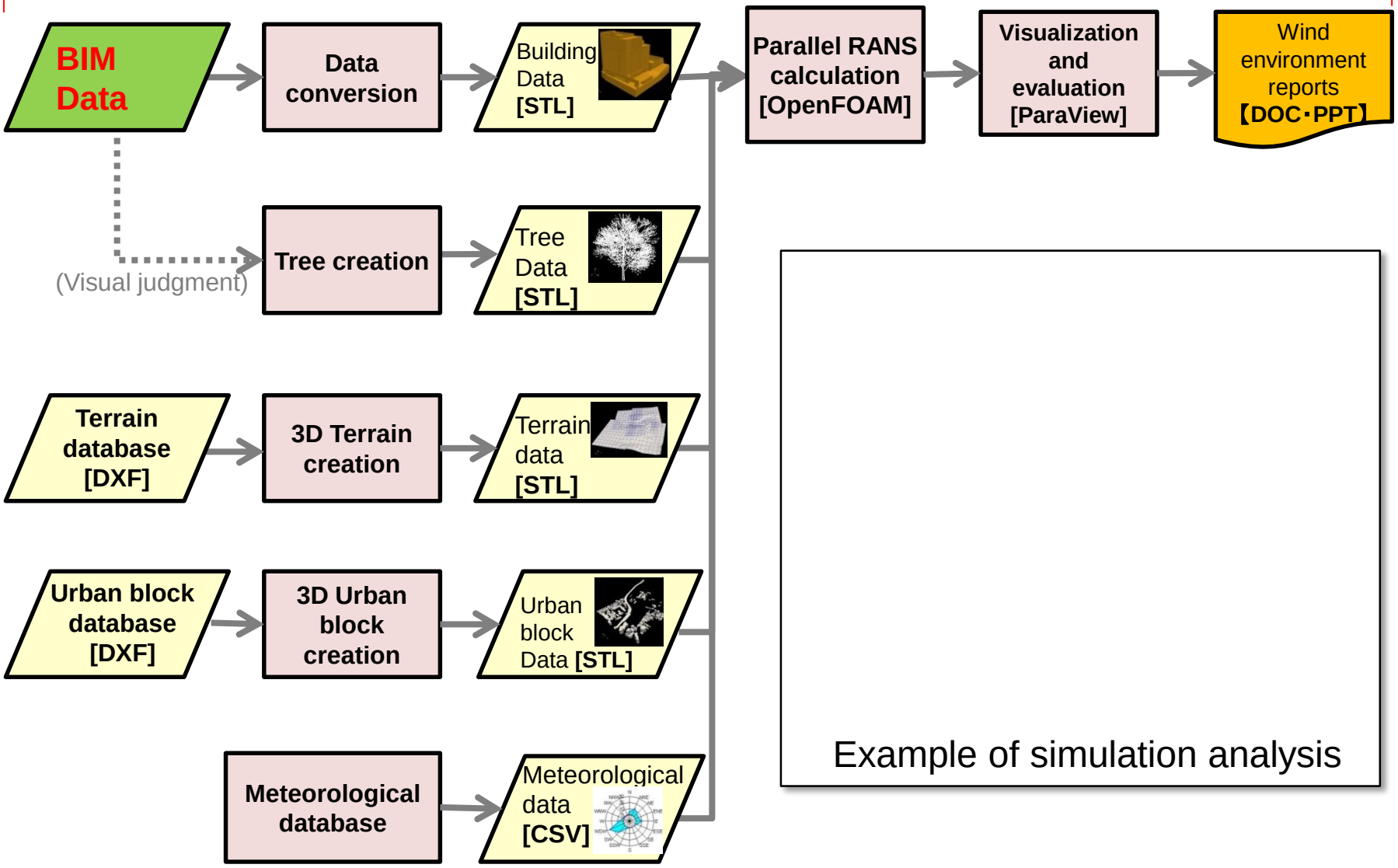
Example of flow visualization on urban area



Strong wind prevention using plantation

Example of Wind Environment Evaluation Process

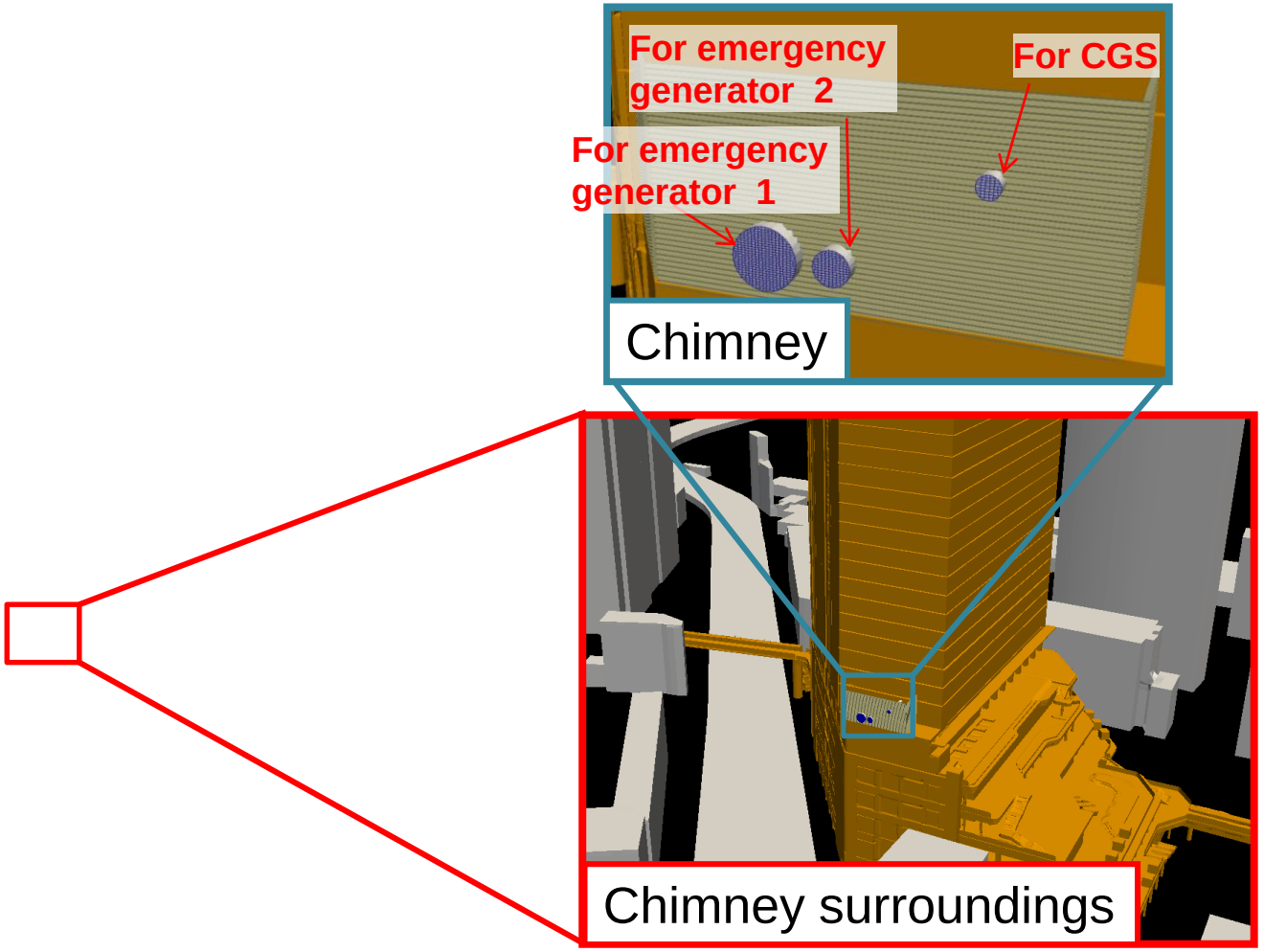
Evaluation process into less than two days



Example of simulation analysis

Gas Diffusion

- Evaluating the hot exhaust diffusion from various chimneys of building sides diffuses depending on the chimney shape.
- Evaluating the effect on the exterior material and the outside air inlet.



Calculation area & mesh

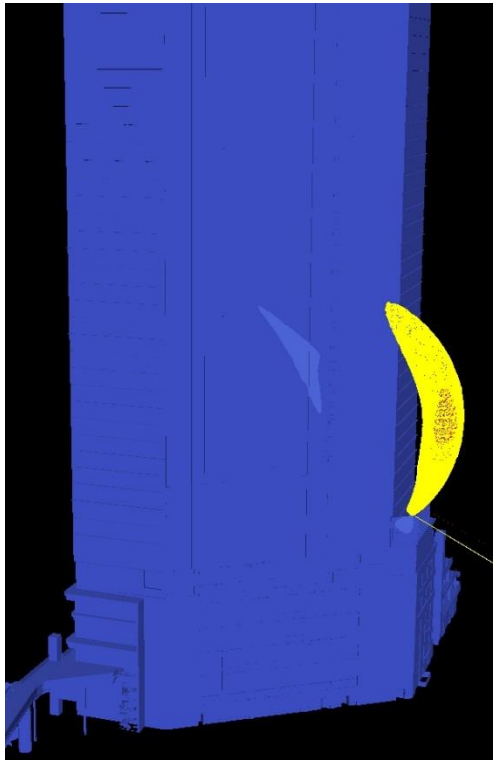
Gas Diffusion

[Temperature]

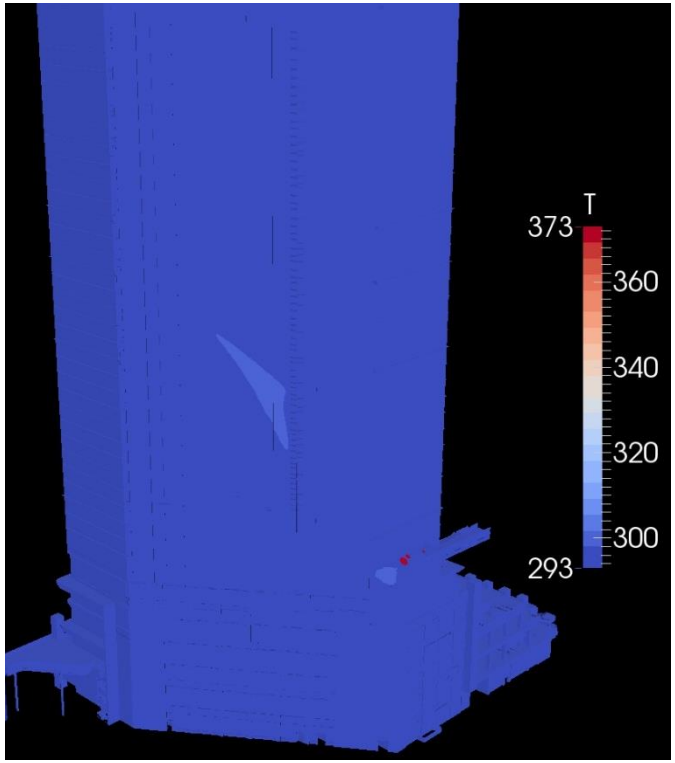
- High-temperature domain is not formed on a building surface.

[CO_2 concentration]

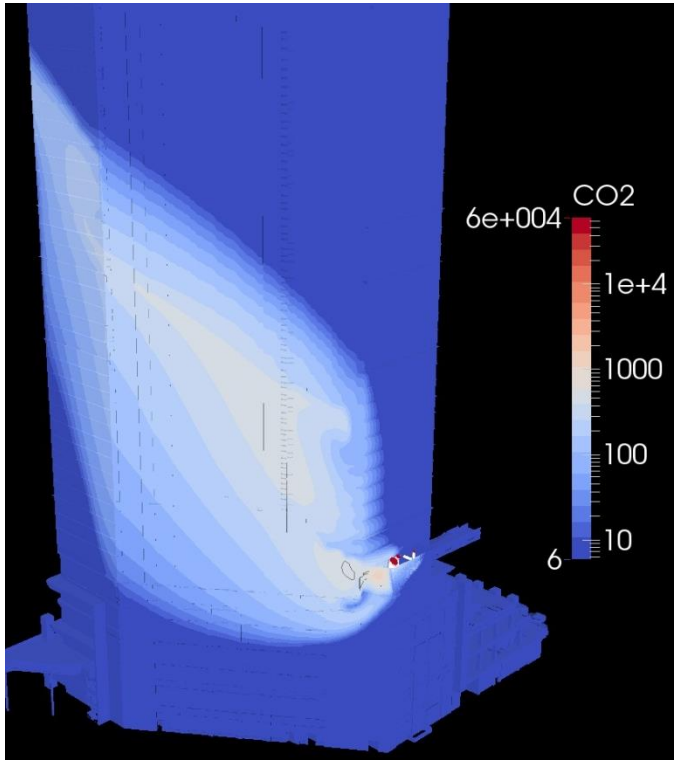
- It is approximately 500 ppm or less and does not flow on the outside air inlet side.



