Application of the Computational Fluid Dynamics in Forest Fires Investigations for Mitigation of the Wildland-Urban Interface Fires' Risks

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9th INTERNATIONAL CONFERENCE ON

FOREST FIRE RESEARCH

& 17th International Wildland Fire Safety Summit

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Introduction

❑ Forest fires:

- Uncontrolled
- Unprescribed

➛ **Burn of Plants** ➛ **Serious threats for:**

- ✓ lives
- ✓ residential areas
- ✓ construction sites

❑ Wildfires in the USA (NIFC)

Numbers (1990 – 2021)	Destroyed area (1983 – 2021)	Suppression costs (1985 – 2020)
Average: 70,543 Wildfires	Average: 3×10^6 ha	Average: 1.1 $B
	3.94% AGR	6.62% AGR
		2021: 4.4 $B

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Introduction

❑ Burned area in Europe (JRC)

- ✓ Total Annual Average (2006 – 2021)

  ① **Portugal: 1.1% country is burned (96,625.4 ha)**
  ② Spain: 66,965.1 ha
  ③ Italy: 53,961.4 ha
  ④ Greece: 44,640.1 ha
  ⑤ Romania: 14,313.4 ha
  ⑥ Croatia: 13,520.9 ha
  ⑦ France: 9,825.7 ha

- ✓ 2020 ➛ **340,000 ha ≈ 1.3 ×**

- ✓ 2021 ➛ **500,566 ha**

Wildfire in Coimbra, central Portugal, on June 18, 2017. Photograph by Patricia De Melo Moreira / AFP – Getty Images.

Wildfire blaze in Castelo Branco, central Portugal, on June 19, 2017. Photograph by Miguel Riopa / AFP – Getty Images.

Literature Review

❑ Fire Mathematical/Numerical Analysis

- **Andrews** (1986)
  BEHAVE
  (Mathematical fire modeling program)
- **Finney** (1995)
  FARSITE
  (fire growth simulator)
- **Rodman Linn** (1997)
  (A transport model for prediction of wildfire behavior)
- **Rodman Linn** (2002)
  (FIRETEC)
- **Mell et. al.,** (2005)
  FDS ▸ WFDS
  (3D LES)
- **Andrews** (2007)
  BehavePlus

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Background Theory

❑ Fire Dynamics Simulation

1. Conservation of Mass $\Rightarrow$ $$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = 0$$

2. Conservation of Momentum (**LES**)

Deardorff's Turbulent Viscosity

$$\frac{\partial \bar{\rho}\tilde{u}_i}{\partial t} + \frac{\partial}{\partial x_j}\left(\bar{\rho}\tilde{u}_i\tilde{u}_j\right) = -\frac{\partial \bar{p}}{\partial x_i} - \frac{\partial\left(-2\left(\mu+\mu_t\right)\left(\tilde{S}_{ij} - \frac{1}{3}(\nabla \cdot \tilde{\mathbf{u}})\delta_{ij}\right)\right)}{\partial x_j} + \bar{\rho} g_i + \bar{f}_{d,i} + \overline{\dot{m}_b'''}\tilde{u}_{b,i}$$

3. Conservation of Energy $\Rightarrow$ Velocity Divergence

4. Equation of State $$\bar{p}_m = \rho T \Re \sum \frac{Y_\alpha}{W_\alpha} = \frac{\rho T \Re}{\overline{W}}$$

Fire: *Subsonic flow*

5. Conservation of Species

$$\frac{\partial}{\partial t}\left(\rho Y_\alpha\right) + \nabla \cdot \rho Y_\alpha \mathbf{u} = \nabla \cdot \rho D_\alpha \nabla Y_\alpha + \dot{m}_\alpha''' + \dot{m}_{b,\alpha}'''$$

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Objectives

- ❑ **Flammability Analysis**
    - **Ignitibility (time-to-ignition)**
    - **Combustibility (combustion rate)**
    - **Sustainability (burning duration)**
    - **Consumability (burning completeness)**
- ❑ **Validation of FDS based on the Experimental data**
- ❑ **Prediction of key parameters using FDS**
- ❑ **Firebrands’ analysis using PIV**
- ❑ **Classification of forest species in terms of flammability**

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Universidade de Coimbra ADAI AEIF House Refuge FCT Fundação para a Ciência e a Tecnologia

