Research and Development of Wind Environment Evaluation Method Using Geographic Information System (GIS) to Support Planning

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1. Introduction

There has been an increase in the importance toward understanding the urban wind environment, such as the measures against strong winds in structures, the comfortable urban spaces in harmony with the environment, and the practical use of air transport such as drones. It is important to streamline the analysis process in order to use the wind simulation technology for complex urban areas. Therefore, the authors have been developing a software "Airflow Analyst" (AFA), that integrates computational fluid dynamics (CFD) on a general-purpose geographic information system (GIS). AFA is a system that realizes (1) the calculation grid generation, (2) airflow simulation, and (3) visualization and analysis of the results on a map. It has a feature in which the planner can focus on decision-making such as studying the analysis results and alternatives, without using data conversion and multiple softwares in the analysis. There are reports of using GIS data for CFD analysis, but no case has been fully integrated on the GIS platform. For airflow simulation, a solver (RC-GIS) based on the large-eddy simulation (LES) model that can reproduce wind phenomena, was adopted [1]. In this paper, we use this analysis system to perform a benchmark test of urban wind condition prediction and verify the prediction accuracy. Additionally, we will conduct wind condition prediction and evaluate ventilation performance of urban spaces to confirm the effectiveness of the tool.

2. Benchmark test methods and results

Verification is performed based on the model, "Building complexes with simple building shape in actual urban area (Niigata)," using the benchmark test [2] published by the Architectural Institute of Japan. In the Table 1, the RC-GIS calculation algorithm is displayed. The specified city shape was imported into the GIS, and computational grids and numerical simulations were performed using the AFA software and compared with the results of wind tunnel experiments. The minimum grid width in calculation grid was 1 m in the horizontal direction and 0.5 m in the vertical direction, and the interval was widened toward the periphery, thereby forming a calculation grid of 350 × 350 × 80 (Fig. 1). Calculation for 16 directions was performed by rotating the calculation grid, with the center point of the city model as the origin.

Unsteady calculation by LES was performed for 50,000 steps, and the average wind speed was obtained and evaluated from the calculation results for the latter 15,000 steps. The time required for the calculation was about 180 minutes per wind direction using NVIDEA’s GeForce GTX 1080 (8-GB memory).

When the wind speed ratios of W and NNE that are the prevailing wind directions in the simulation results are compared with those in the wind tunnel experiment, they show generally good agreement as shown in the Figs. 2 and 3. At 24,25, and 28 in the case of the E wind, and

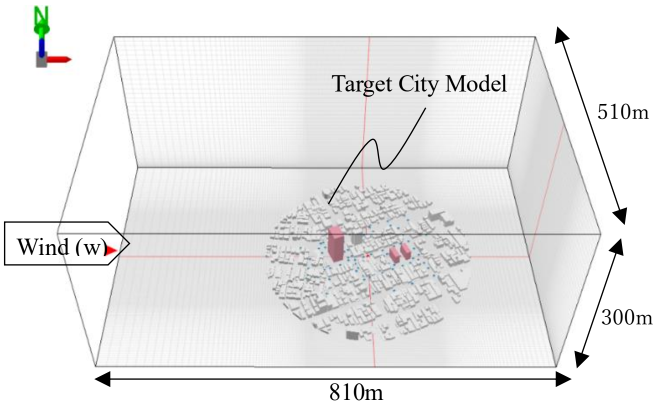

Fig. 1 Calculation Domain

Table 1 Calculation Method

Inflow Boundary Condition	Speed Profile Specified in Benchmark
Top and Side Boundary Conditions	Slip Wall
Outflow Boundary Conditions	Zero Gradient
Wall and Ground Boundary Conditions	Adhesion Condition
Discretization Method	Finite-Difference Method (FDM)
Turbulence Model	LES (Standard Smagorinsky SGS Model)
Poisson Equation for Pressure	Successive Over-Relaxation (SOR) Method
Convective Term	3rd-order Upwind Biased Scheme based on an Interpolation Method ($\alpha = 0.5$)
Time Advancement Method	Euler Explicit Method
Coupling Algorithm	Fractional Step (FS) Method
Computational Grid Division Method	Structured Grid (Unequally Spaced Orthogonal)

23,26, and 28 in the case of the NNE wind, the predicted values are overestimated compared with experimental values. This corresponds to a speedup area because of the separation of the corners of a high-rise building. The distribution tendency of the entire remaining area is well reproduced. Looking at the correlation and average absolute error of each wind direction in 16 directions, the wind speed ratio can be predicted with a correlation of about 80% and an absolute error rate of about 10%, and the prediction accuracy is good for all wind directions (Table 2).