Isosurface contour (50ºC)



Surface temperature distribution (unit: K)



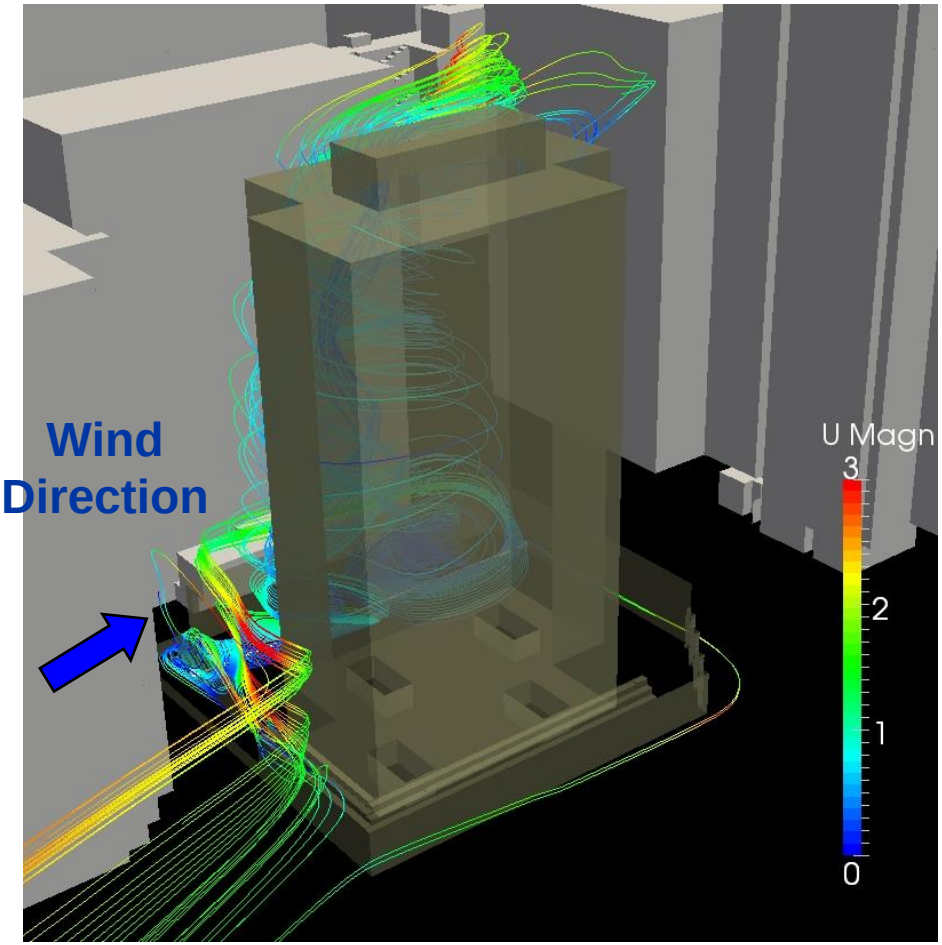
Surface CO_2 concentration distribution (unit: ppm)

Dust Diffusion

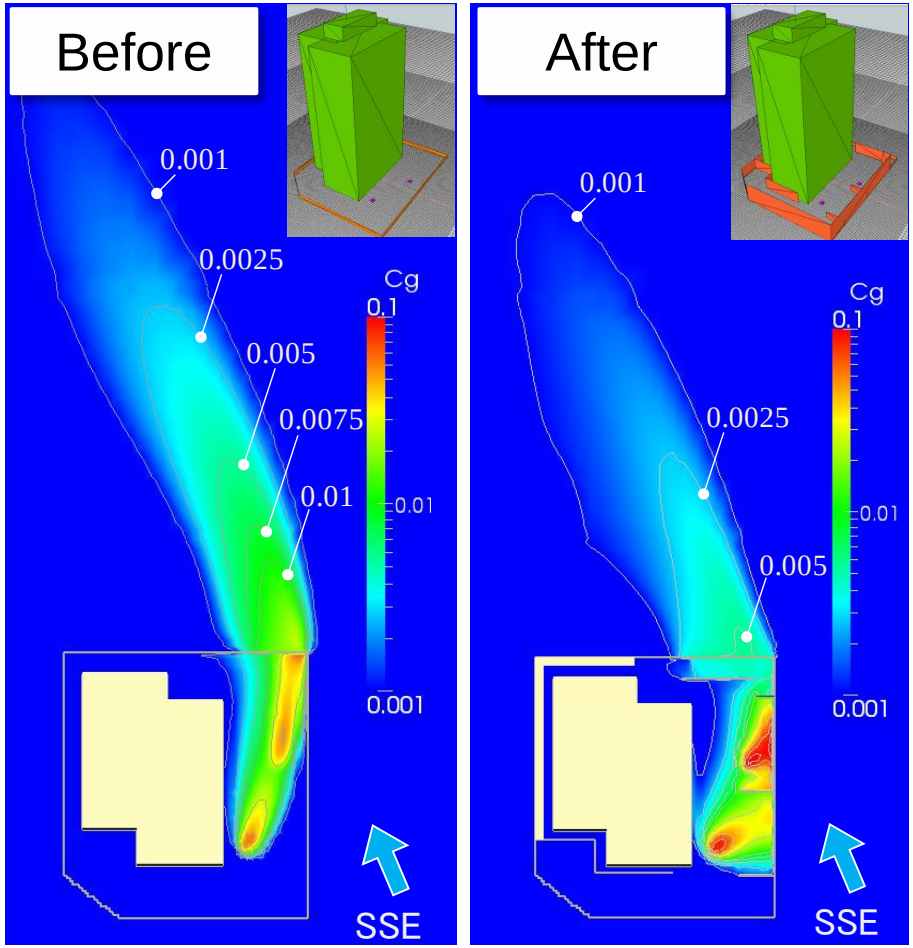


Dust diffusion situation on building demolition site

Dust Diffusion

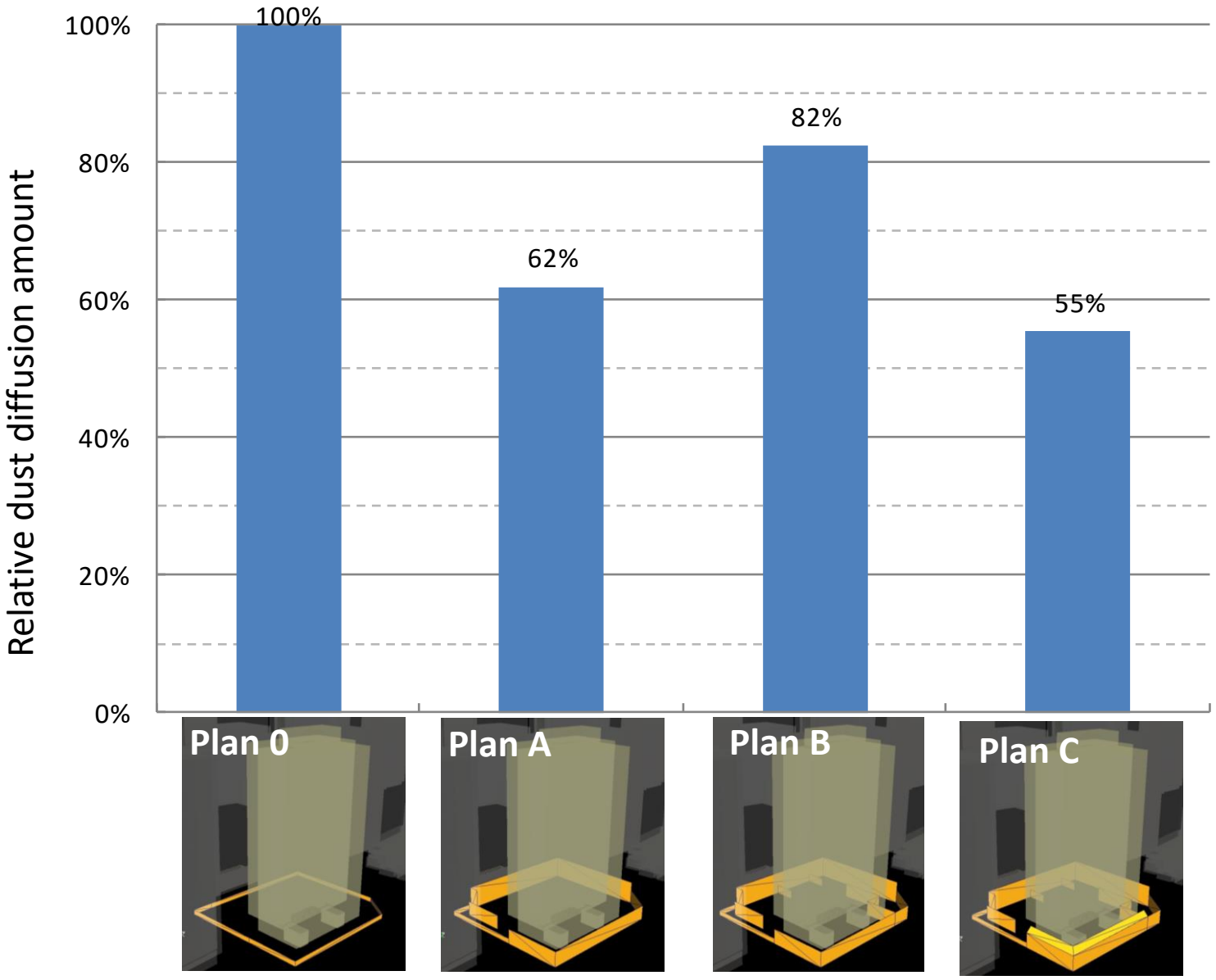


Flow visualization
in construction site



Suppression of dust diffusion
by modification of fence

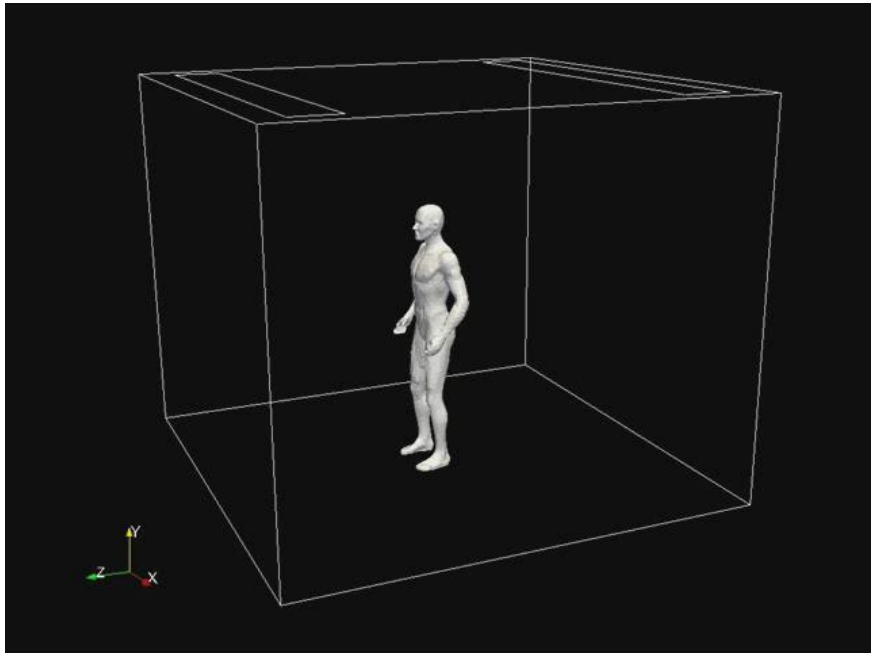
Dust Diffusion



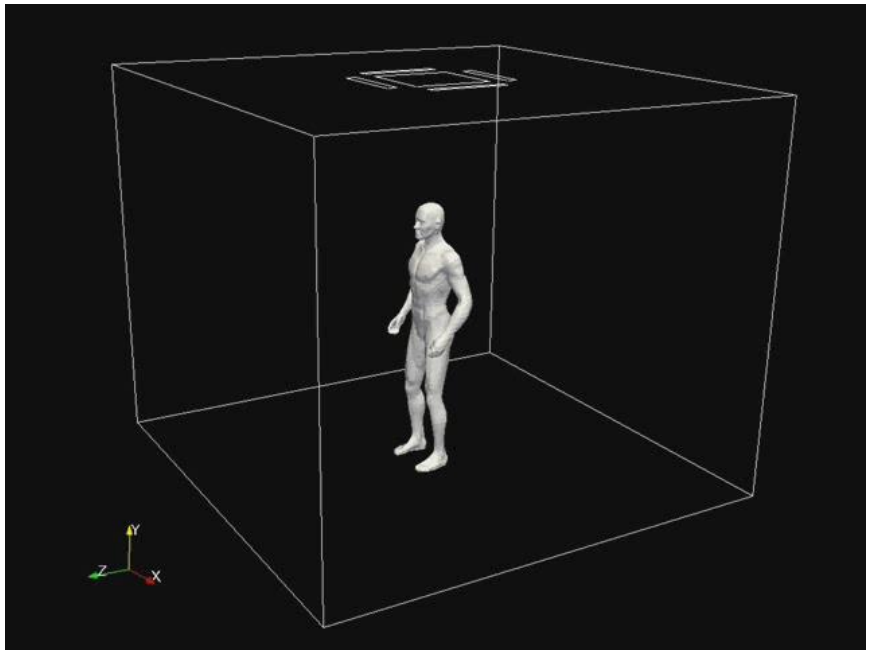
Relative dust diffusion amount from construction site (standardized by “Plan 0”)

Decay Characteristics of Expiratory Aerosol

- In terms of evaluating ability to prevent pathogen infections in typical indoor environments
- Using LES & Lagrangian particle tracking for unsteady decay characteristics of coughed spit droplets