Methodology

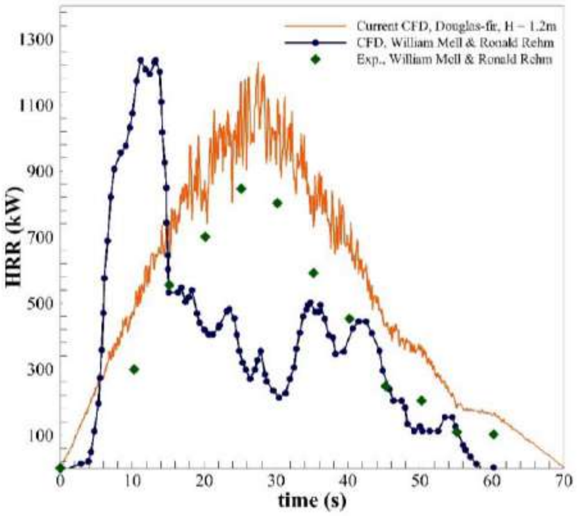
❑ Experimental Analysis

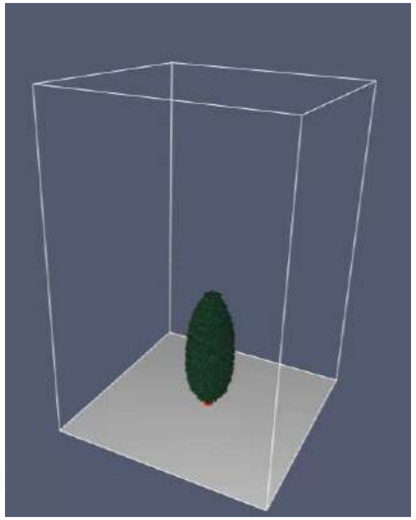
- Thermocouples
- Heat flux sensor
- S-type pitot tube
- Mass aquisition system
- RGB Cameras
- IR Cameras
- PIV System

Experimental setup in LEIF-ADAI (2021)

❑ Numerical Analysis of Fire

- FDS/WFDS





Comparison of Results for Heat Release Rate (HRR) in kWs, for Douglas-fir H = 1.2m. Moisture Content: 25%

Methodology

❑ Experimental Analysis

- Fire behavior analysis has been accomplished for the **24 species** so far:

Acacia	Apple tree	Arizona cypress	Bay laurel (Laurus nobilis)	Blueberry tree (Prunus Spinosa)	Cherry Tree
Fig tree	Common Ivy (Hedera helix)	Gum rockrose (Cistus ladanifer)	Grapevine (Vitis)	Hydrangea	Kiwi tree
Leyland cypress	Lindens (Tilia)	Loquat (Eriobotrya japonica)	Nerium oleander	Olive tree	Pacific madrone (Arbutus menziesii)
Rhus typhina (Anacardiaceae)	The Holly (Ilex Aquifolium)	Thuja occidentalis (white cedar)	Wild Blackberry (Rubus Ulmifolius)	Lemon Tree	Eucalyptus globulus