3. Evaluation of wind ventilation in real city area

As an example of an application for actual urban development, the wind environment around the new national stadium in Tokyo was evaluated. AW3D [3] provided as detailed 3D GIS data was used to reproduce the topography, buildings, and trees of the target area. For the shape of the new national stadium, a 3D model was created using CAD and placed on the spatial database. Under the calculation conditions for North wind shown in the Table 3, calculation was performed (Fig.5).

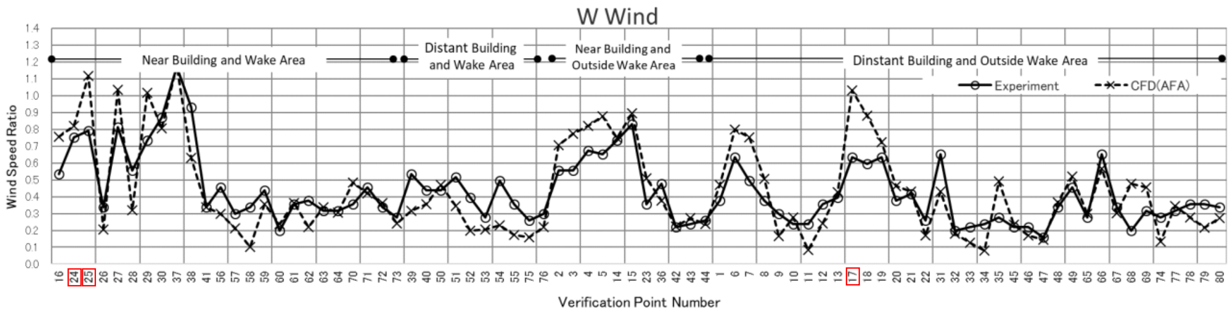

Fig. 2 Comparison of Wind Speed from W (U/Uin)

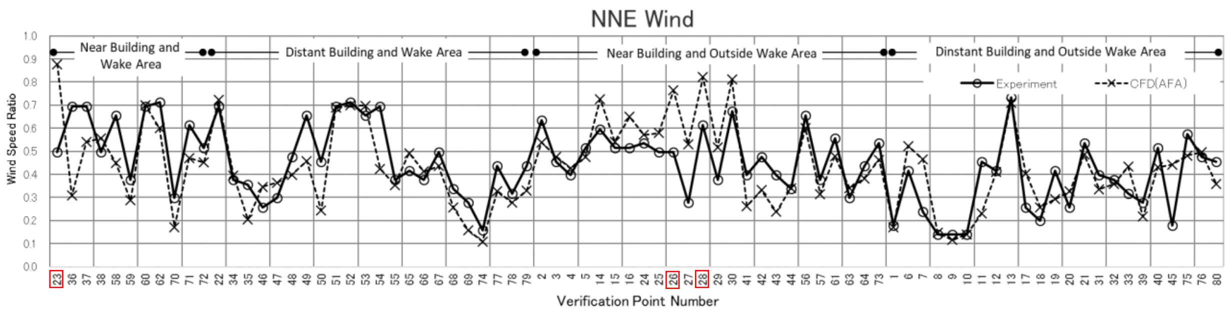

Fig. 3 Comparison of Wind Speed from NNE (U/Uin)