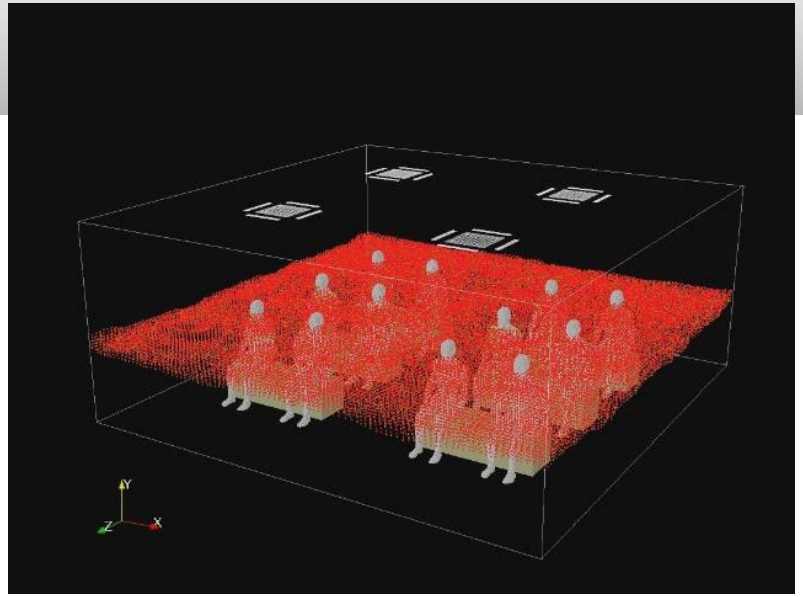


Line-diffuser type

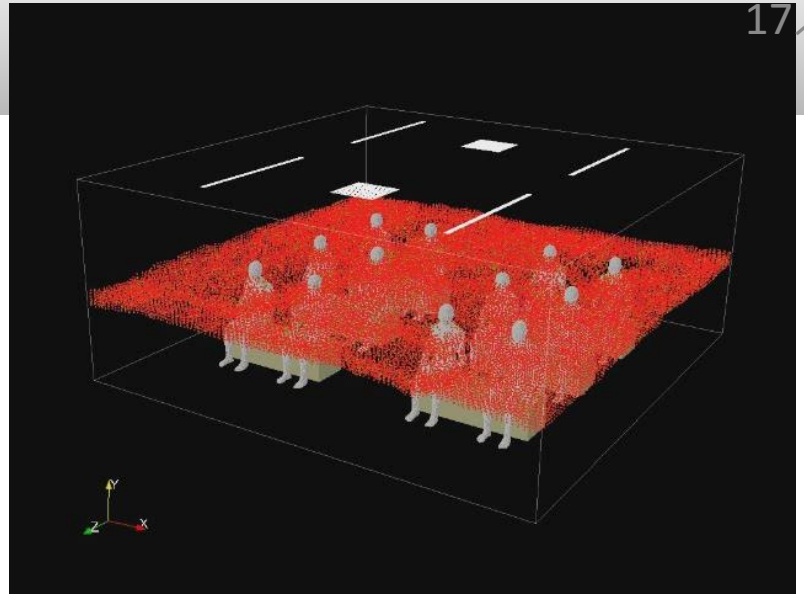


4-way cassette unit type

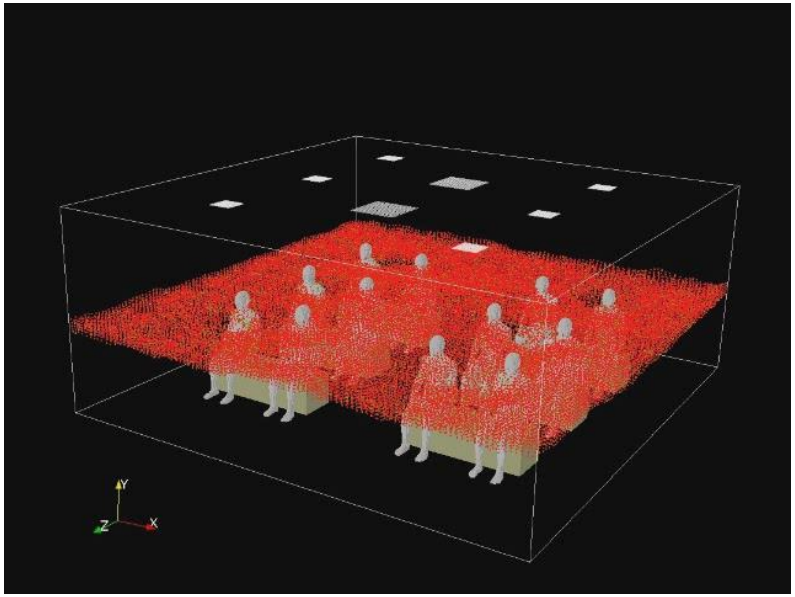
Example of Dispersion pattern of Different Diffuse-induced Air



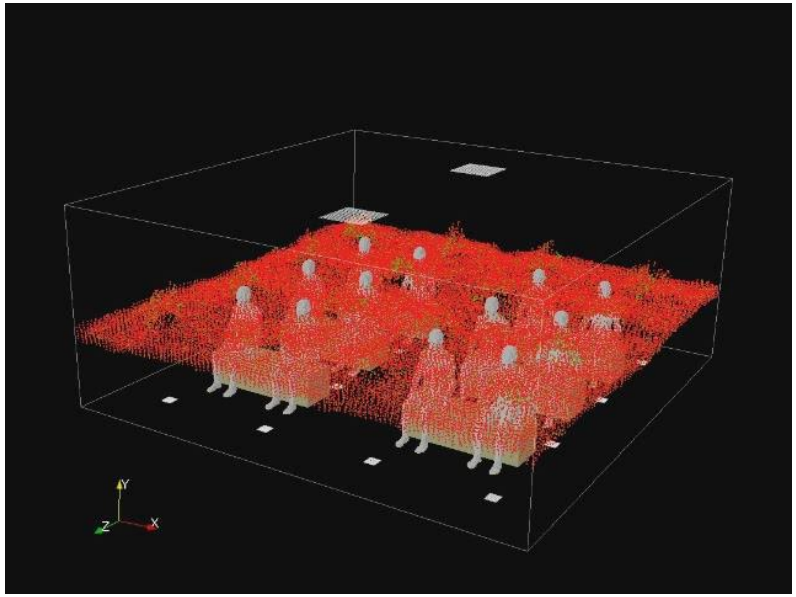
(a) 4-way cassette unit type (Case 4WC)



(b) Breeze-line diffuser type (Case BLD)

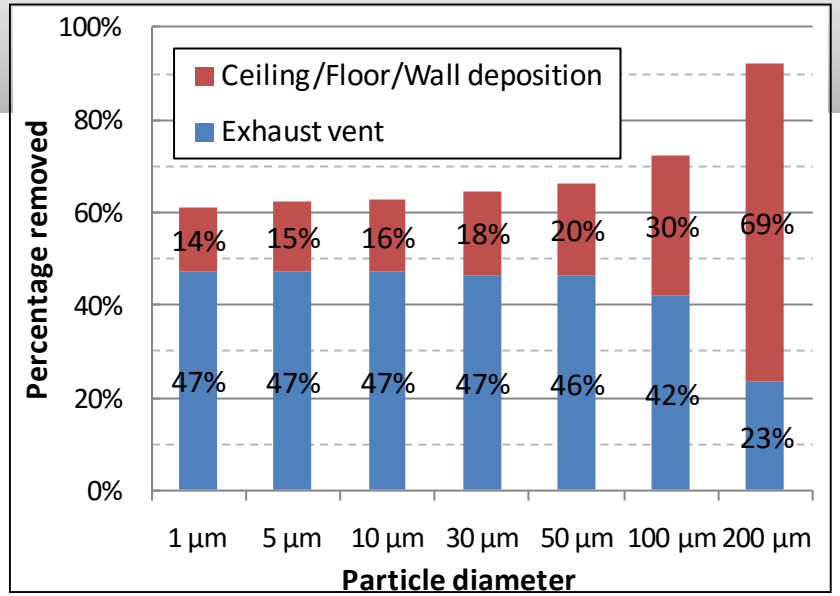


(c) Square diffuser type (Case SD)

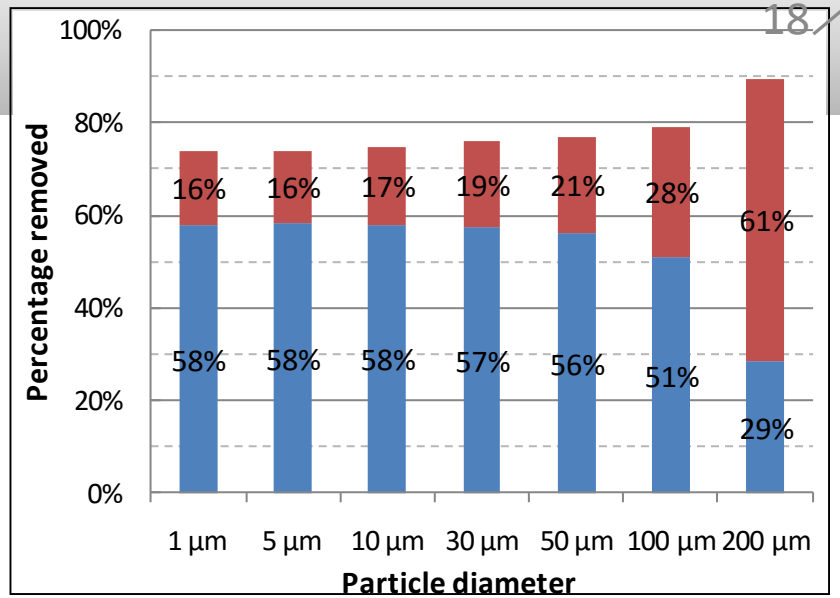


(d) Floor diffuser type (Case FD)

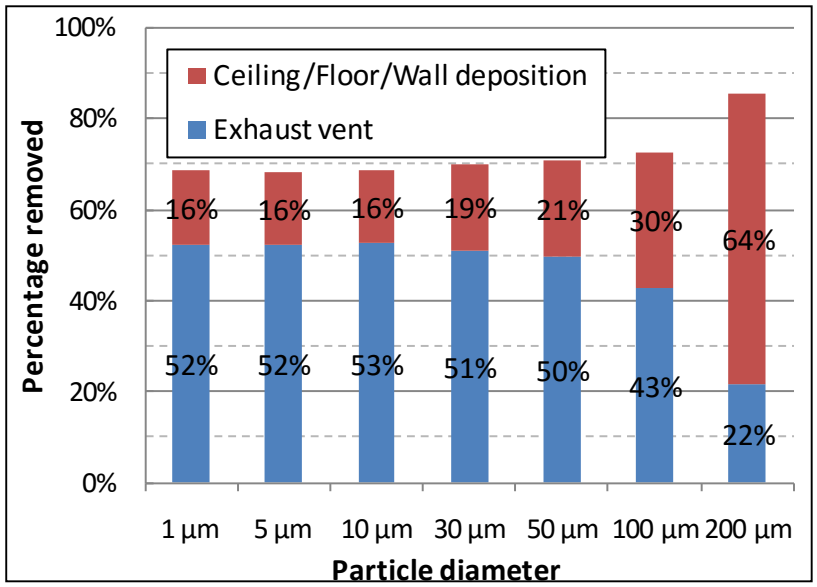
Movie of Particle Behaviour with bodies (x5, red:10μm , green:100μm)



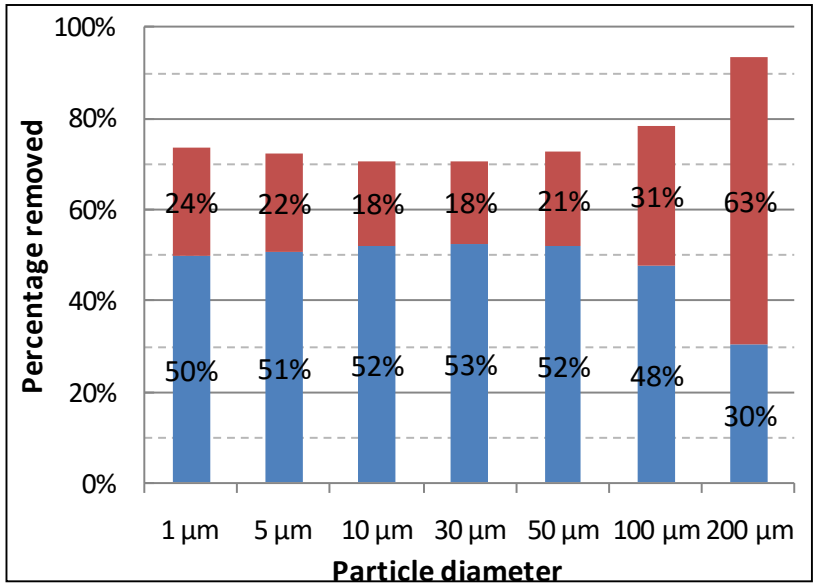
(a) 4-way cassette unit type (Case 4WC)



(b) Breeze-line diffuser type (Case BLD)



(c) Square diffuser type (Case SD)



