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Integration of Fire Spread Models for Wildland and Urban Areas for the Coupled Simulation of Fire Behavior at their Interfaces

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1. Background and Objectives

To examine the effectiveness of measures against wildland-urban interface (WUI) fires, a computational model that can reasonably predict fire behavior in WUI areas need to be developed. To date, most models are designed primarily for predicting fire behavior in wildland areas and rarely for predicting building-to-building fire spread. Unlike other countries, cities in Japan have historically experienced large urban conflagrations. Consequently, there is extensive knowledge on prediction models for building-to-building fire spread in urban areas. To leverage this circumstance, this study aims to integrate the prediction model for fire spread in wildland fuels with the prediction model for fire spread in urban areas developed in Japan, so that the integrated model can predict the damage caused by WUI fires.

2. Methods

The computational flow of the integrated model is shown in Fig. 1. In this study, the model proposed by Himoto et al. (2008) is used to predict fire spread in urban areas, and the model proposed by Rothermel (1972) is used to predict fire spread in wildland fuels. Integrating the two models requires the introduction of common temporal and spatial axes and the determination of coupling conditions that control fire spread from one side to the other. The coupling conditions include two scenarios:

(1) the radiant heat flux from a fire source on one side to combustibles on the other side exceeds a certain level, and

(2) firebrands from a fire source on one side are scattered by the wind and ignite combustibles on the other side.

For scenario (1), a three-dimensional solid flame model is set up at the fire source, from which the radiative heat flux to combustibles is calculated based on their geometrical relationship. For scenario (2), a statistical model based on the results of past full-scale experiments is used to calculate probabilistic spattering ranges of firebrands according to the size of the fire source and wind velocity.