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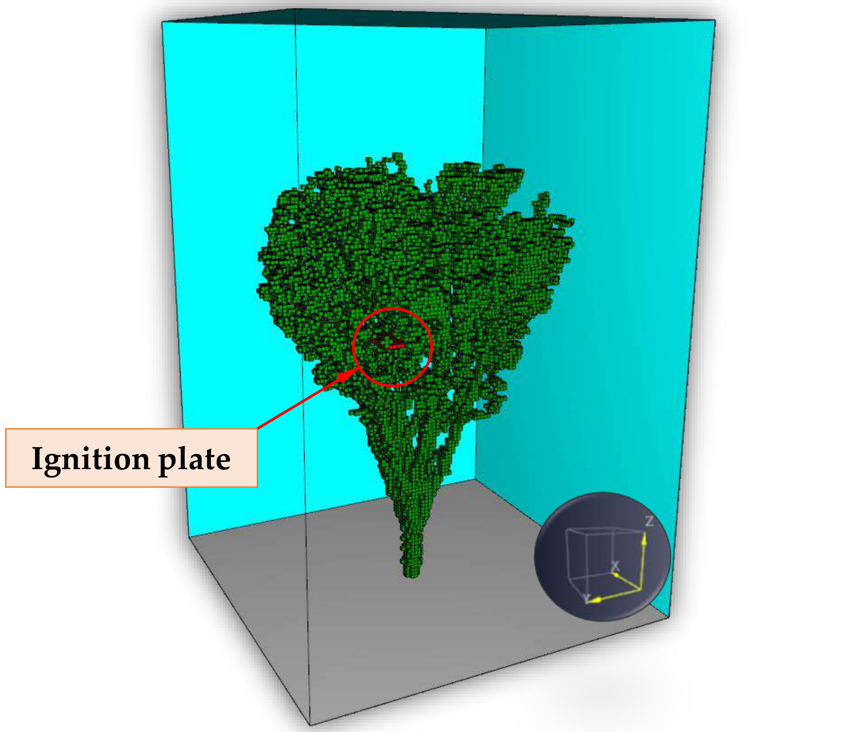
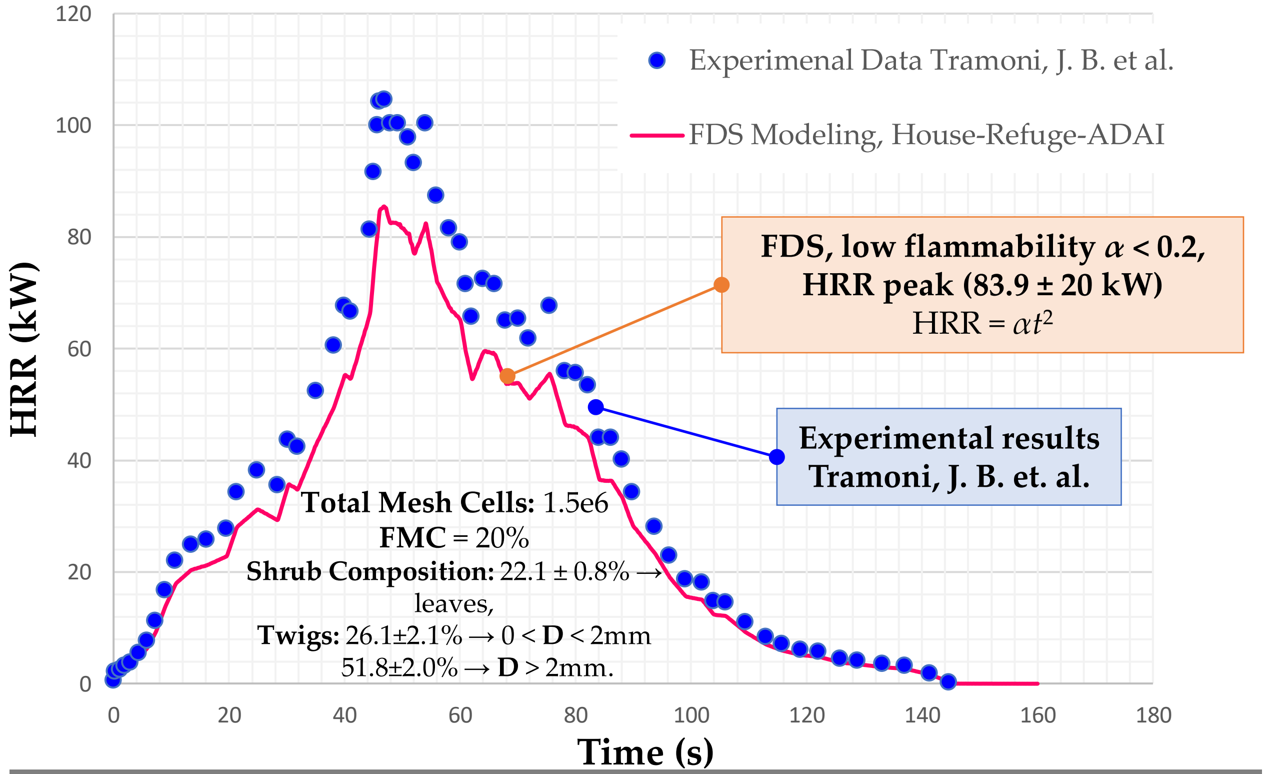
Methodology

❑ Numerical Analysis of Fire ▸ Rockrose



RockRose shrub, Dimensions: 0.8×0.8×1.16m³
Computational domain size: 1.0×1.0×1.5m³
Fuel Composition: C=3.875, H=6.8, O=2.74, N=0.28 (mass ratios)



Comparison between the Experimental and FDS Modeling of the **ROCKROSE** Shrub, (Cistus Monspeliensis)