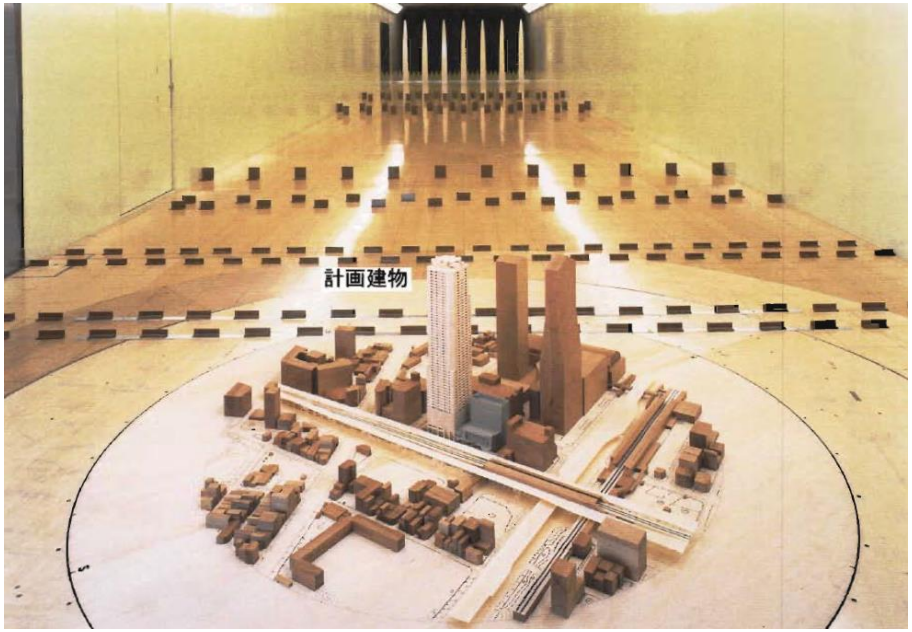
(d) Floor diffuser type (Case FD)

Percentage of Particles Removed after Nominal Time Constant

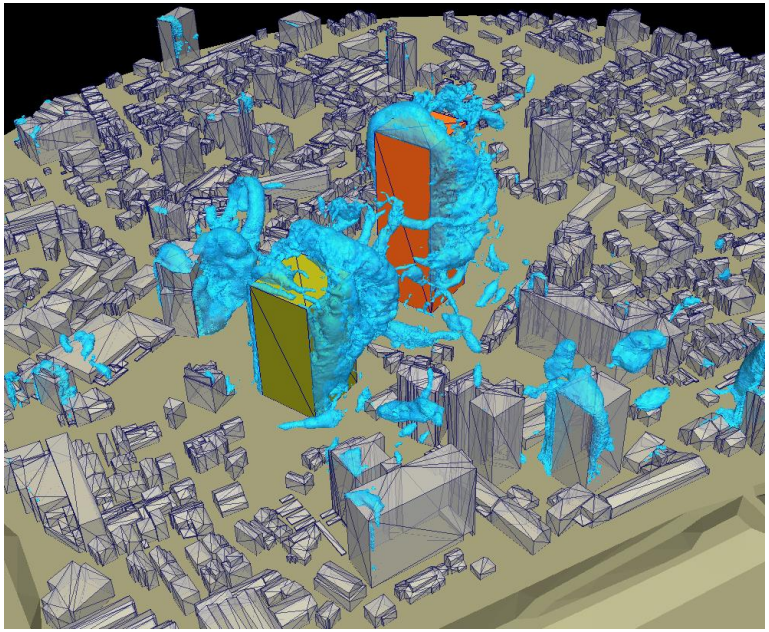
3. Development of Numerical Wind Tunnel for Wind Load Prediction

Motivation for Numerical Wind Tunnel

- By the advancements of computer, large-eddy simulation (LES) has become increasingly practical in wind load prediction for building structure frames or exterior materials.
  - ▶ “Numerical wind tunnel(NWT) for practical work”
- Not only Low cost & short term evaluation, but also achieving a valuable building design by the simultaneous shape optimization by adjoint operation. ▶ establish “HPC oriented design process”

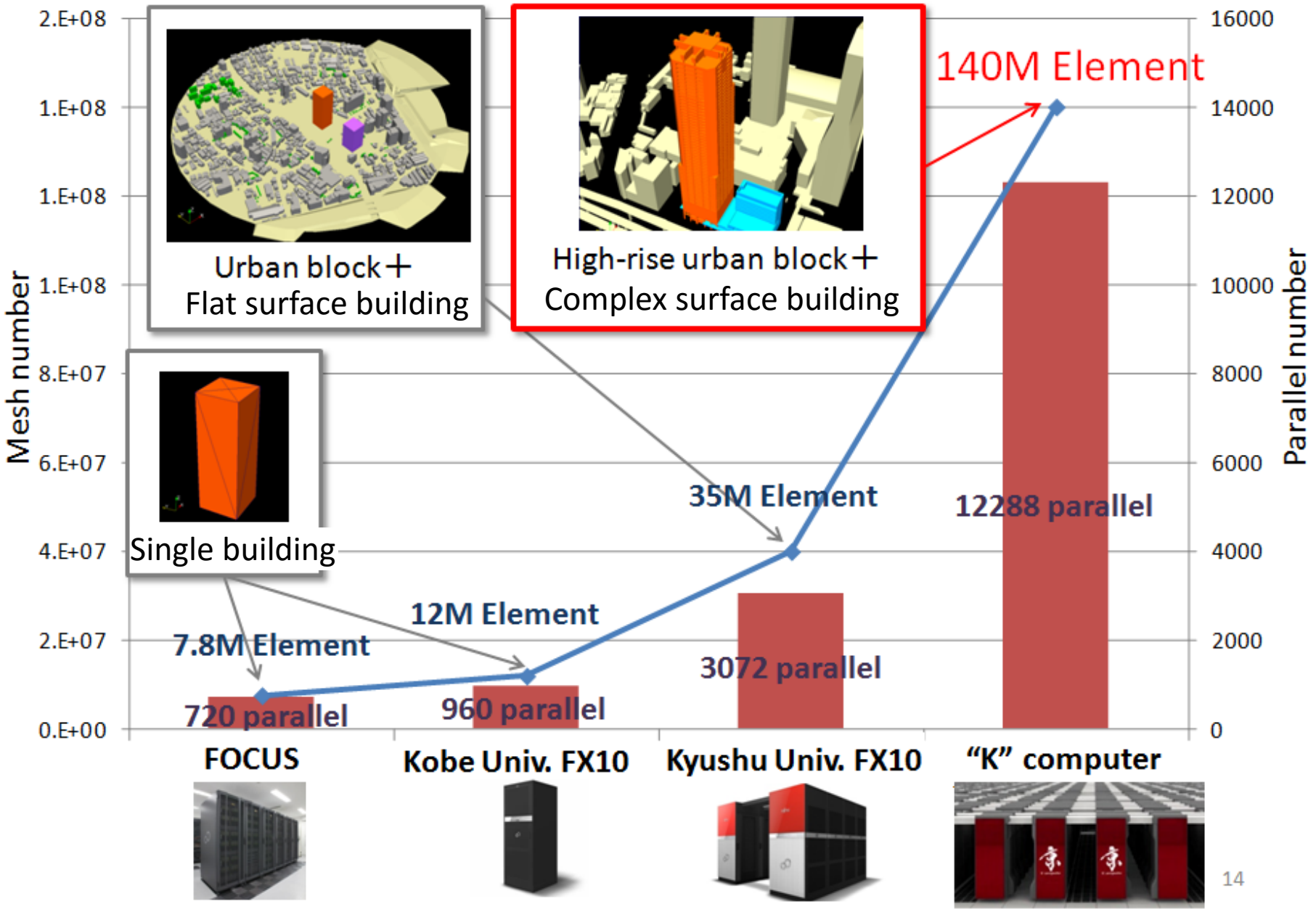


Wind tunnel experiment



Numerical wind tunnel

HPC Resource for NWT

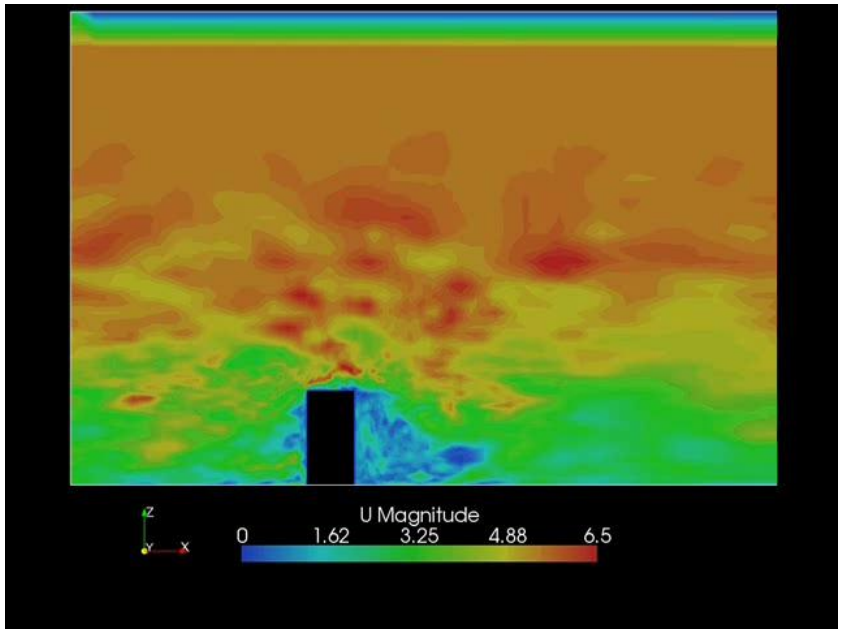


Key Point of Pressure Prediction

■Inflow boundary condition

- Simulate atmospheric boundary layer unsteady characteristics
  - Mean velocity & turbulent intensity profile & turbulent length scale
  - Power spectrum density of velocity

→ Generate by cyclic driver region with synthetic velocity fluctuation(Itoh et al., 2014)

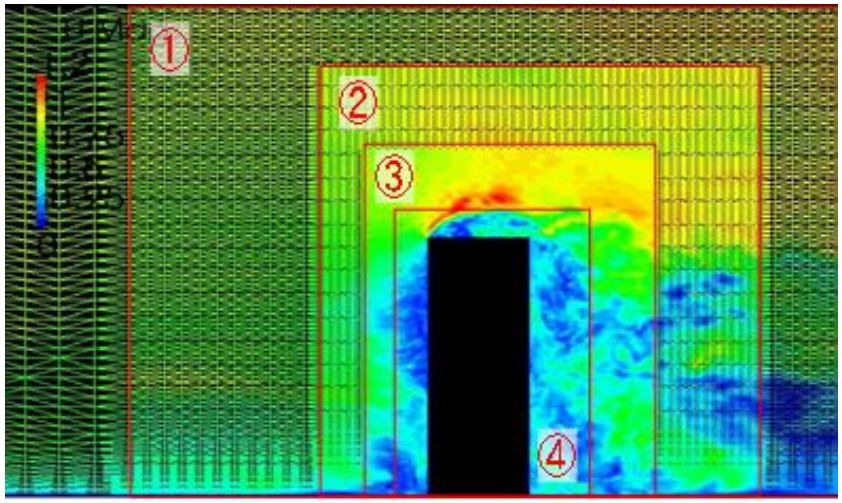


Fluctuation wind from inflow boundary

■Calculation mesh resolution

- Resolve target building with calculation mesh with 1/100 of Average breadths of target building（AIJ PD，2013）

→ Application of octree nested mesh based on hexahedral mesh



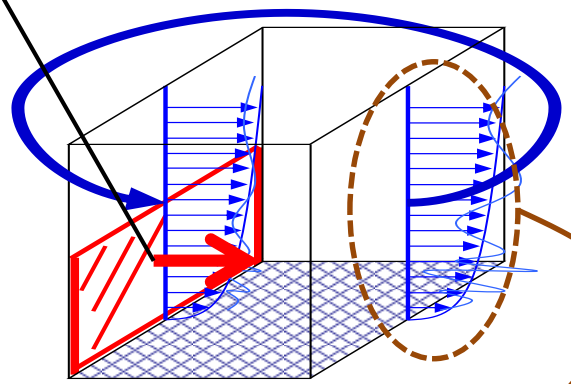
Nested mesh application for building

Turbulent Inflow Generation



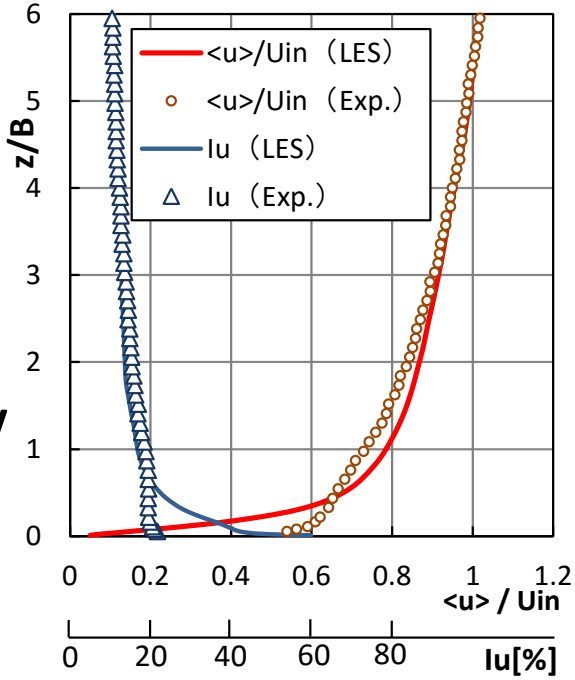
Synthetic velocity fluctuation base on Karman type dist.

