Bushfire Risk to Buildings at the Bushland-Urban Interface from Garden Vegetation

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Contents

- Background
- Methodology
- Full-scale Burning Experiments
- Fuel Characterisation
- Model Development & Validation
- Scenario Modelling

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Bushland-Urban Interface (BUI)

- Close proximity to bushland
- Limited separation between buildings
- Highly combustible materials
- Intermix of buildings and vegetation

*Both the **Vegetation** in bushland and the **Structures** in the built environment can act as continuous fuel sources for fire spread*

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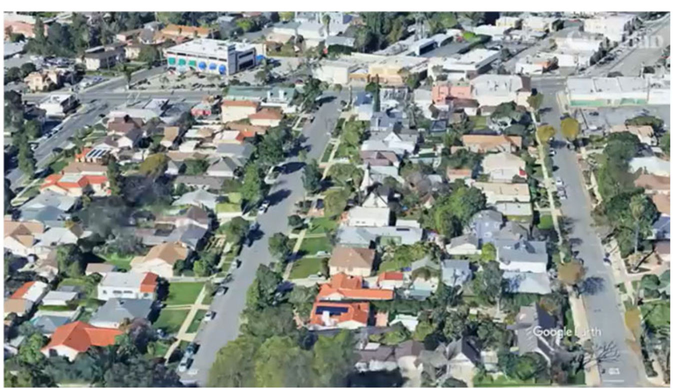
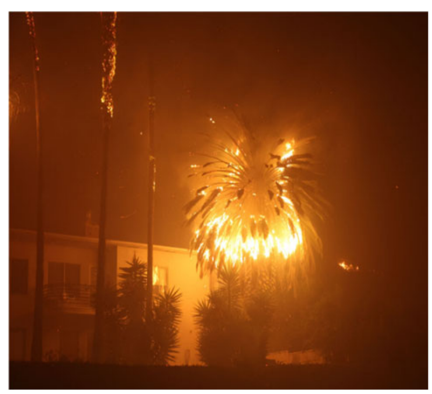
2025 Los Angeles Fire, California



Source: https://www.youtube.com/watch?v=5UHSfJHc6H8



Palm trees torching in the Palisades Fire *(Source: Babrauskas (2025))*

*In the LA fire, **Palm trees** used for decorative landscaping ignited easily, intensifying the fire spread by acting like torches*

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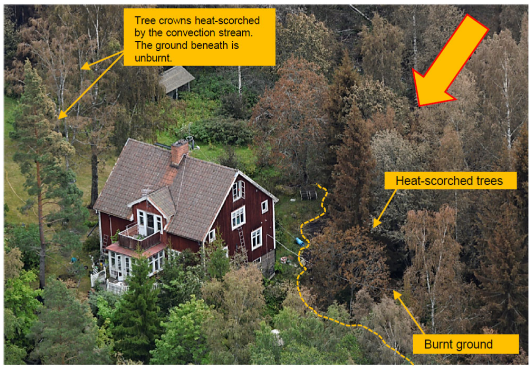
Sweden Fires 2014 and 2018 – Vastmanland and Exkogen, Notberget and Angra



- To find the physical features of the buildings and their surroundings
- 187 Buildings - Nearly all with wood panels and tile or sheet metal roofing - 35 % of the buildings were lost or badly damaged.
- Most buildings were approached by relatively **low-intensity fire** and that ignition primarily occurred through **direct flame contact**.
- Building survivability - **Maintained lawn**, and **no flammable material** was present close to the building façade.
- Swedish WUI is to keep the area immediately surrounding the building (~5 m) free from tree litter and other flammable material.

Reference: Plathner, F. V., Sjöström, J., & Granström, A. (2023). Garden structure is critical for building survival in northern forest fires: An analysis using large Swedish wildfires. Safety Science, 157, 105928. https://doi.org/10.1016/j.ssci.2022.105928