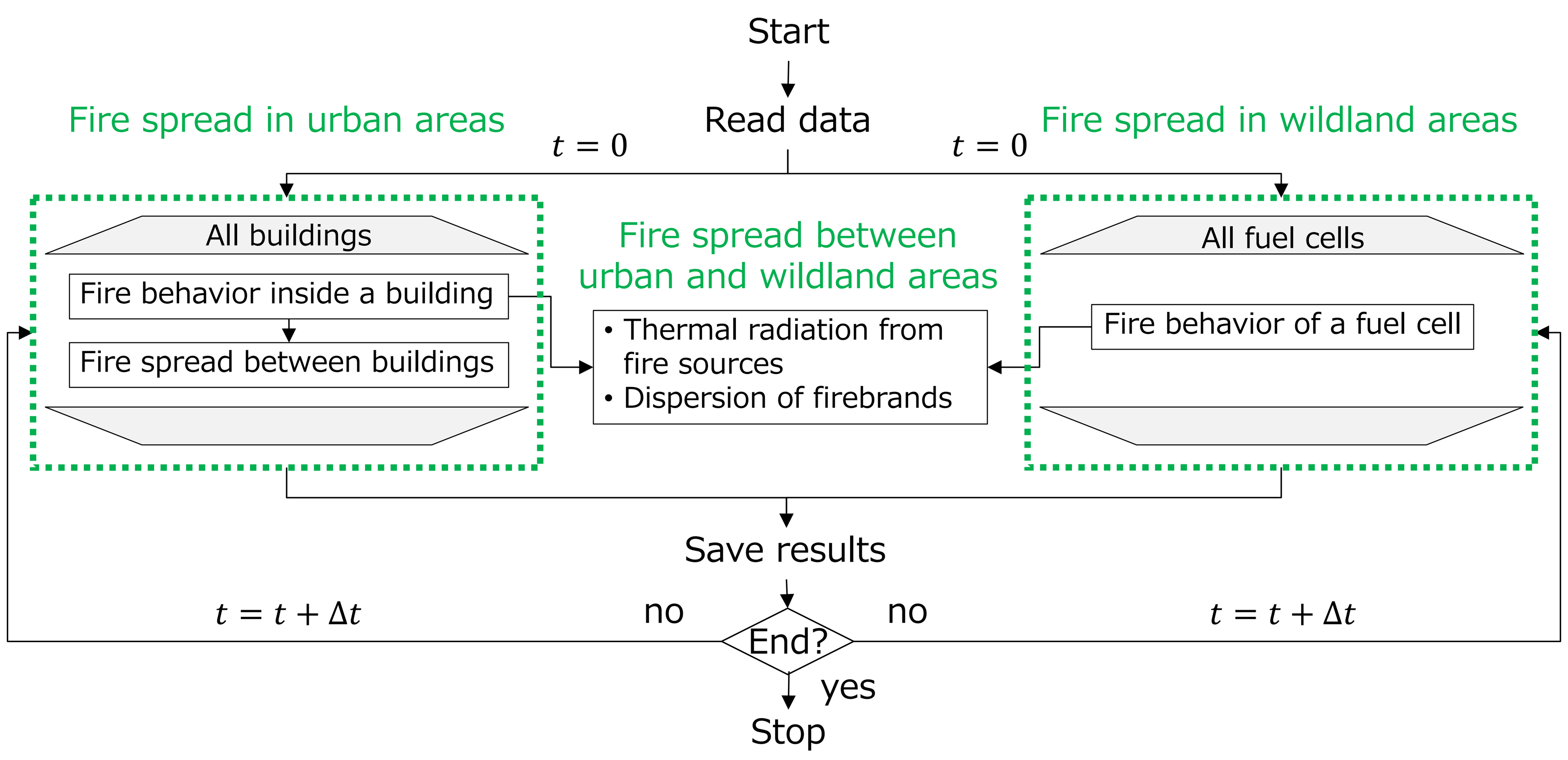

Fig. 1. Computational flow of the integrated model.

2.1 Fire spread in urban areas

The model predicts fire behavior inside a building using a one-layer zone model, whose governing equations are shown below. Based on the results, the model evaluates the hazard of each burning building to its neighboring buildings and predicts the spread of fire in urban areas.

Mass: $\frac{d}{dt}(\rho_i V_i) = \sum_j (\dot{m}_{ji} - \dot{m}_{ij}) + \dot{m}_{F,i}$

Energy: $\frac{d}{dt}(c_P \rho_i T_i V_i) = \dot{Q}_{B,i} - \sum_j \dot{Q}_{L,ij} + \sum_j (c_P \dot{m}_{ji} T_j - c_P \dot{m}_{ij} T_i) - \dot{m}_{F,i} L_P$

Chemical species: $\frac{d}{dt}(\rho_i V_i Y_{X,i}) = \sum_j (\dot{m}_{ji} Y_{X,j} - \dot{m}_{ij} Y_{X,i}) + \dot{\Gamma}_{X,i}$

State: $P = \rho_i R T_i$

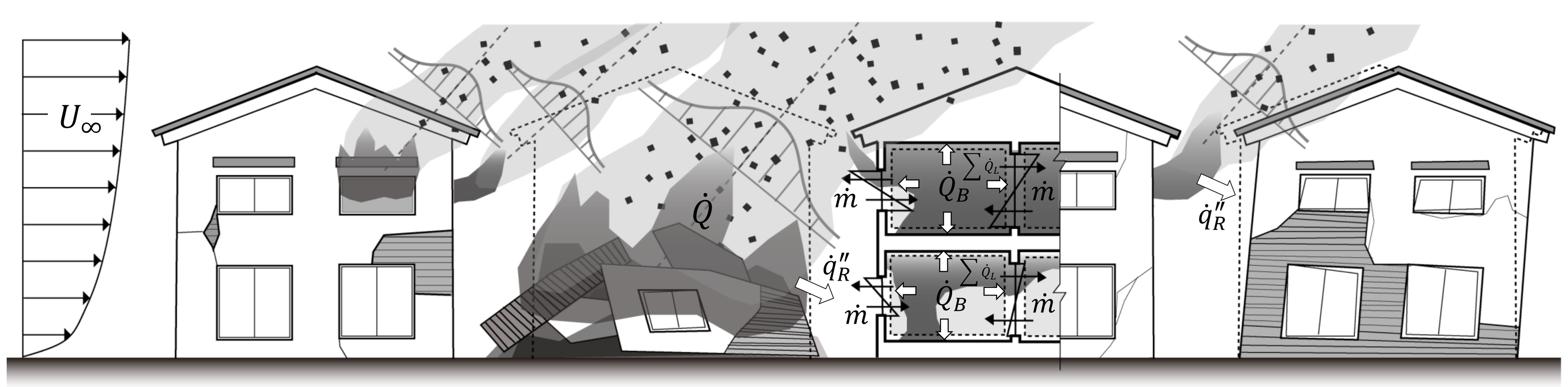

Fig. 2. Schematic of the model for fire spread in urban areas (Himoto et al., 2008).