Driver region

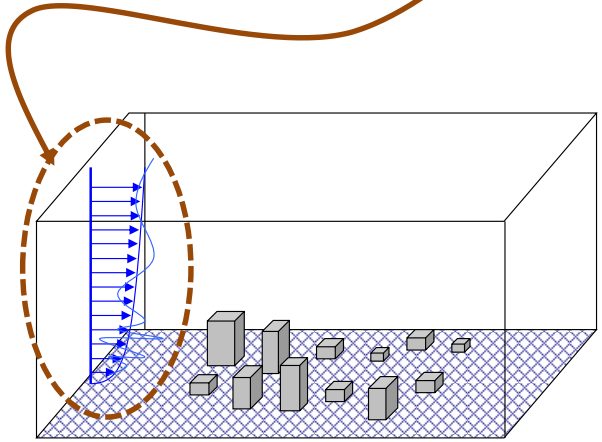


Store on storage

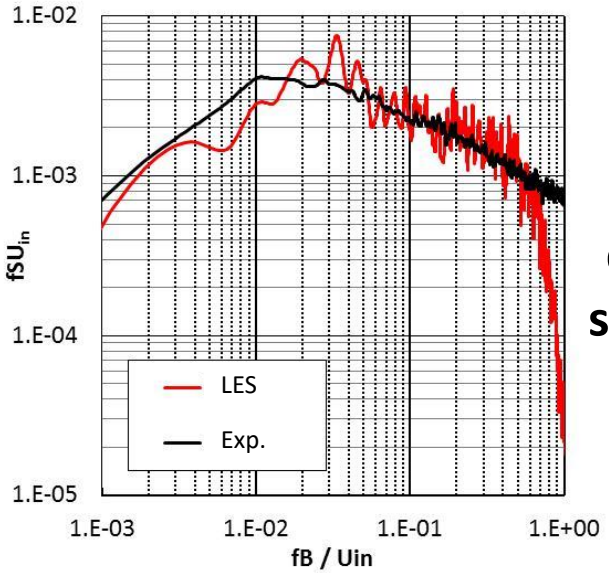
Mean streamwise velocity & Turb. intensity



Main calc. region

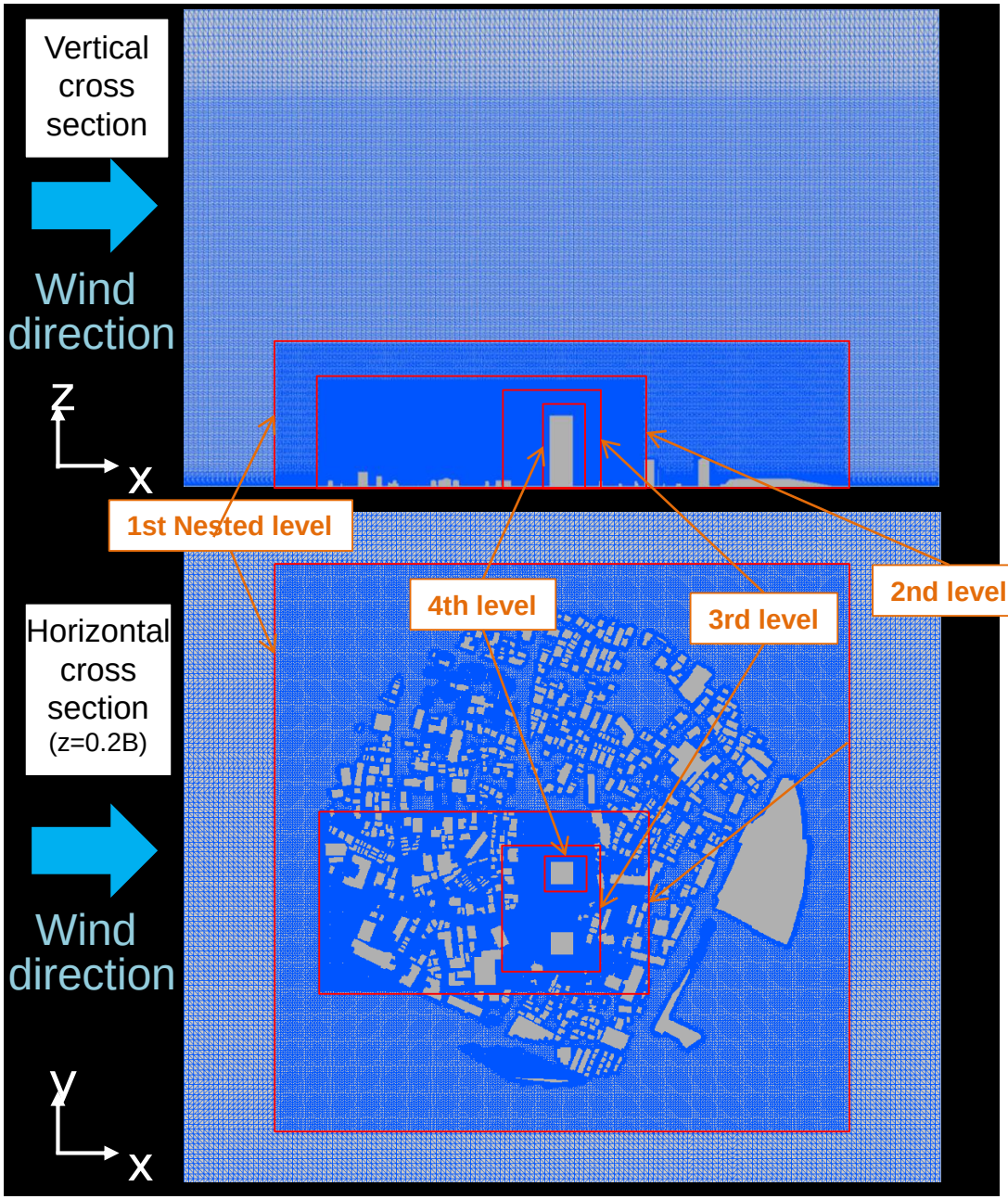


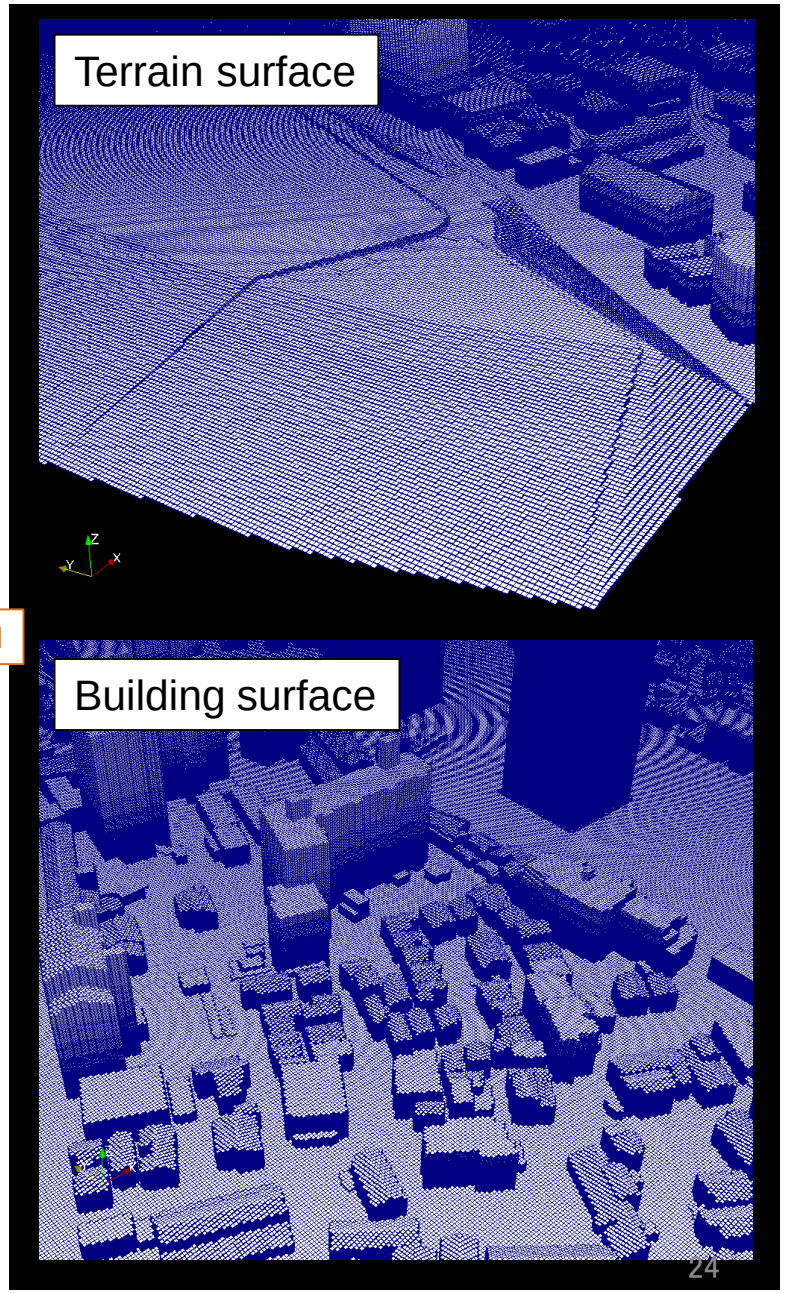
Schematic image of turbulent inflow generation



Power spectrum density of streamwise velocity at z/B=3

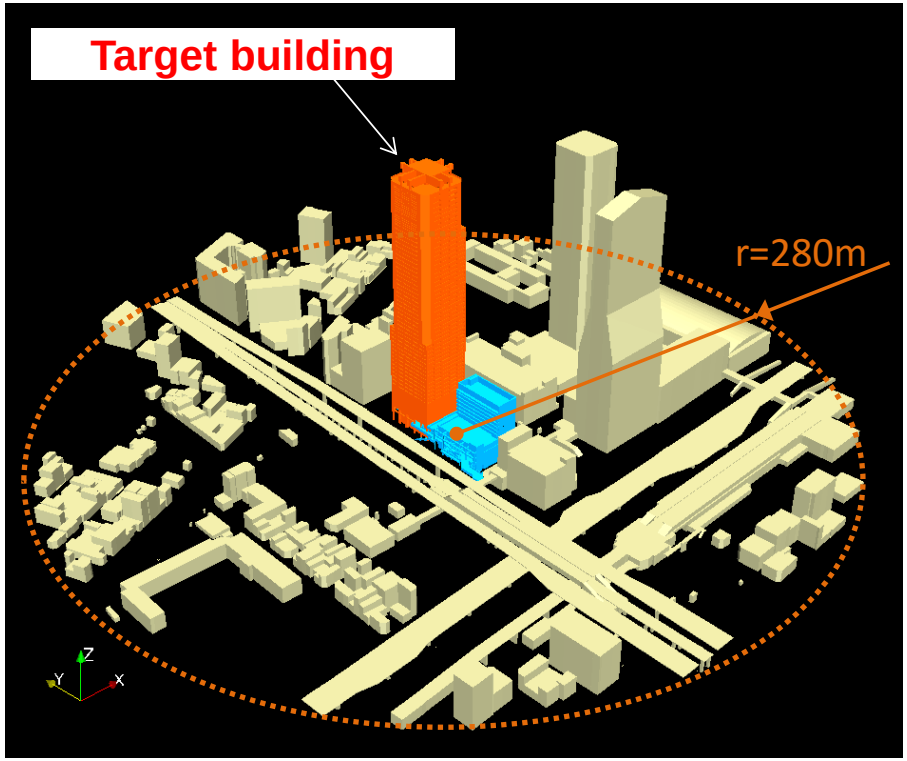
Example of Calculation Mesh



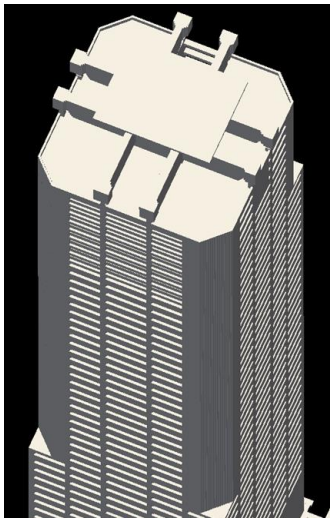


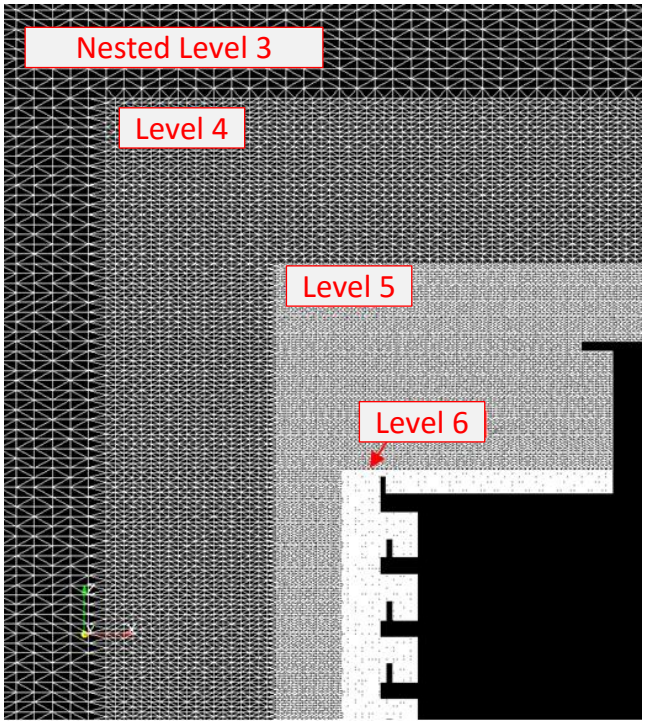
Example of Wind Pressure Prediction

- High-rise target building with corner-cut and inner balcony a high-rise urban area.
- Maximum 13 cm mesh resolution and 140M meshes.