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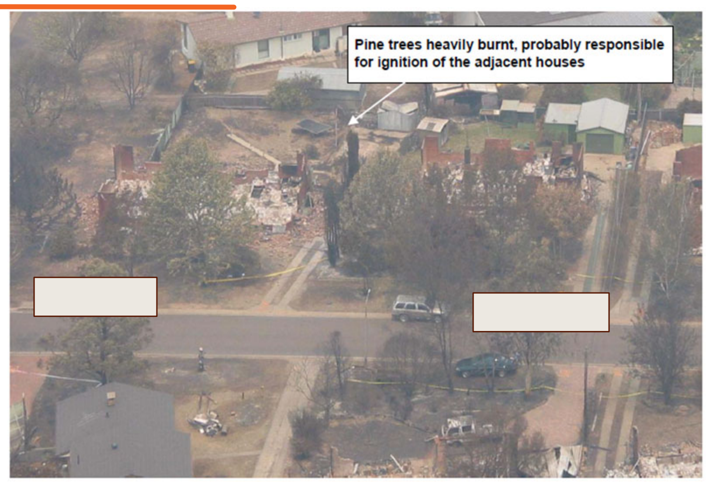
Australian Context

Post-fire investigations indicate that planted or garden vegetation adjacent to houses has contributed to the house loss.

ACT / Canberra bushfires (Duffy), 2003



Source: ACT / Canberra 2003 bushfire attack mechanisms report

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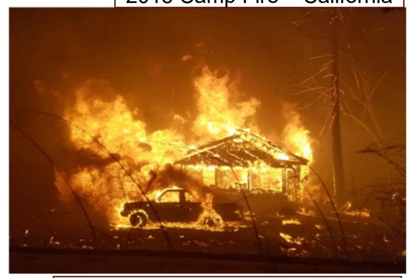
Building-to-Building Fire

Flame Contact
through connective fuels

Radiant Heat

Maranghides et al., (2021)

2018 Camp Fire – California

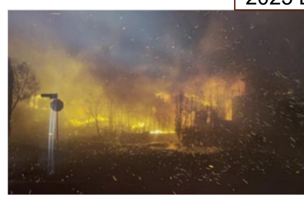


Embers

Vegetation-driven embers

Structure-driven embers

2025 Los Angeles Fire – California



2025 LA County Wildfires: Early insights from field observations. (2025).

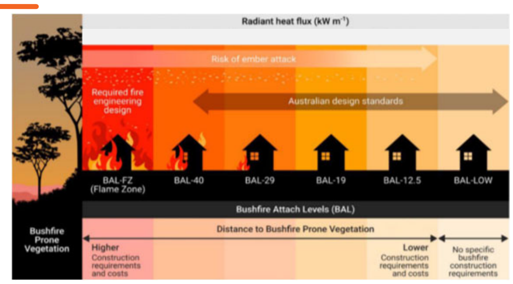
Building Standards

AS 3959: 2018

The BAL system has been derived based on;

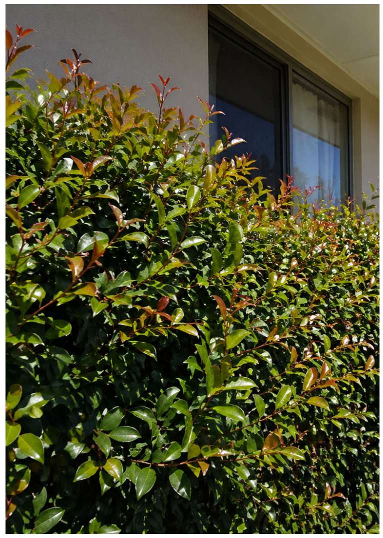
- Fire Danger Index (FDI)
- Vegetation type
- Distance to classified vegetation
- Slope under the vegetation

It does not consider combustible materials surrounding buildings, such as ornamental plants and fences.



National Construction Code (NCC)

The NCC includes provisions for preventing the spread of fire from allotment boundaries (which may include hedges and fences) only within 0.9 m; however, guidance beyond this distance is not specified (NCC V2.3.1.2 - H3V2).



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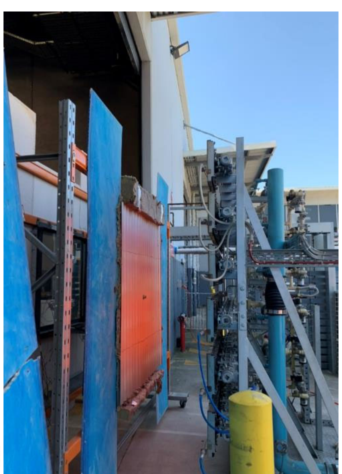
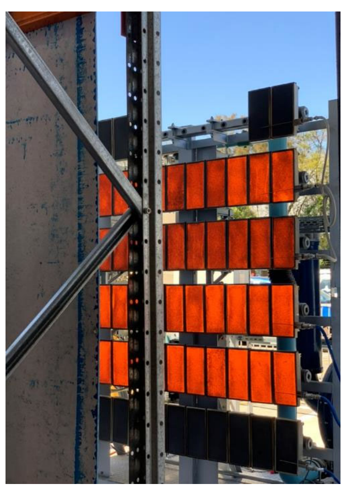
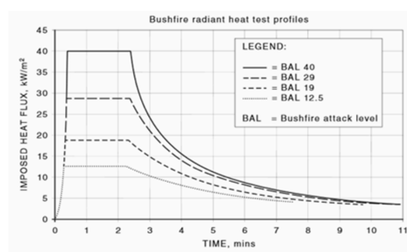
Radiant Heat Panel - Bushfire