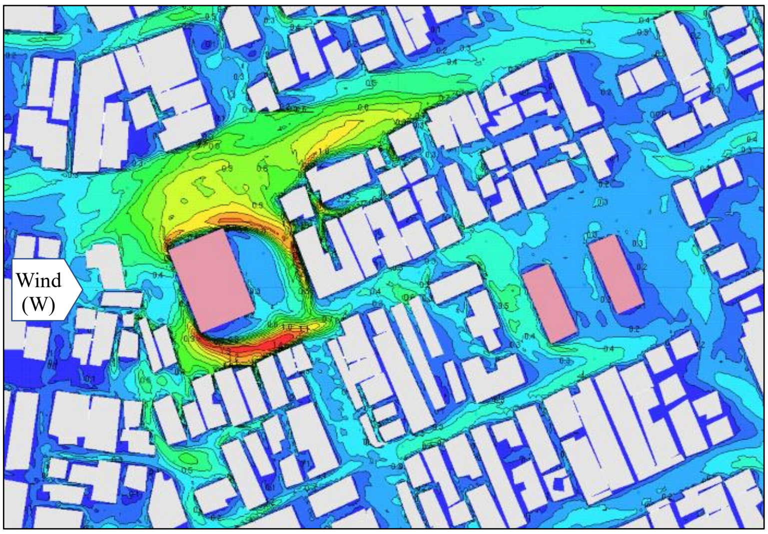

Fig. 4 Wind Speed Rate from W（2m Above the Ground）

Table 2 Prediction Accuracy of 16 Wind Directions

Wind Direction	Correlation Coefficient	Mean Absolute Error
N	69.1%	0.13
NNE	71.2%	0.10
NE	73.5%	0.11
ENE	79.5%	0.10
ENE	87.4%	0.09
ESE	79.6%	0.12
SE	77.4%	0.11
SSE	74.2%	0.10
S	84.5%	0.10
SSW	84.5%	0.10
SW	90.6%	0.10
WSW	86.0%	0.10
W	84.8%	0.11
WNW	84.2%	0.11
NW	79.9%	0.15
NNW	83.0%	0.09

Next, a diffusion simulation was performed with a virtual air mass inside the stadium. The time taken for the concentration of the air mass to decrease sufficiently was measured. The results showed that at a wind speed of 3 m/s outside the stadium, the air mass inside the stadium (Point A, B and C) was replaced by the air from outside in about 13 minutes (Fig.7.1, 7.2)

Ventilation in large spaces with large numbers of people has become an important measure against Covid-19 infection. The numerical simulation of natural wind flowing through a complex urban area made it possible to evaluate the building ventilation performance in advance. This method is useful for future facility design and operation.

Table 3 Calculation Condition

Calculation Domain	1032m, 780m, 285m
Number of Calculation Grid	400 × 330 × 92 (12,144k mesh)
Minimum Grid Spacing	1.5m, 1.5m, 0.5m
Stadard Height	40m
Δt	0.002
Inflow Boundary Condition	3 m/s at 40m Height Power law of α = 4
Number of Calculation Steps	75,000 steps (Evaluate based on Last 25,000 steps)

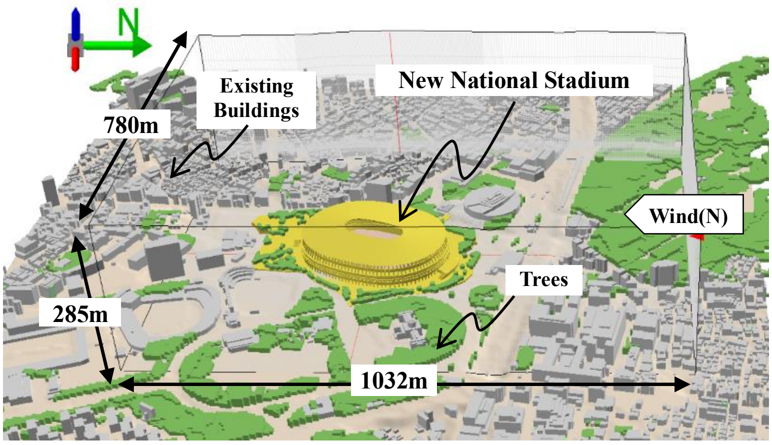

Fig. 5 Calculation Domain

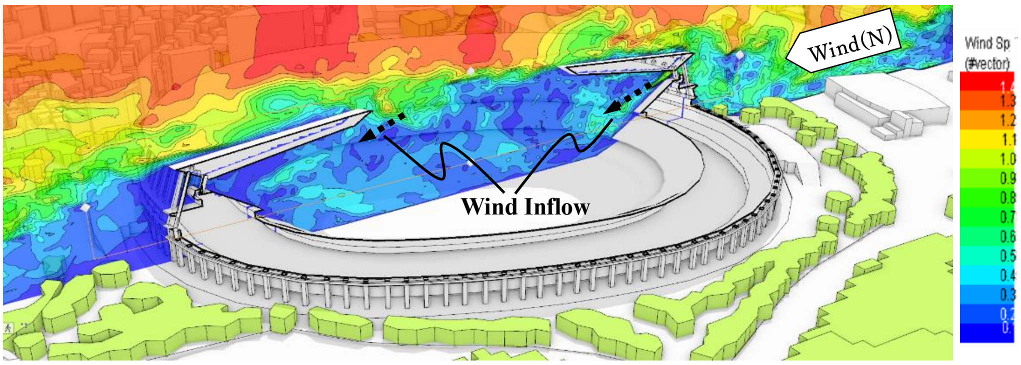

Fig. 6 Wind Speed at Vertical Section of the Stadium (Stadium Roof is Hidden)