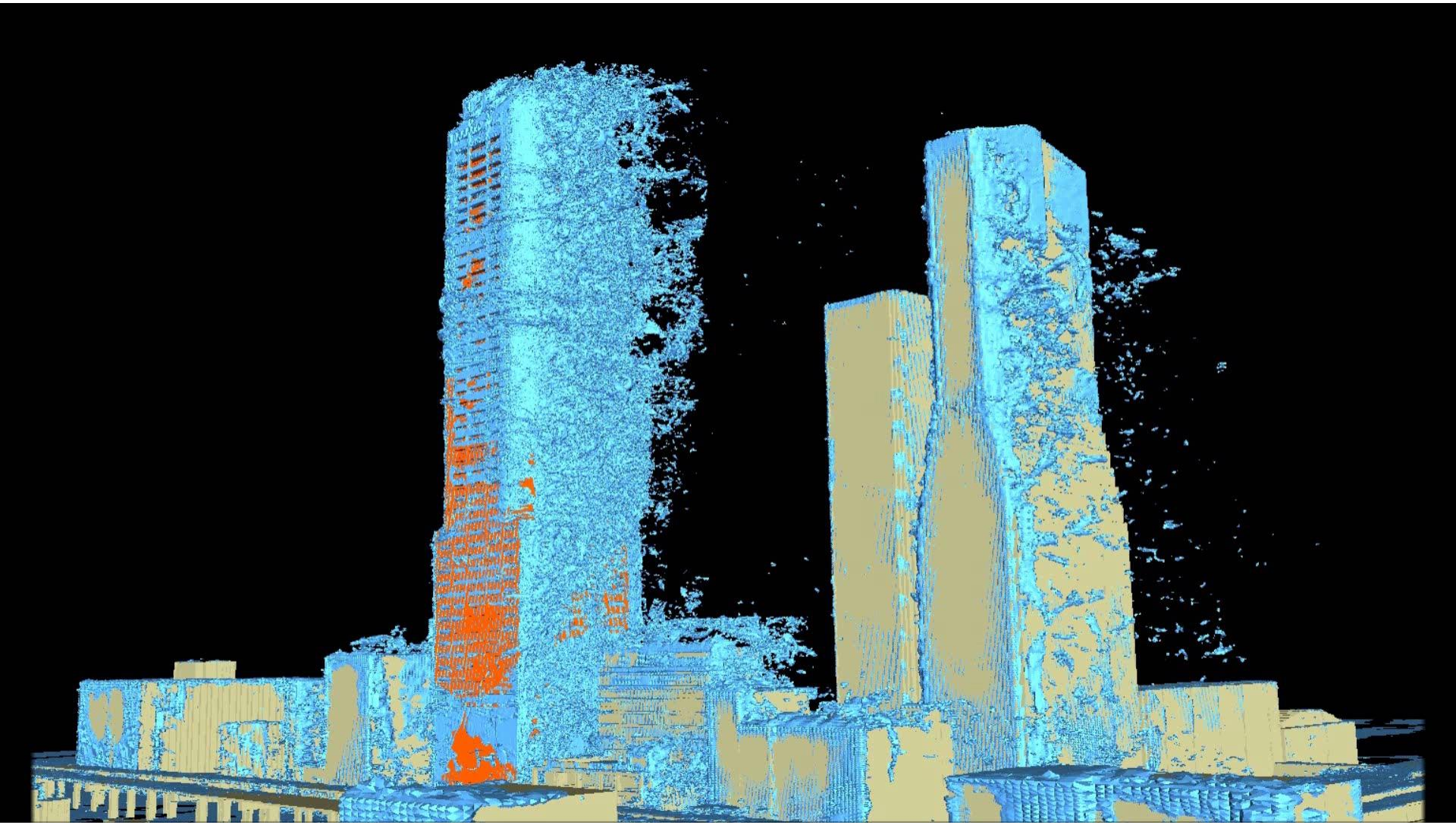
CFD model





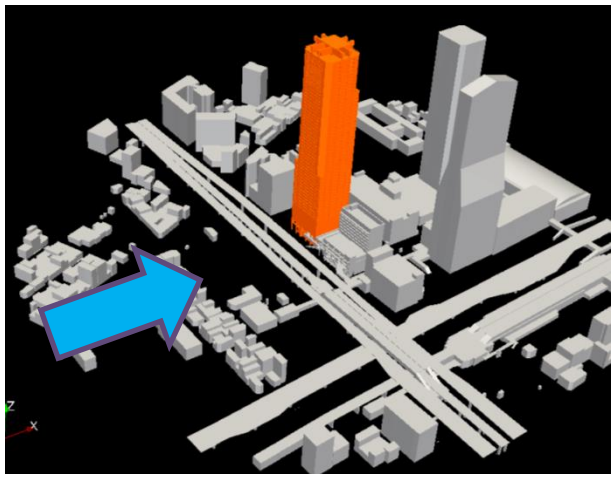
Surface mesh &
Mesh vicinity of building