BAL 12.5 to 40
Heat flux vs Time Curves

Radiant Heat Exposure

(QUT Wind and Fire Lab)

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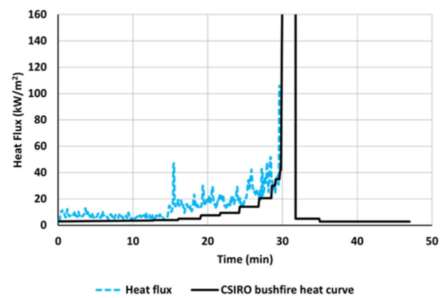
Flame Exposure - Bushfire

Flame Exposure
(QFD – Port of Brisbane)



Bushfire flame zone curve used in the test (NASH bushfire standard, 2021)

Ref: QUT Wind and Fire Lab publications - https://research.qut.edu.au/wafel/publications/

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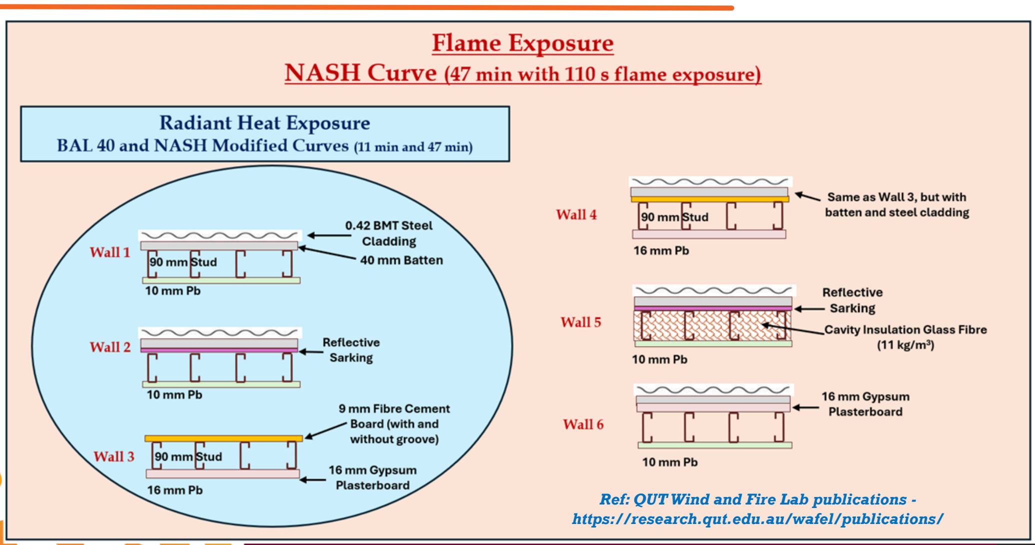
Radiant Heat Panel - Bushfire



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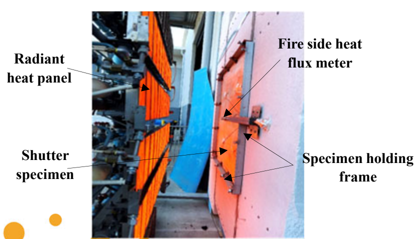
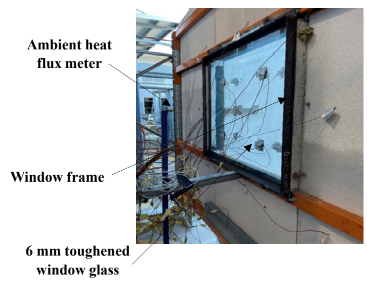
Windows and Shutters