2.2 Fire spread in wildland areas

The model predicts the rate of fire spread in wildland fuels by comprehensively incorporating fuel, terrain, and weather parameters. To simulate fire spread in wildland areas, the target area is discretized into equally spaced meshes, and the following equation is implemented.

Rate of surface fire spread: $V = \frac{I_R \xi (1+\phi_W+\phi_S)}{\rho_b \varepsilon Q_{ig}}$

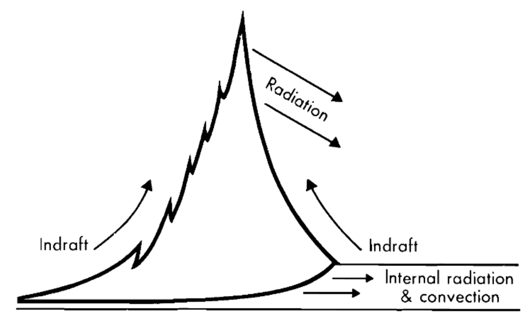

Fig. 3. Schematic of the model for fire spread in wildland areas (Rothermel, 1972).

2.3 Fire spread between urban and wildland areas

The model calculates the radiant heat flux from a burning building in an urban area to an unignited fuel cell in a wildland. Ignition of the unignited fuel cell, indicating the spread of fire from the urban to the wildland interface, is assumed to occur when a critical heat flux is reached. Similar calculations were developed for fire spread from wildland to urban areas. The model also accounts for fire spread due to scattered firebrands, considering their mutual interactions.

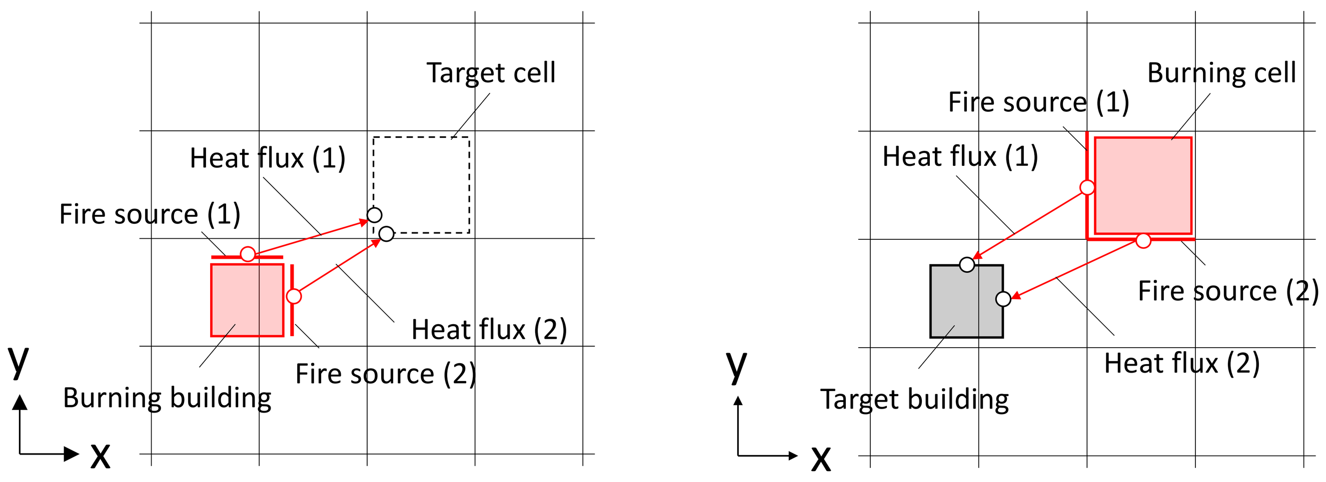

Fig. 4. Fire spread by radiant heat transfer from a burning building to its adjacent cells (left), and from a burning cell to its adjacent buildings (right).

3. Results

Using the integrated model developed in this study, the conditions under which a fire in a wildland area would spread to buildings in an adjacent urban area under a hypothetical WUI environment. A snapshot of the simulation is shown in Fig. 5. To assess the effect of parameter values on the simulation results, we systematically varied wind direction and velocity, and the conditions of surface fuels.