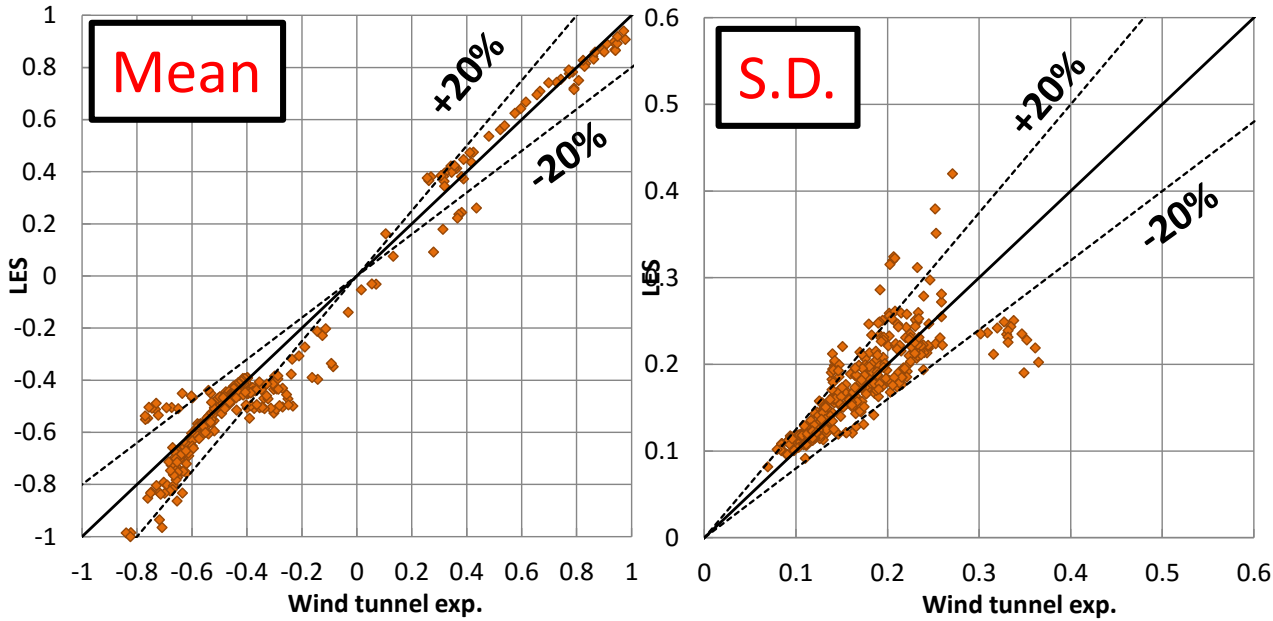
Flow Visualization

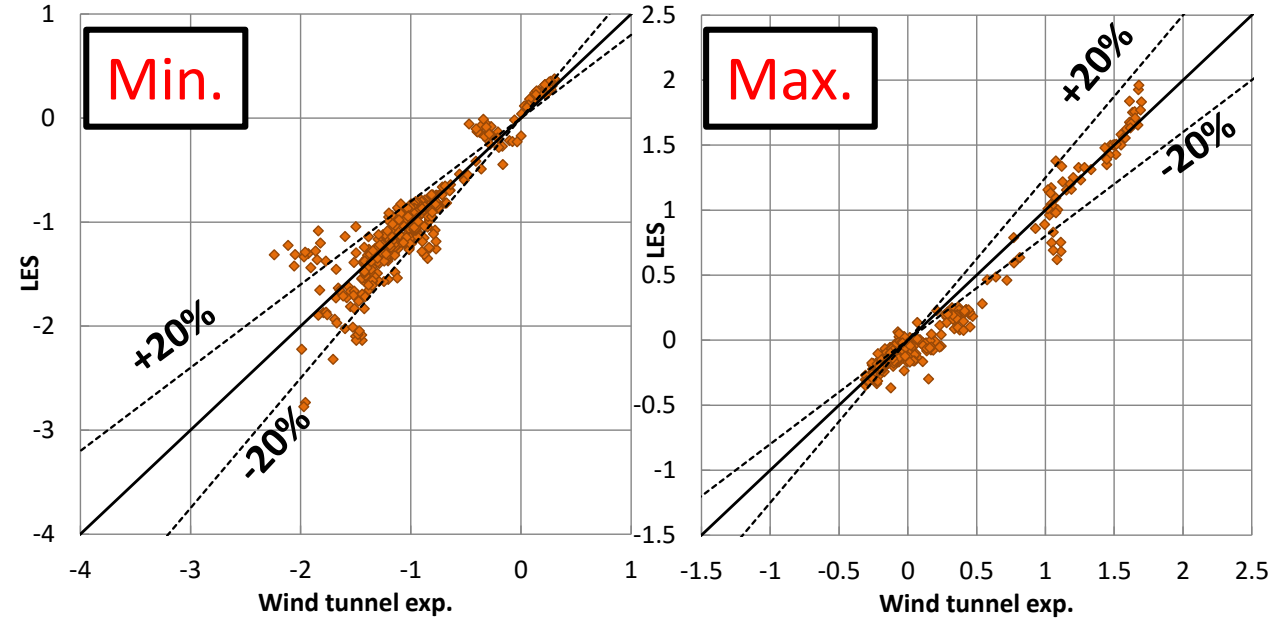


Iso-Surface contour of Vorticity Magnitude $|\omega| / (U_{in}/B)=20$

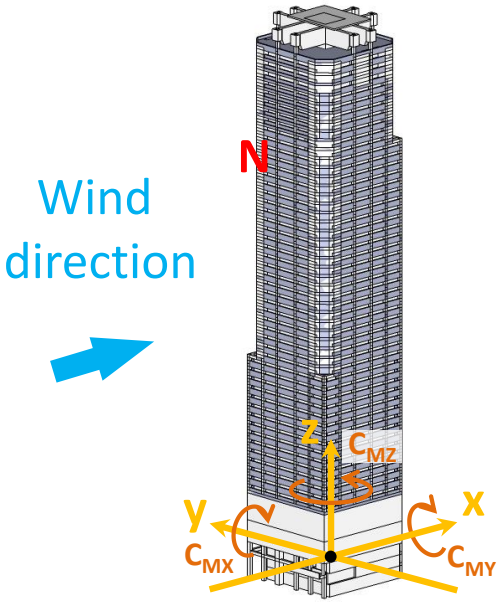
Comparison of Wind Pressure Coefficient

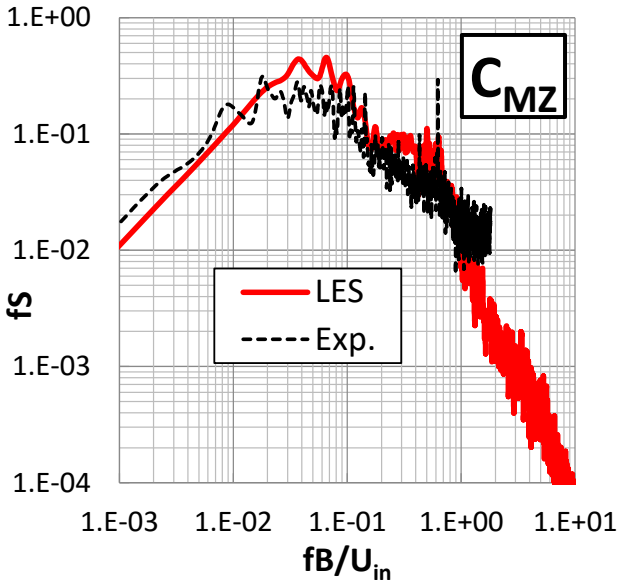




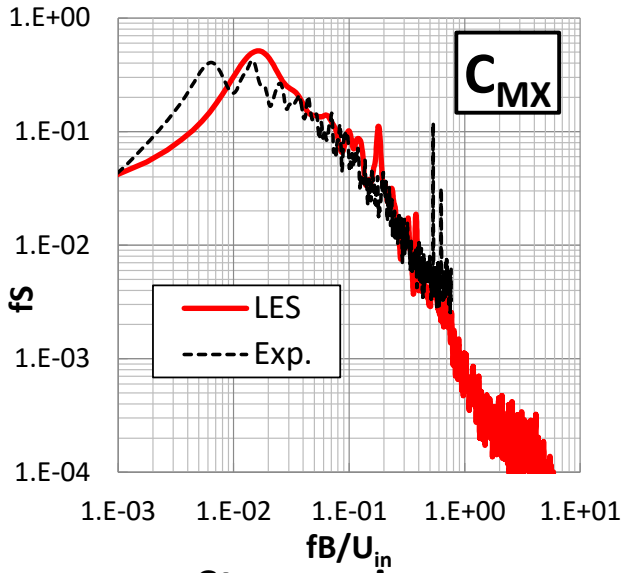


Each Moment Coefficients

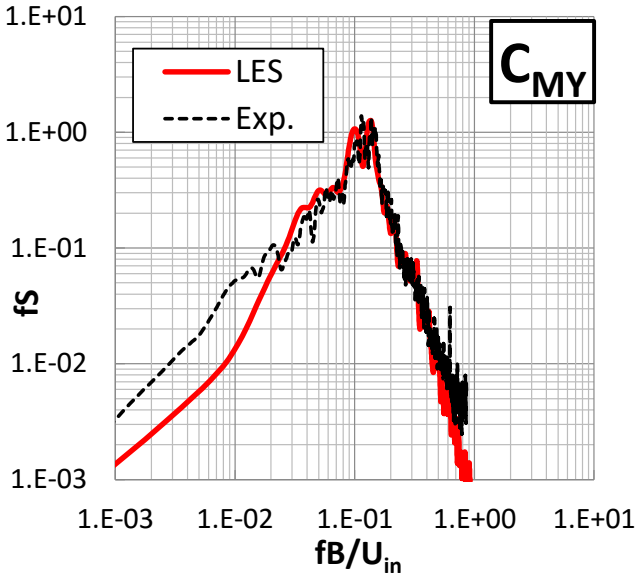




Torsional



Streamwise

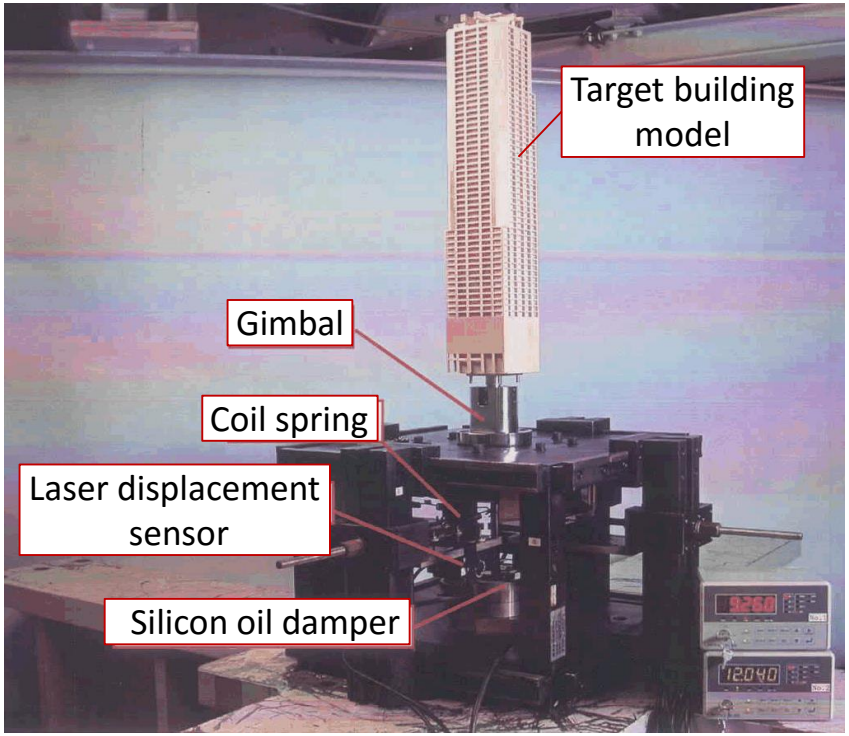


Lateral

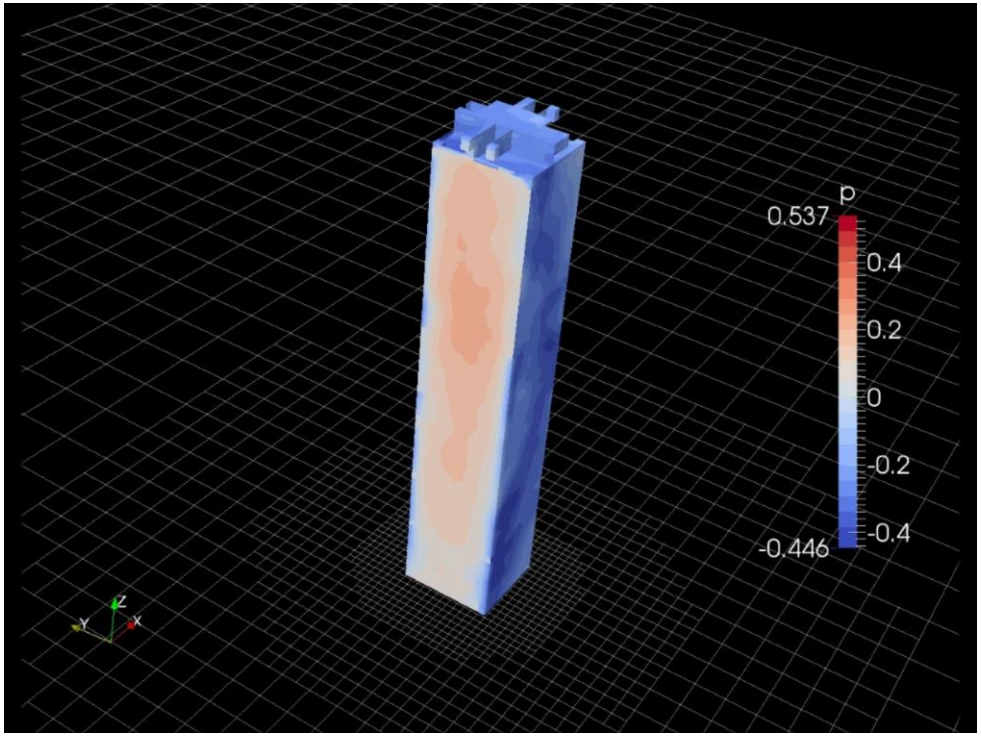
Power Spectrum Density

Aeroelastic Instability Evaluation by FSI

- Development of evaluation method of building structural vibration responseff3 caused by wind-building interaction.
- Aims to simulate aeroelastic instability of building.
- For practical use, we need to treat high-rise building with complex surface shape. → **Unexampled analysis !**