- Glass Types - float/annealed, heat-strengthened, toughened, laminated, wired, fire-resistant glass, and glazing systems like double and triple-glazed windows
- Glass cracking temperatures
  - ✓ **Annealed (Float) glass** - Cracks around 150°C but stays intact until 200°C (~ 16 kW/m²)
  - ✓ **Laminated Glass** – Cracks at similar or even lower temperatures due to the melting of the interlayer
  - ✓ **Toughened Glass** - Shatters between 290°C–380°C (framing conditions)

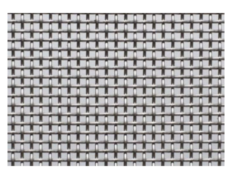


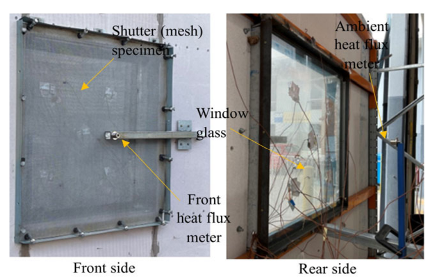


Perforated Mesh Screen Shutters – Radiant Heat Exposure

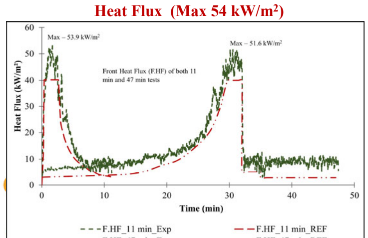
Name	Wire Diameter (mm)	Aperture (mm)	Open Area (%)	Unit Weight (kg/m²)
0.18W	0.18	1.23	76	0.3
0.45W	0.45	1.67	62	1.24
0.8W	0.8	1.51	43	3.61
0.9W	0.9	1.64	42	4.16

Tested for Radiant Heat Exposures – 11 min and 47 min

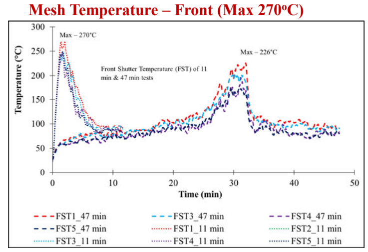


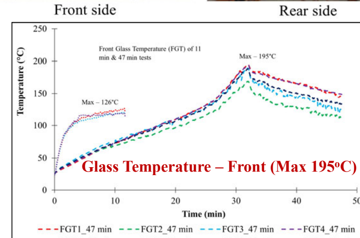


Heat Flux (Max 54 kW/m²)



Mesh Temperature – Front (Max 270°C)





Bushfire Shutters – Radiant Heat Exposure

- Examined the effectiveness of various construction materials as shutters to protect windows during bushfires, including:
  - ✓ 1.2 mm thick steel sheet
  - ✓ 0.4 mm thick glass fibre blanket - 430 g/m^2
  - ✓ 0.4 mm thick glass fibre blanket - 430 g/m^2 with 35-micron aluminium foil
- Shutters were tested under two radiant heat exposure scenarios:
  - ✓ Rapid exposure (11 min) – BAL 40 (AS1530.8.1)
  - ✓ Prolonged exposure (47 min) – Modified NASH Curve

fire MDPI

Article

Experimental and Numerical Studies of Window Shutters Under Bushfire Radiant Heat Exposure

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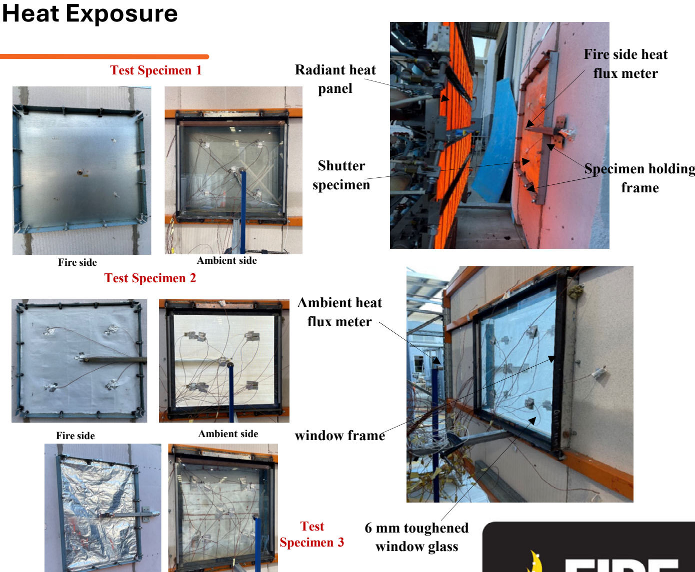

Bushfire Shutters – Flame Exposure

1. Test 1: 13 mm mineral wool (Rockwool) sandwiched between two 1.2 mm steel sheets (rigid shutter)
2. Test 2: 13 mm plasterboard sandwiched between two 1.2 mm steel sheets (rigid shutter)
3. Test 3: Two 3 mm ceramic fibre blankets and 35-micron aluminium foil (flexible shutter).
4. Test 4: 3 mm ceramic fibre blanket, 0.4 mm glass fibre blanket and 35-micron aluminium foil (flexible shutter).