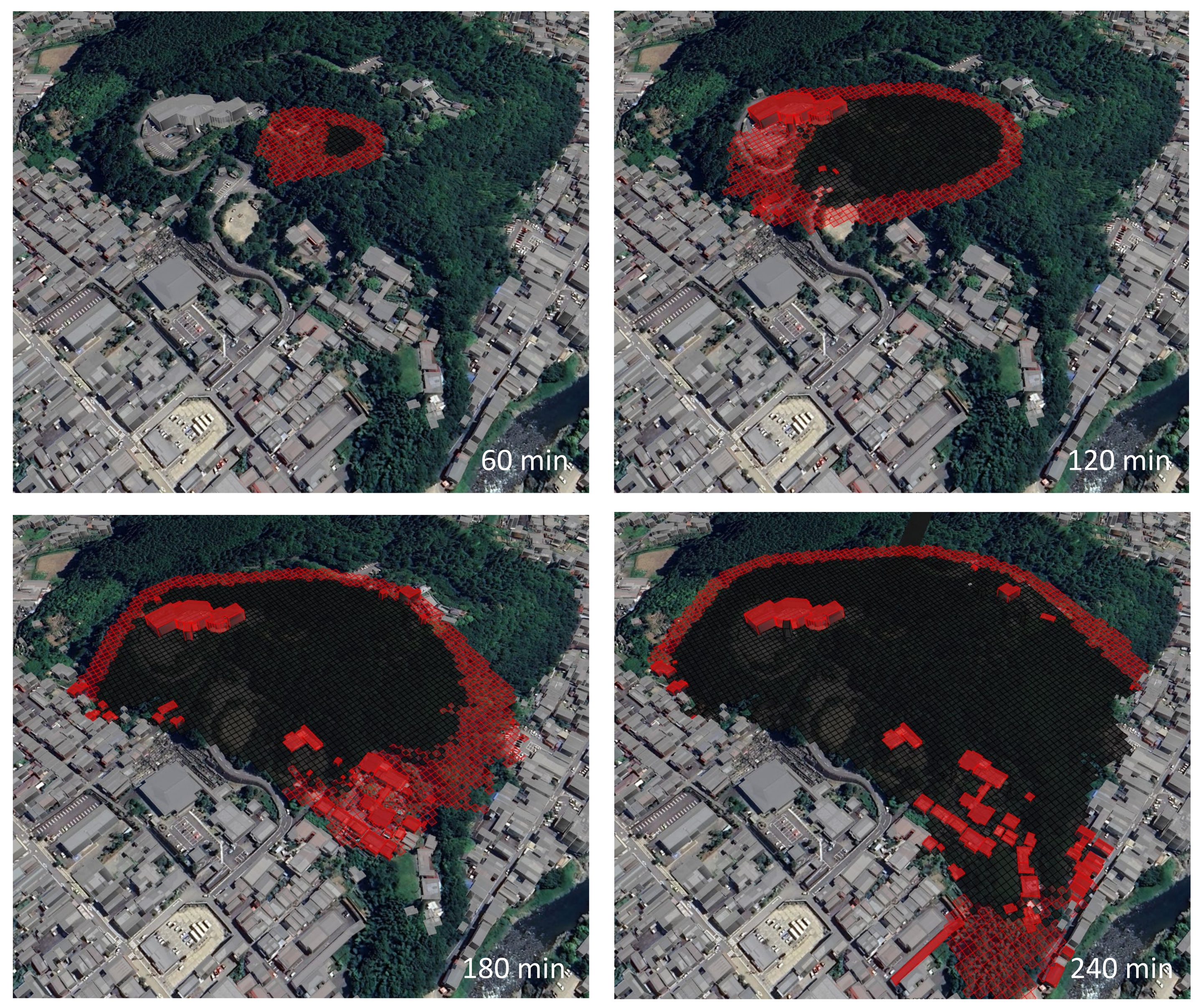

Fig. 5. A snapshot of the simulation result in a hypothetical WUI environment.

4. Conclusions

In this study, existing fire spread models for urban areas and wildlands were coupled to predict fire behavior in a WUI environment. The predictions by this integrated model have only been tested under a hypothetical WUI environment. Future work will involve examining the validity of this model through comparisons with past fire cases.

References

- Himoto K, Tanaka T. Development and validation of a physics-based urban fire spread model, Fire Safety Journal 43: 477-494, 2008.
- Rothermel RC. A mathematical model for predicting fire spread in wildland fuels, URDA Forest Service Research Paper INT-115, 1972.