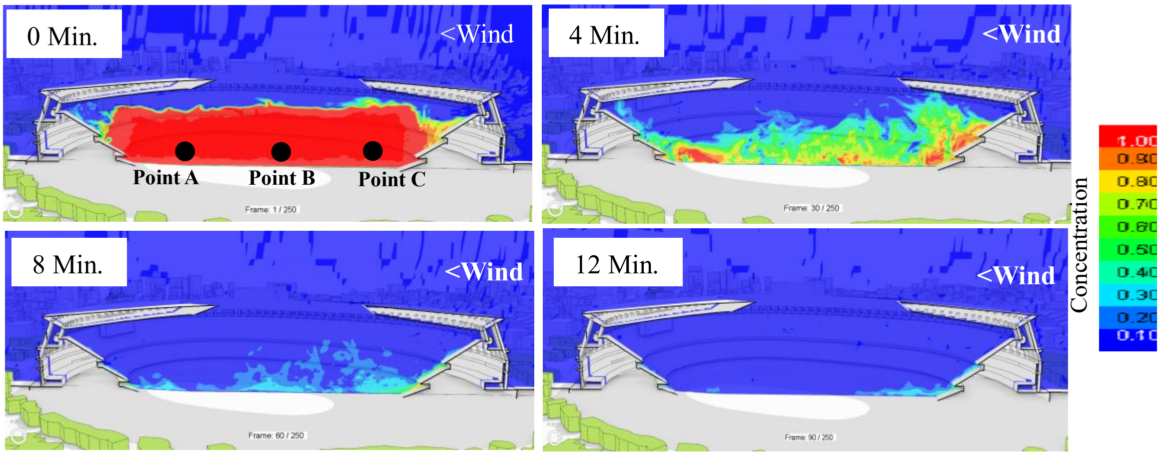

Fig. 7.1 Time Variation of the Concentration of a Virtual Air Mass

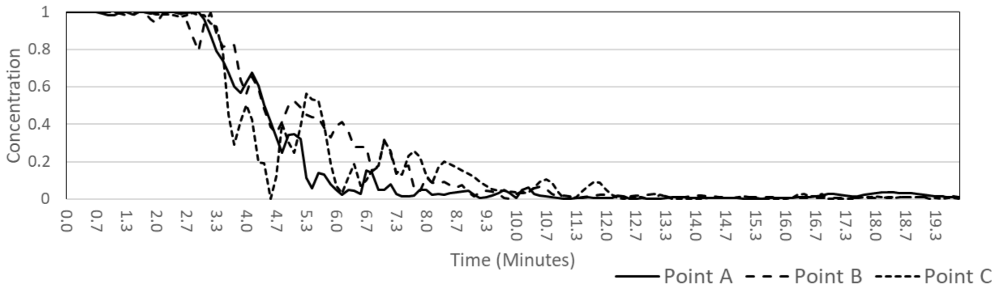

Fig. 7.2 Time Variation of the Concentration of a Virtual Air Mass

4. Conclusion

In this paper, we developed AFA, a CFD tool integrated with GIS, and verified the prediction accuracy using benchmark tests. Calculations using LES showed good agreement with the wind tunnel experiment results. Next, as an actual development example, the urban area around the new national stadium was reproduced using existing spatial data and CAD and analyzed using GIS. As a result, it was possible to confirm the wind pattern inside and outside the stadium and to quantitatively evaluate the ventilation in the stadium by natural wind flowing through the city. Normally, this kind of simulation requires a large amount of time to create a calculation grid that reproduces the precise shape of the indoor and outdoor areas. This system, which is linked to the GIS and CAD technology, has proven to be an efficient way to simulate such a situation.

References

[1] T. Uchida and R. Araya: Practical Applications of the Large-Eddy Simulation Technique for Wind Environment Assessment around New National Stadium Japan (Tokyo Olympic Stadium), Open Journal of Fluid Dynamics, Vol.09 No.04 (2019),

[2] Architectural Institute of Japan: Working group for CFD prediction of pedestrian wind environment around building: Guidebook for Practical Applications of CFD to Pedestrian Wind Environment around Buildings, https://www.aij.or.jp/jpn/publish/cfdguide/

[3] NTT Data and RESTEC: AW3D, https://www.aw3d.jp/products/building/

[4] T. Uchida and R. Araya: Practical Applications of the Large-Eddy Simulation Technique for Wind Environment Assessment around New National Stadium, Japan (Tokyo Olympic Stadium), Open Journal of Fluid Dynamics, Vol.9 No.4, 2019