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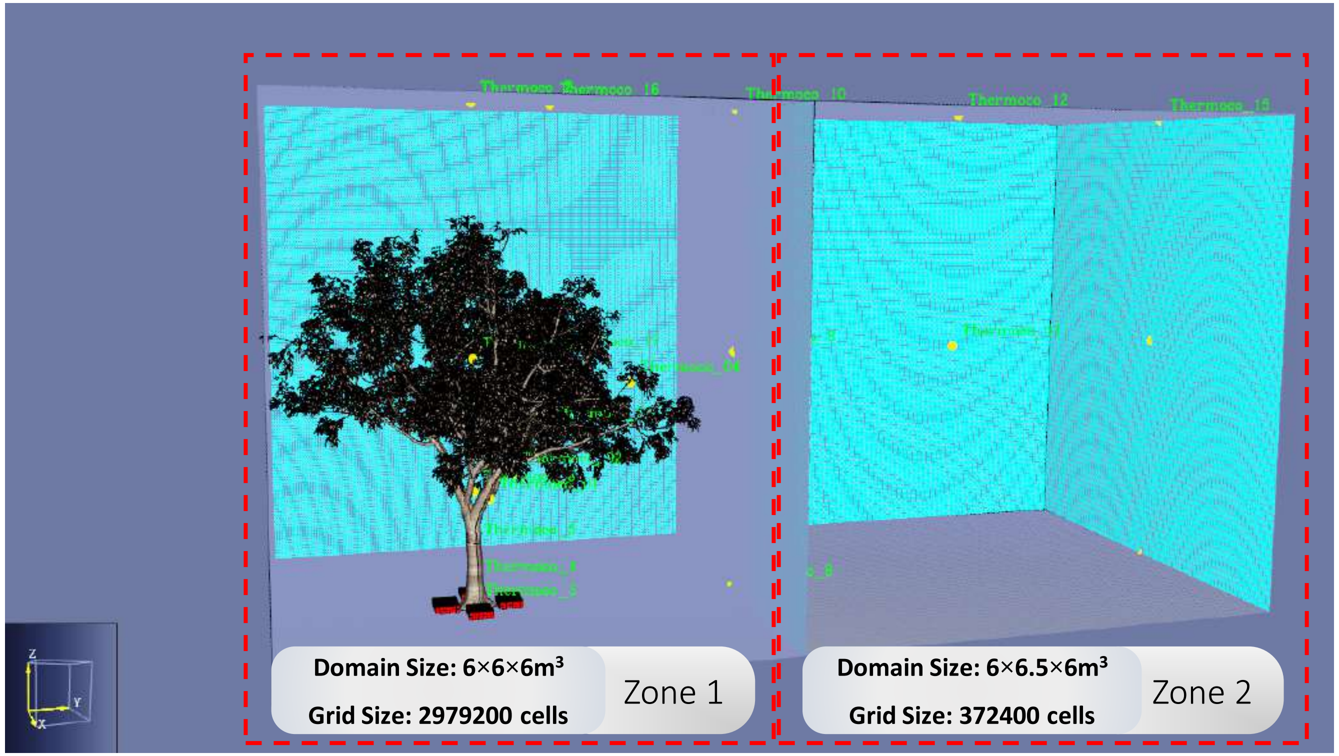
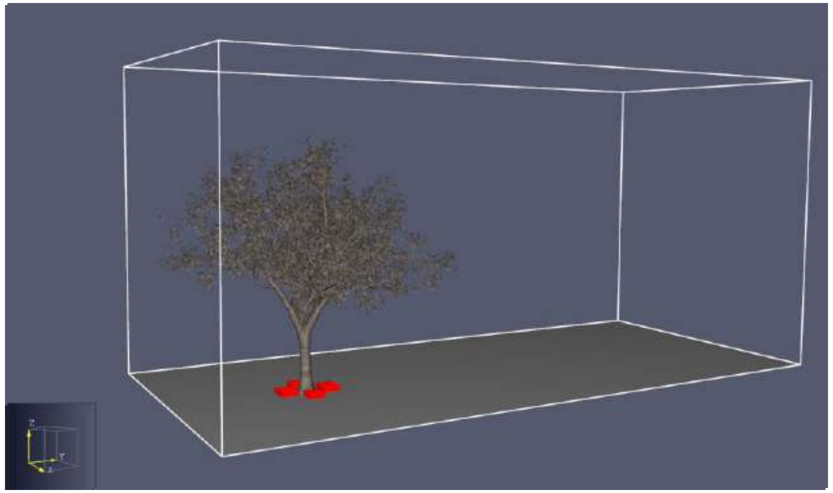
Methodology