- During **flame immersion zone**, Conditions exceed:
  - Flame temperatures > **1000 °C**
  - Heat fluxes > **140 kW/m^2**

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Evaluating the performance of window shutters using experimental and numerical studies under flame zone exposure

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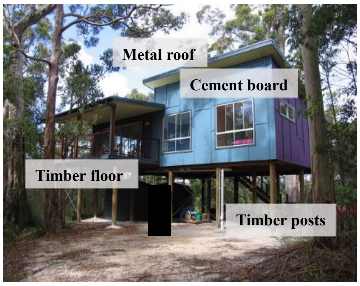
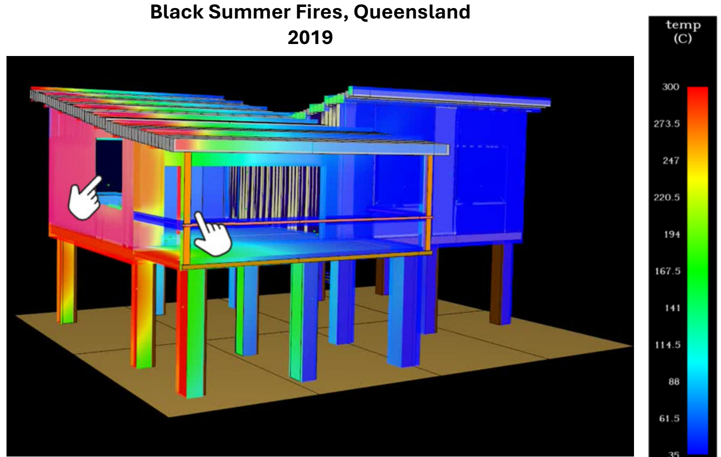
Advanced Numerical Models of Damaged Houses



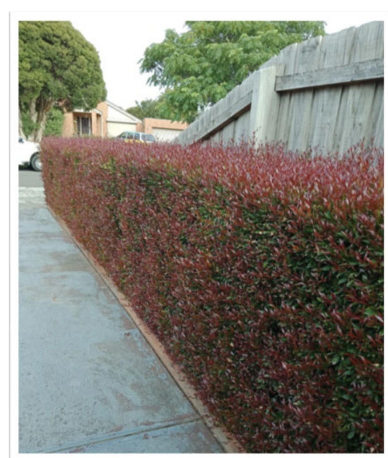
Black Summer Fires, Queensland 2019



Motivation

Current Australian bushfire building assessment frameworks, including NCC/AS 3959, use simplified **BAL procedures** based on **Vegetation Classification**, **Separation Distance** and **Slope**. These methods do not explicitly represent the burning behaviour of Ornamental Plants located close to buildings.

Recent bushfire events highlight the need to better understand the risk posed by ornamental vegetation at the individual-building scale. However, full-scale fire testing is costly and presents safety challenges. Therefore, validated CFD models are needed to assess the bushfire risk of ornamental plants near buildings.



Full-Scale Burning Experiments

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Lilly Pilly (Syzygium Australe)

- Plant Flammability – Australian Native (Uni. of Tasmania)
  - ✓ How easily the plant burnt
  - ✓ How hot the plant burnt
  - ✓ How long the plant burnt
  - ✓ How much of the plant burnt

Your guide to plant flammability

Find out how your garden plants rated for flammability.