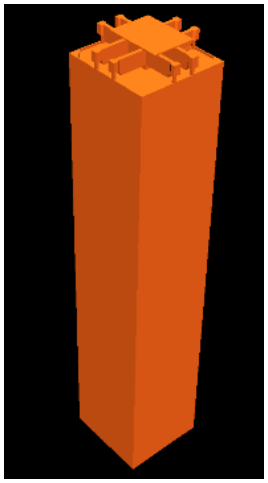


Rocking oscillation wind tunnel experiment

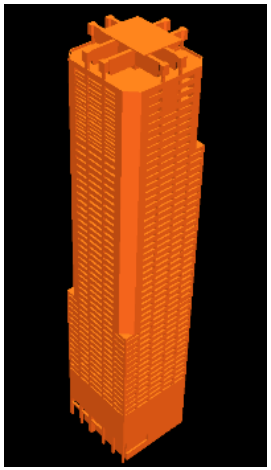


FSI simulation

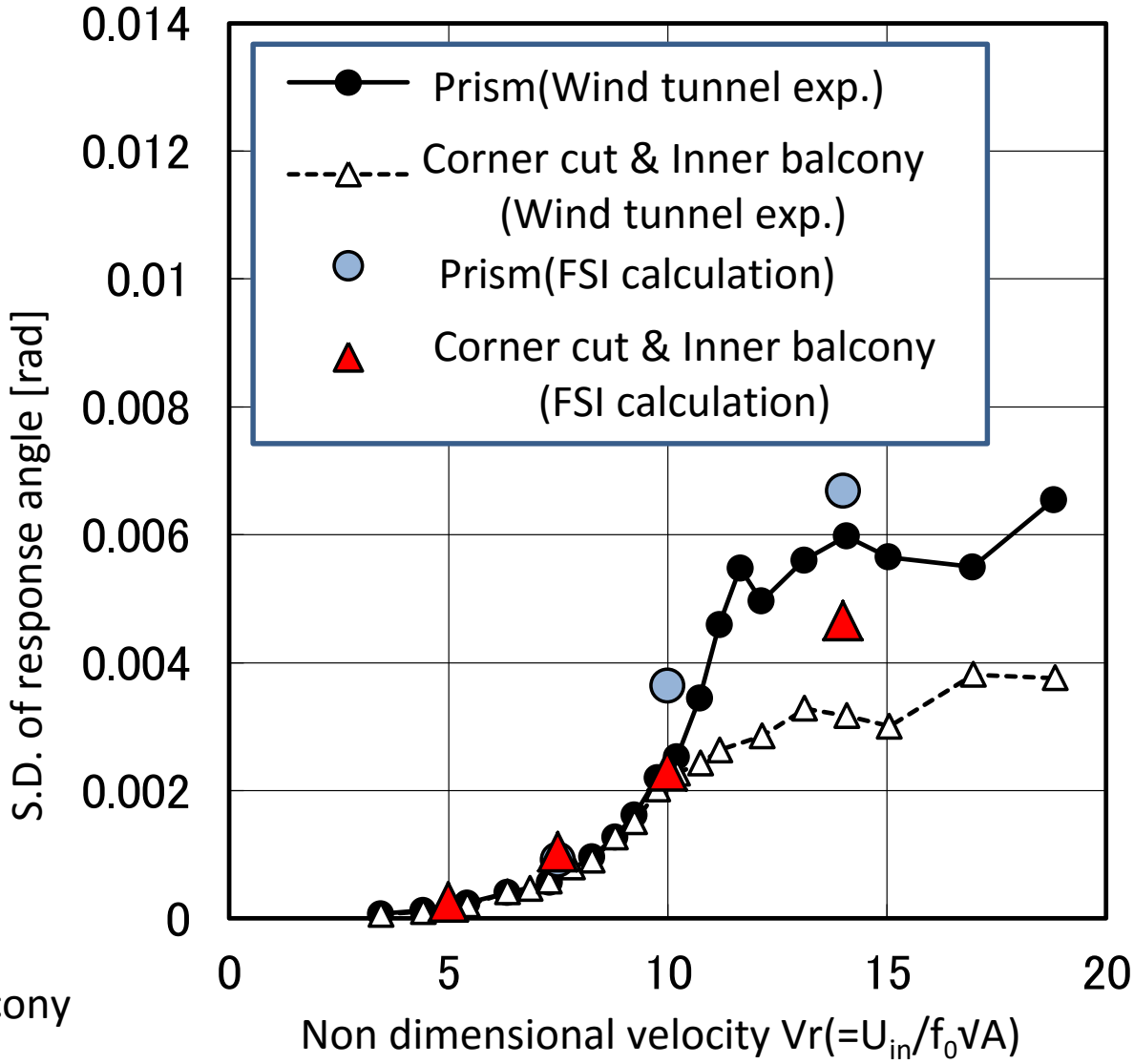
Example of FSI result



Prism



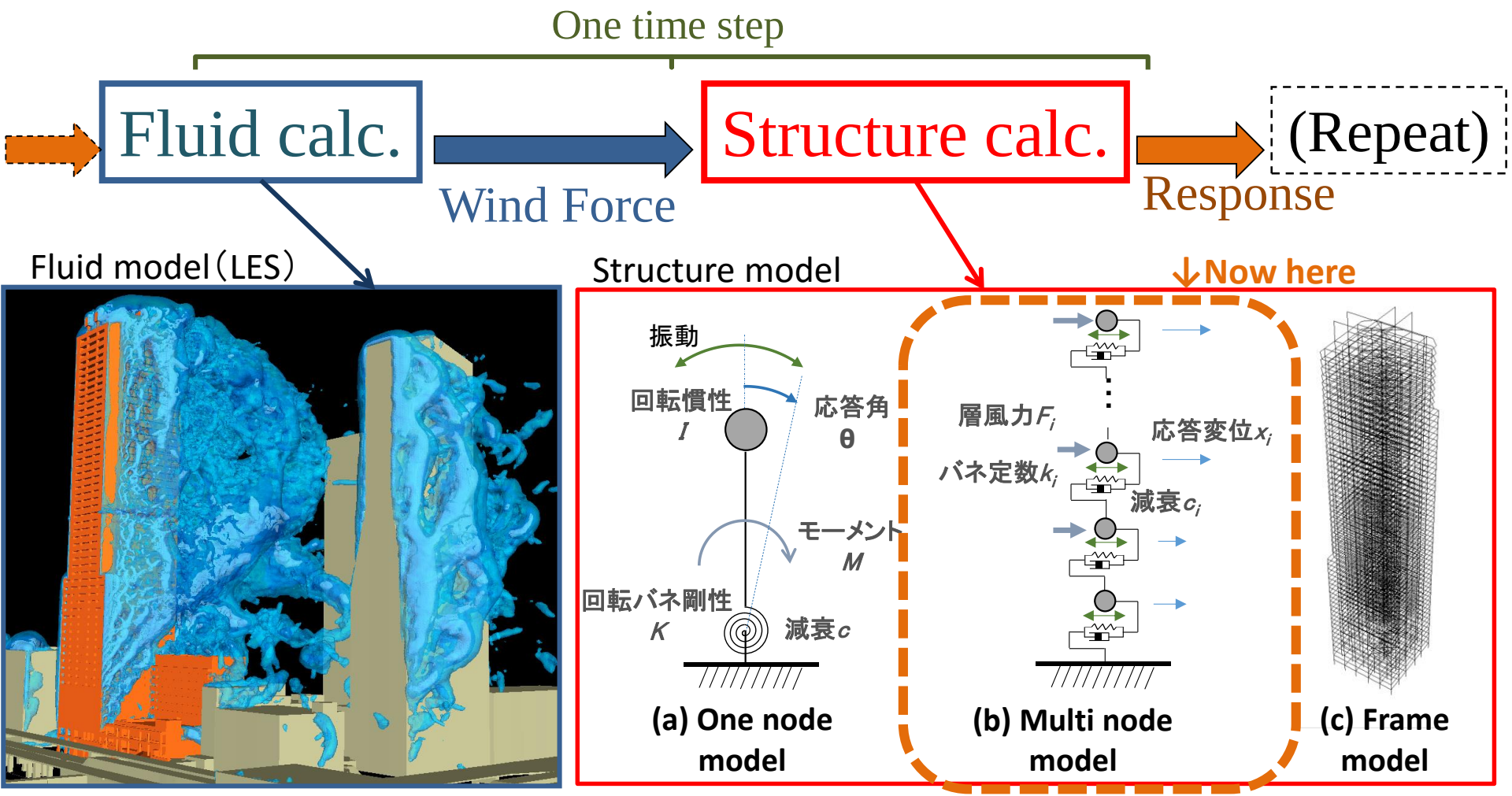
Corner cut & Inner balcony



Standard deviation of response angle (Cross wind direction)

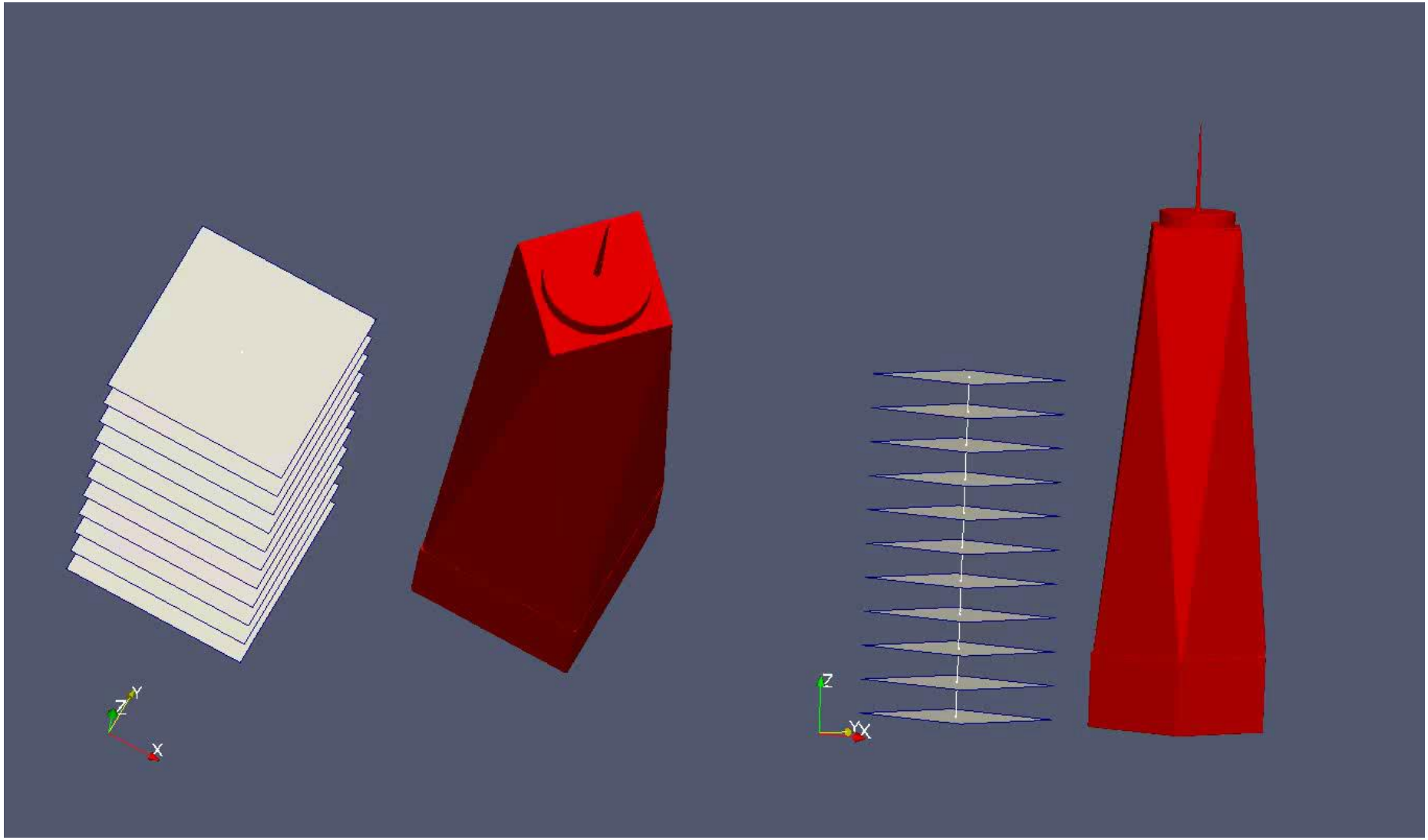
Further FSI Development

- Combination of more complicated structure model and fluid model for the evaluation of high order oscillation mode.
  - ▶ It is difficult for the wind tunnel experiment.



Mesh Motion Demonstration

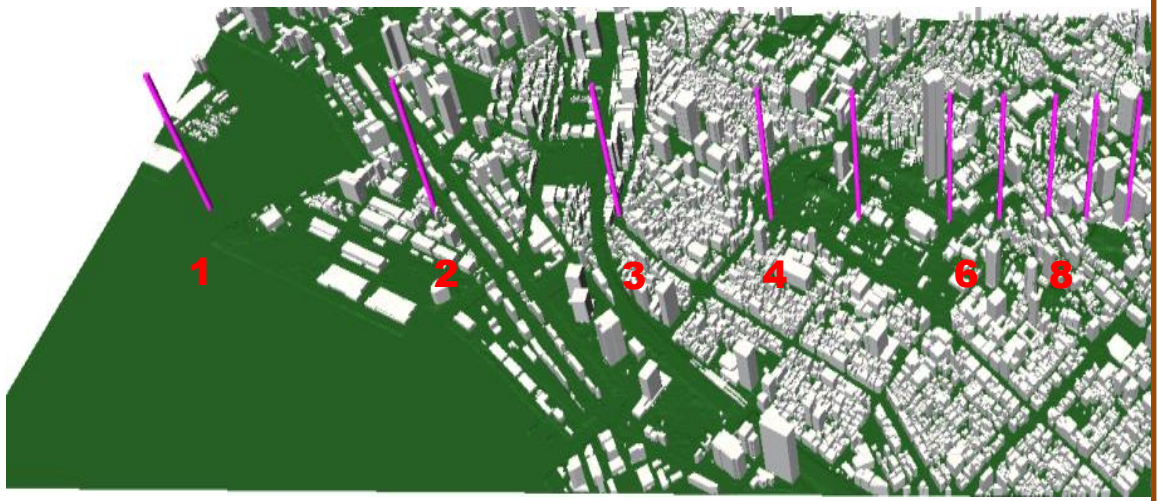
- Corresponding to the behavior of multi-node structure model.



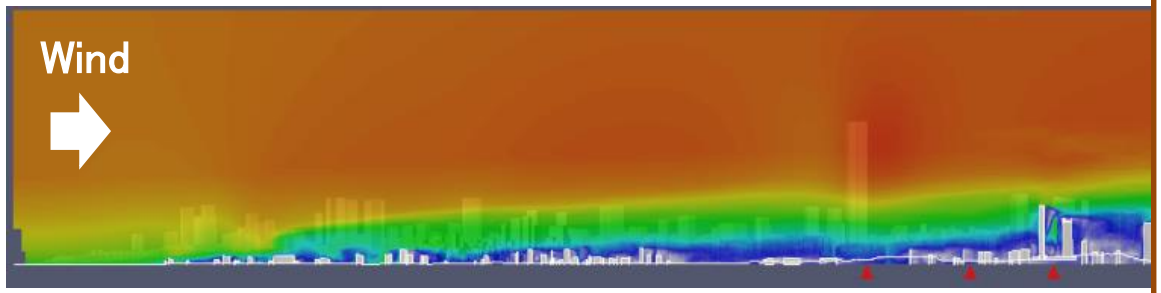
Large Urban Area Simulation

- For the establishment of rational wind r
  considering the developed boundary lay
  （Collaboration research with RIKEN・Tit

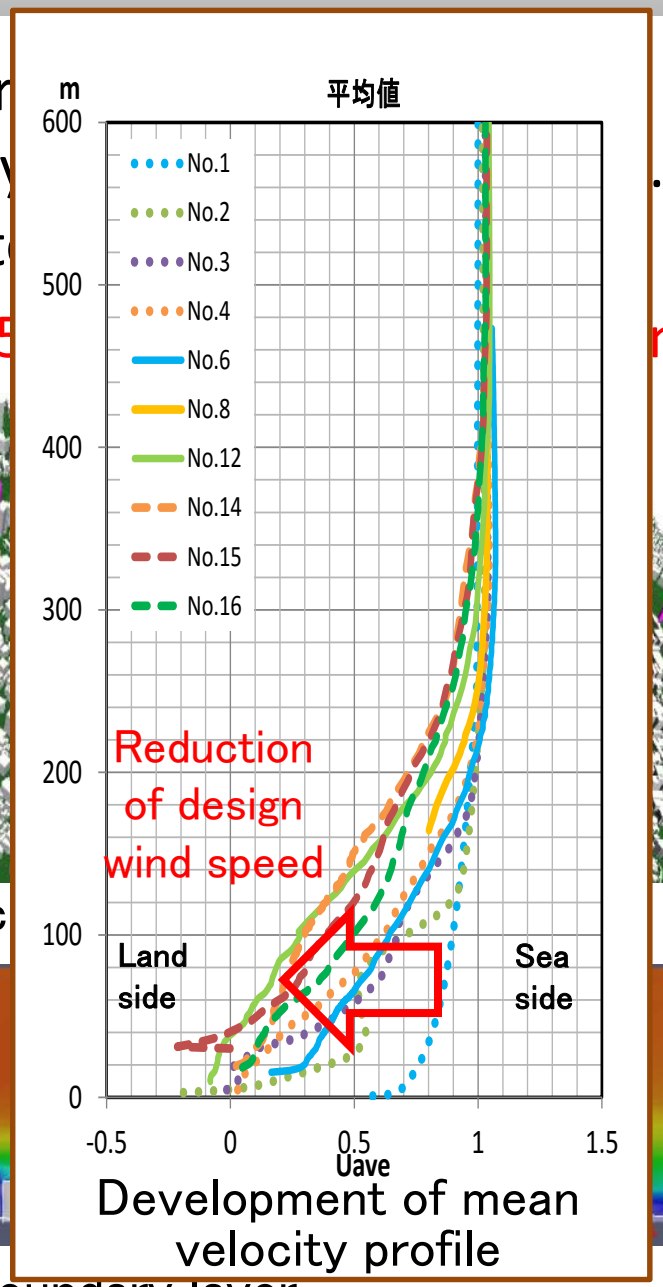
Difficult to investigate by wind tunnel➔ 25 n



Large urban CAD data and veloc



Development of urban boundary layer



Development of mean velocity profile

4. Conclusion

Conclusion

- This presentation introduced the utilization of air flow simulation in construction Field.
- To conduct the “Front loading” using BIM data, each simulations are important role, furthermore CFD is becoming one of the most important tool by the advancement of computer speed.
- As a example of CFD, wind environment, gas diffusion, dust diffusion and decay characteristics of expiratory aerosol using RANS were introduced.
- Development of numerical wind tunnel(NWT) for practical wind load evaluation using LES was introduced.
- The aim of NWT is not only Low cost & short term evaluation, but also achieving a valuable building design by the simultaneous shape optimization for establish “HPC oriented design process”.



Sotatsu Tawaraya, Fujin Raijin zu (Image of the Wind and Thunder Gods in Ancient Japan)