❑ Numerical Analysis of Fire ▸ Apple Tree



Apple Tree, Dimensions: 3.9423×5.4512×4.7058m³



Ongoing FDS Modelling – Apple Tree

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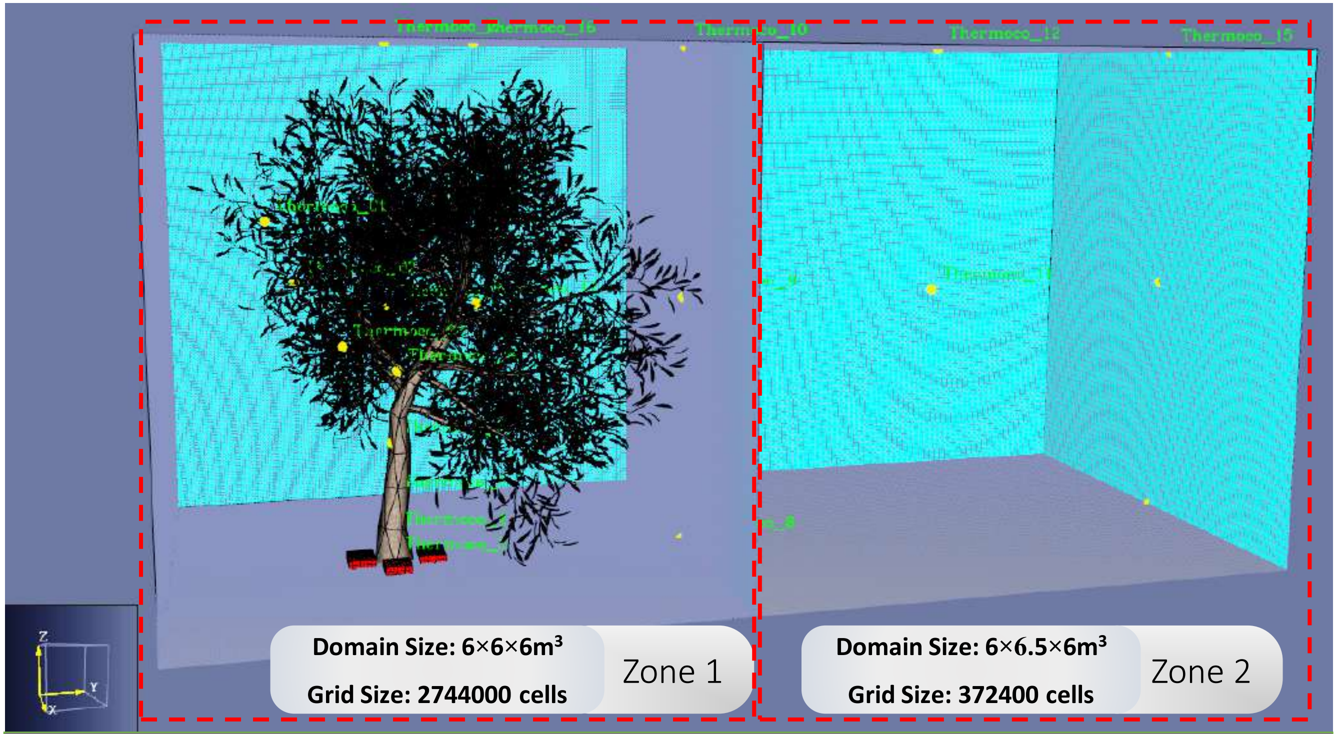
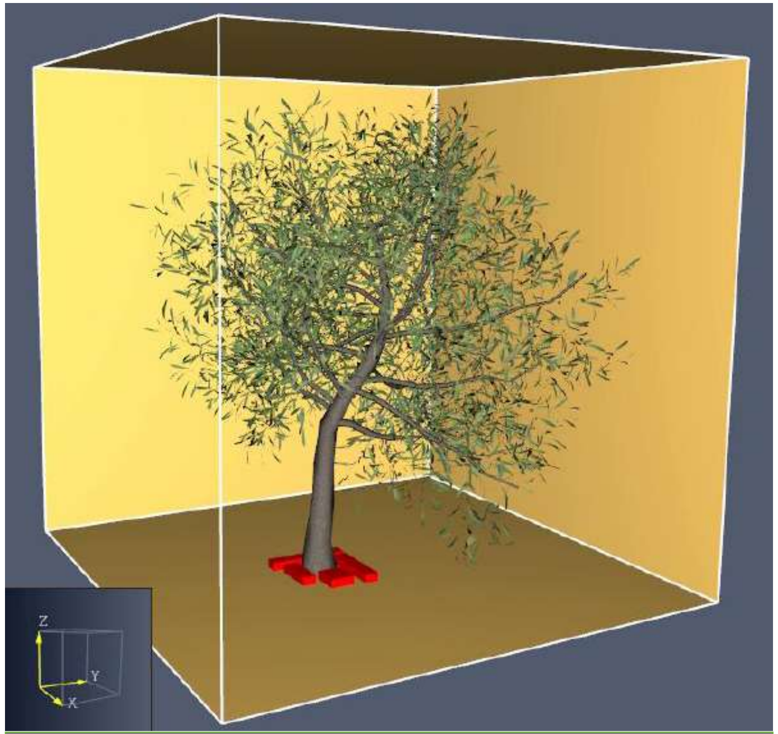
Methodology