Shrubs

Common name	Provenance	Flammability	Scientific name
Slender westringia	Australian native		*Westringia eremicola*
Black wattle	Tasmanian native		*Acacia mearnsii*
Lilly pilly	Australian native		*Syzygium smithii*
Rosemary grevillea	Australian native		*Grevillea rosmarinifolia*
Willow myrtle	Australian native		*Agonis flexuosa*

Source: https://www.sparkingconversations.com.au/fire-adapted-gardens

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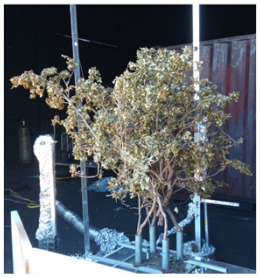
Lilly Pilly (Syzygium Australe)

Test 1



MC 45% Dry basis
Mass 5.545 kg
5 Days*

Test 2

MC 60% Dry basis
Mass 5.240 kg
2 Days*

Test 3

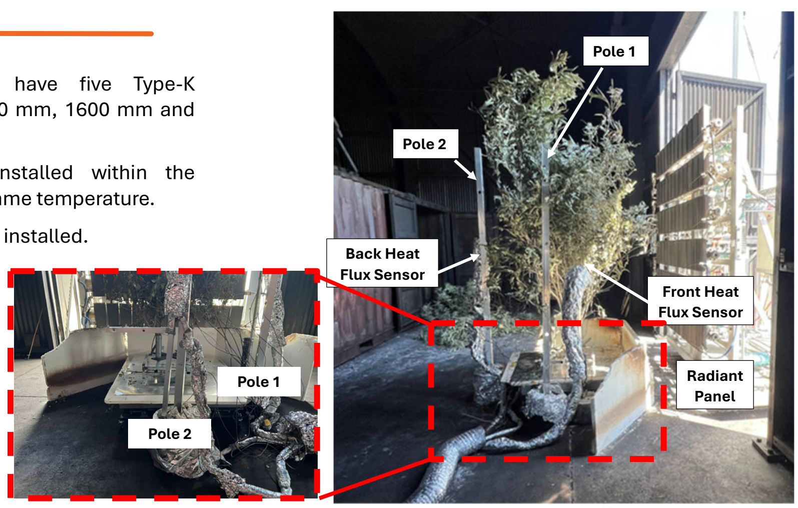
MC 60% Dry basis
Mass 5.775 kg
2 Days*

✓ A 360° video was recorded before each test to capture the overall geometry and shape of the plant specimens.

*- Stored in the open shed after removal of the root ball and residual soil

Test Set-up

- Poles 1 & 2 (Aluminium Poles) have five Type-K thermocouples (600mm, 900 mm, 1200 mm, 1600 mm and 2100 mm)
- Five Type-K Thermocouples were installed within the vegetations randomly to measure the flame temperature.
- Two water-cooled heat flux gauges were installed.



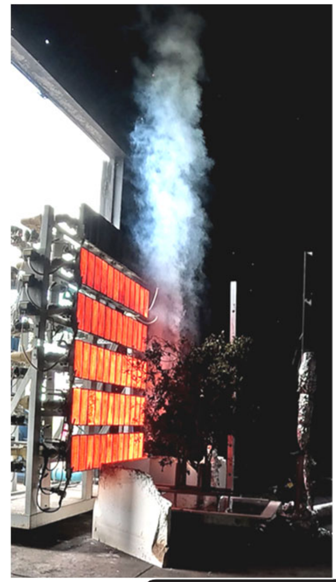
Load-Cell Platform

Fire Test

Test	Ignition Time (s)	Burning Duration (S)	Mass Loss (kg)
Test 1 (LP1)	36 s	~ 122 s	1.6 kg
Test 2 (LP2)	105 s	~ 106 s	1.8 kg
Test 3 (LP3)	164 s	~ 66 s	1.6 kg

Ignition time and burning duration were determined from visual observations and confirmed using video recordings.

- ✓ Ignition was delayed as the moisture content increased, and the burning duration was reduced in the wettest hedge due to prolonged preheating.
- ✓ Fine fuels, including leaves and twigs < 6 mm, were predominantly consumed.



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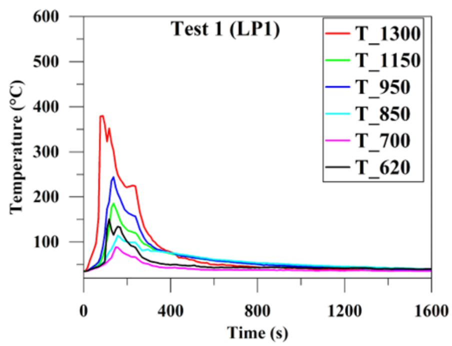
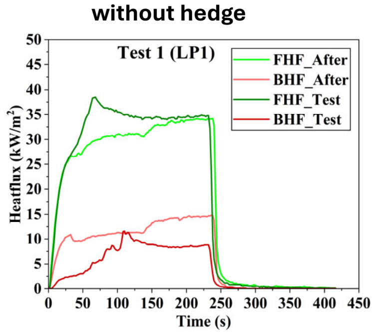
Test 1