❑ Numerical Analysis of Fire ▸ Olive Tree



Olive Tree, Dimensions: 5.6589×5.5653×5.7177m³



Ongoing FDS Modelling – Olive Tree

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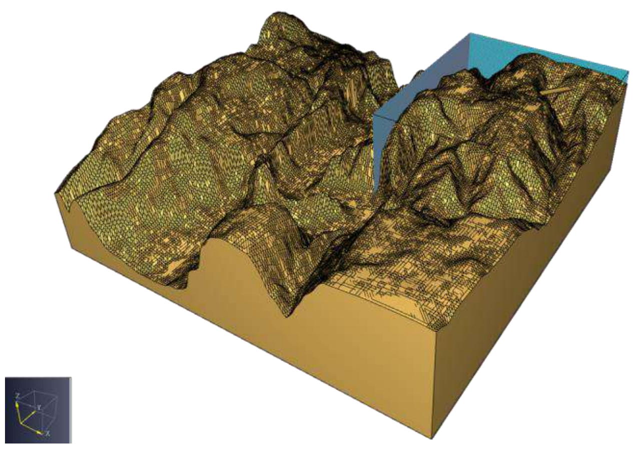
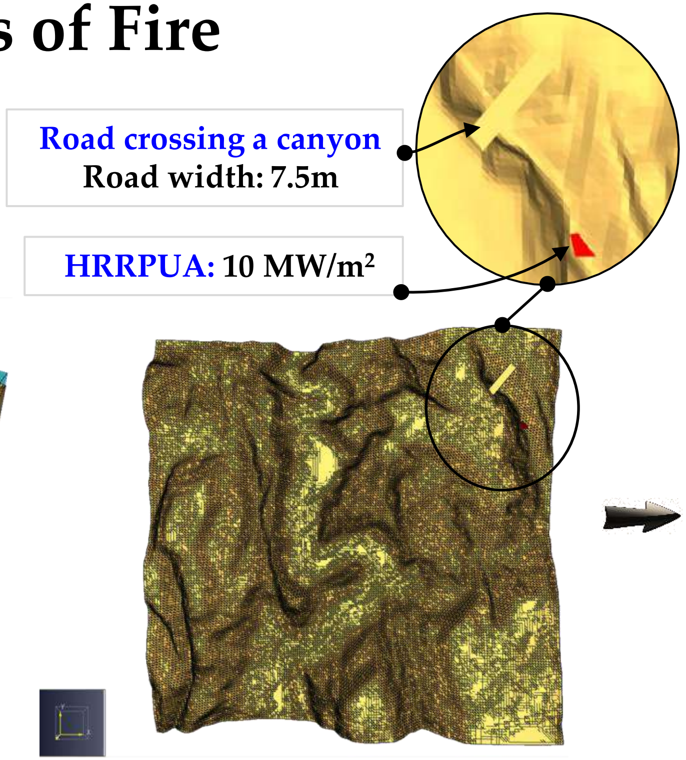
Methodology

❑ Numerical Analysis of Fire

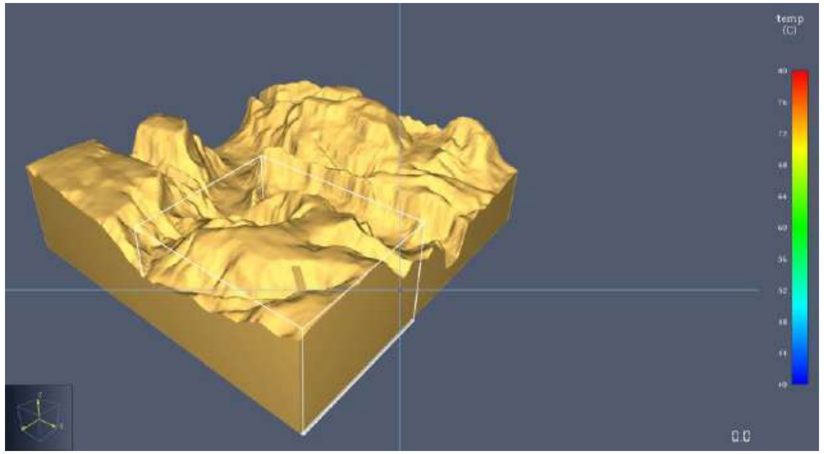
- Fire in Canyon



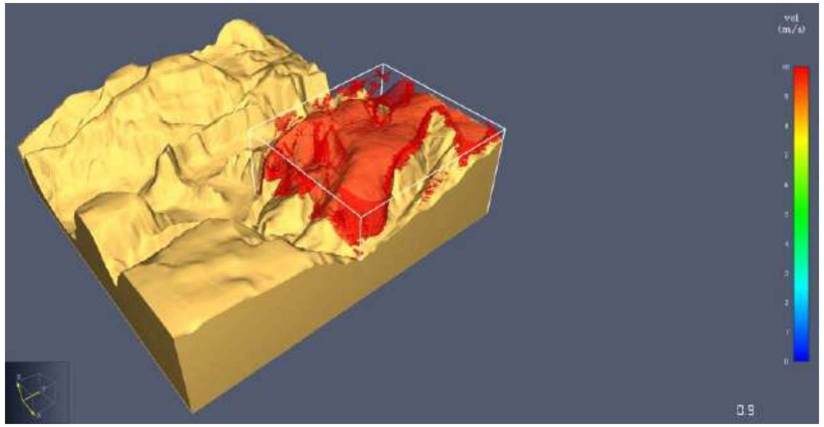
Terrain including canyons
Domain dimension: X: 160m,Y: 159m, Z: 47.63m