Temperature at different heights



Heat Flux with hedge and without hedge



Max Temperature 380 °C
Max Heat Flux Front 39 kW/m^2

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Test 1

t = 0 s | t = 36 s | t = 50 s | t = 66 s | t = 110 s | t = 147 s

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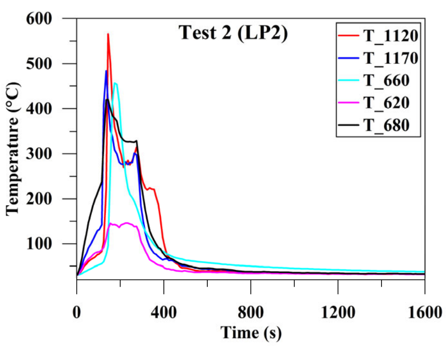
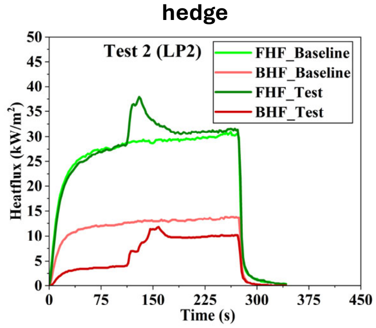
Test 2

Temperature at different heights



Heat Flux with hedge and without hedge



Max Temperature 566 °C
Max Heat Flux Front 38 kW/m²

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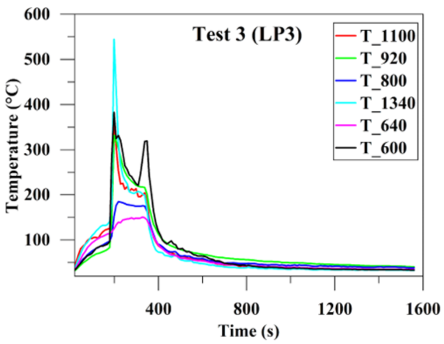
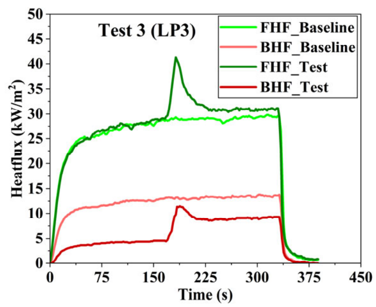
Test 3

Temperature at different heights



Heat Flux with hedge and without hedge



Max Temperature 544 °C
Max Heat Flux Front 41 kW/m^2

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Test 3

t = 0 s

t = 164 s

t = 167 s

t = 184 s

t = 195 s

t = 202 s

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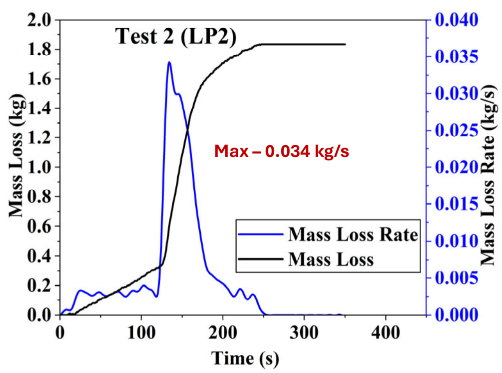
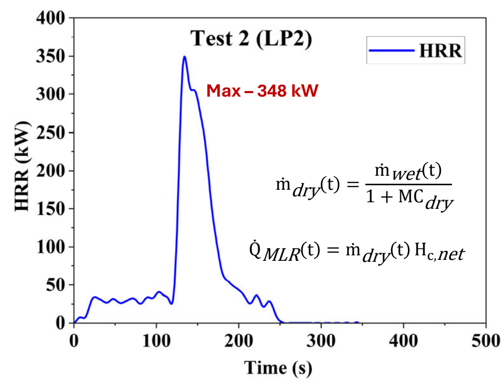
Fire Test

Mass Loss and Mass Loss Rate



HRR

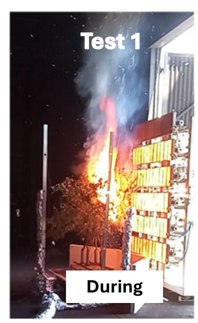


As oxygen-consumption calorimetry was not available, HRR was estimated from the measured MLR and the heat of combustion determined by Bomb calorimetry.