Top view



FDS Results: Temperature Iso-surface Contours



FDS Results: Wind Iso-surface Contours: 10m/s

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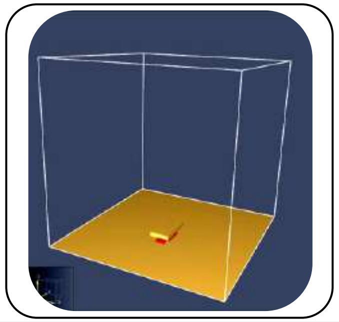
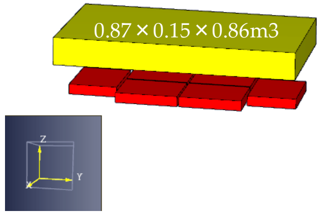
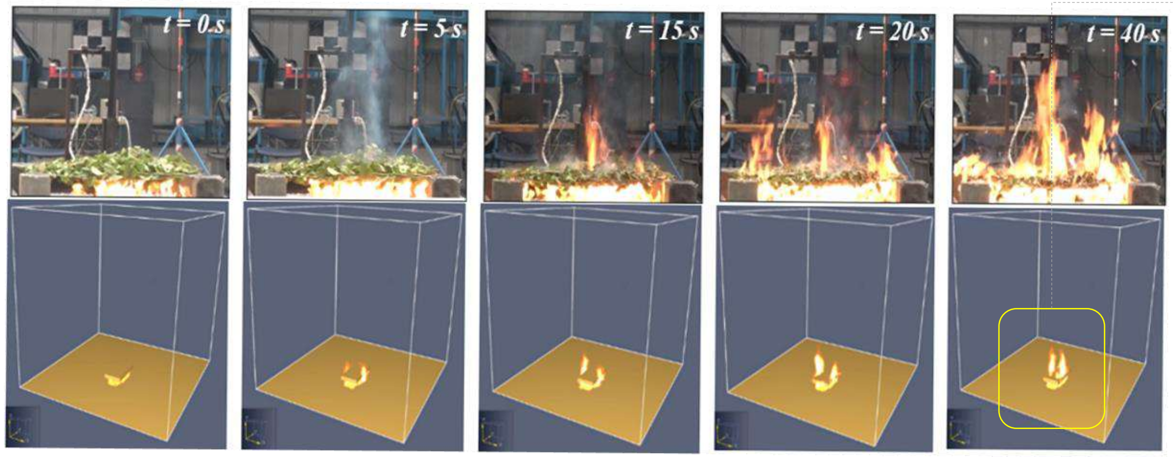
Results and Discussion

❑ Fire Dynamics Simulations

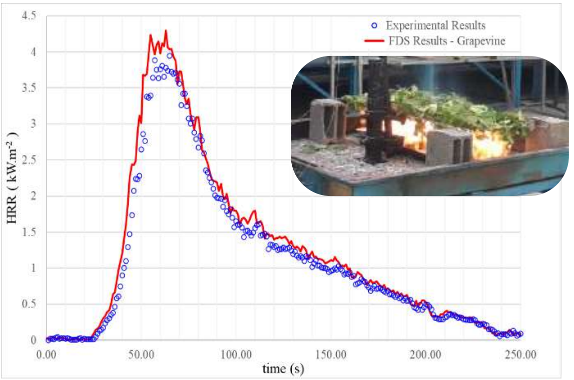
- ✓ Lagrangian particle cloud approach
  - Grapevine







Comparison of the real-time lab experiments with numerical modeling at 0, 5, 15, 20, and 40 s.

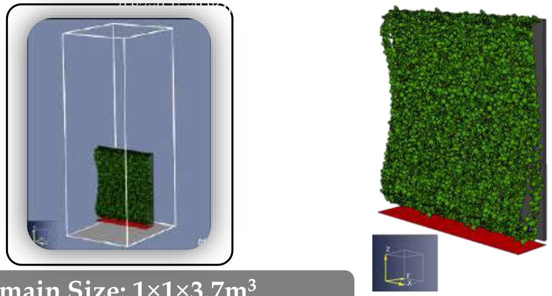


Comparison of HRR (Numerical & Experimental)

Results and Discussion

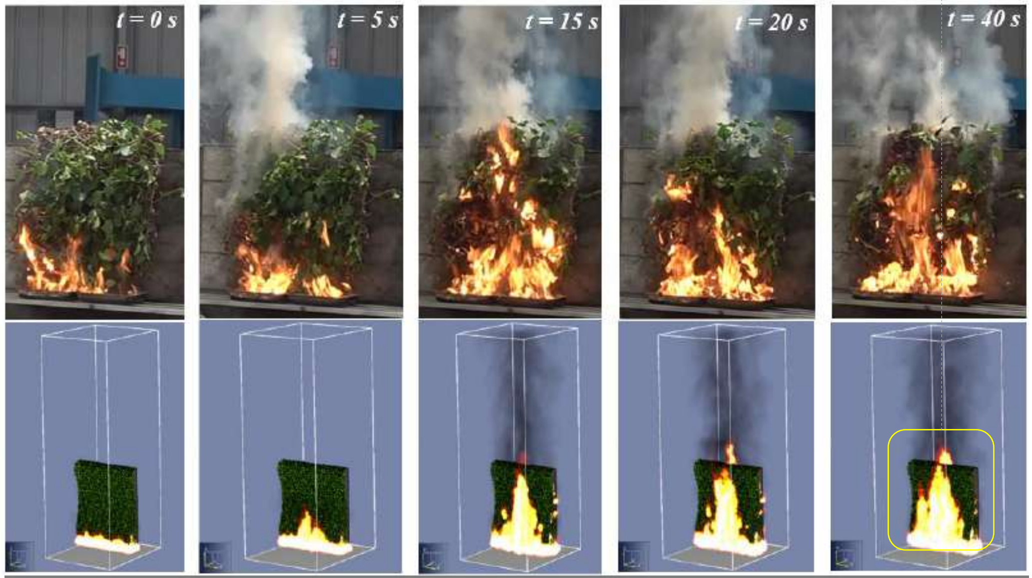
❑ Fire Dynamics Simulations

- ✓ Porous obstruction modeling approach
  - Common Ivy

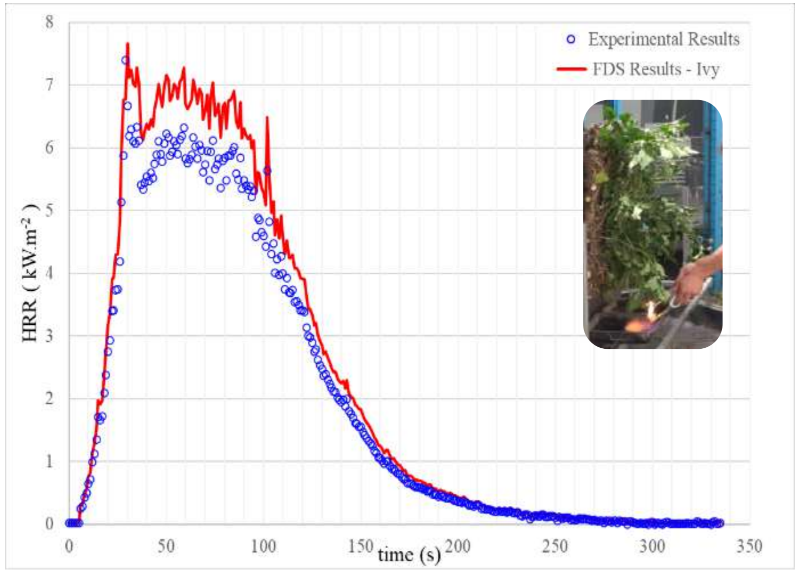


Domain Size: 1×1×3.7m^3

Grid Size: 3,971,968 structured cells



Comparison of the real-time lab experiments with numerical modeling at 0, 5, 15, 20, and 40 s.



Comparison of HRR (Numerical & Experimental)

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Conclusion

- ❑ FDS is an efficient tool which can be used for prediction of fire dynamics
- ❑ Fire impact on the surroundings can be analyzed and predicted by FDS
- ❑ FDS simulations have to be performed based on the reliable experimental data
- ❑ HRR is a key parameter in experimental and numerical analysis for data validation and fire behavior analysis

Future Work

- ❑ Experimental analysis of fire behavior in different forest species will be continued
- ❑ Numerical analysis of fire in various forest species is in progress
- ❑ PIV data post-processing for firebrand will be elaborated
- ❑ The purpose of the ongoing research is to categorize the forest species as less vulnerable to the hazardous types, specifically in WUI regions

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"It is known that wildfires behave unpredictably, this is fundamental, but it is my experience that humans in the presence of wildfire are also likely to behave in aberrant and unpredictable ways" Michael Leunig