$$H_{c,net} = 17.65 - 21.96(0.059) \approx 16.35\ MJ/k$$

Fire Tests - Summary

- Ignition occurred at 36–164 s, depending on moisture content, hedge structure, and radiant exposure.
- Peak mass loss rate reached 0.022–0.037 kg/s.
- Estimated peak HRR was 250–371 kW.
- Burning duration ranged from 66–122 s.
- Burning of the hedge increased façade heat flux to about 39 kW/m^2, shifting exposure toward BAL-40.
- About 1.6–1.8 kg wet mass was lost; burning mainly involved leaves and twigs < 6 mm.
- Live Lilly Pilly hedges display moderate ignitability, particularly at elevated moisture levels. However, once ignition occurs, these hedges can become highly combustible, with sustained flaming sufficient to significantly increase near-field thermal exposure.



Methodology

Geometry
- Geometry from video & Point cloud reconstruction

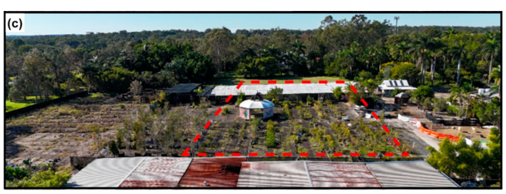
Fuel Characterisation
- TGA
- CHNS-O
- Bomb Calorimetry

Fire Tests
- Plant preparation and Video recording
- Radiant Panel tests
- Data - Video, Mass Loss, Heat flux, Temperature
- Reference tests without the plant

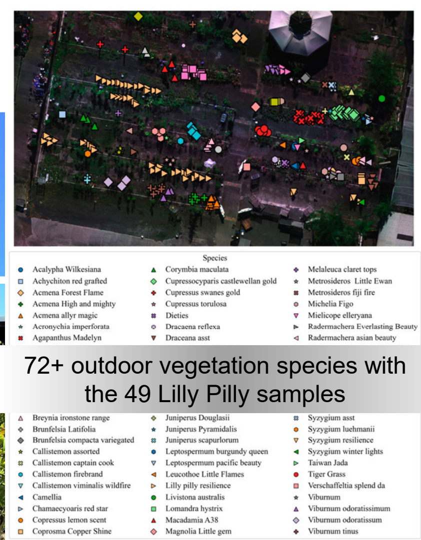
Model Development & Validation
- Modelling of the reference heat flux from no-hedge tests
- Particle-based plant model
- Validation with ignition time, burning duration, mass loss, heat flux and temperature

Scenario Modelling
- Hedge CFD Simulations
- BAL-based Hedge Simulations

Geometry – UAS-Based Remote Sensing and Artificial Intelligence

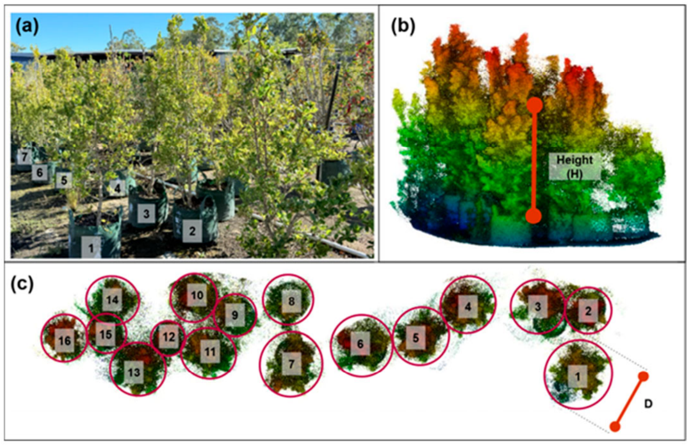


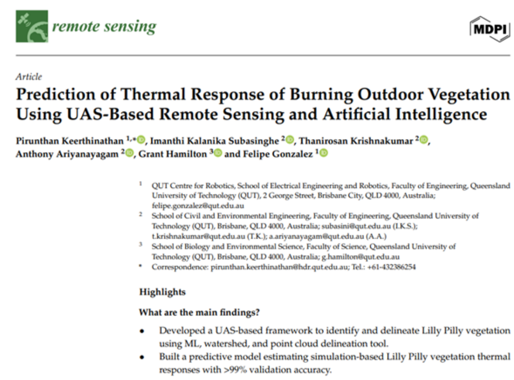
Fusing the photogrammetry-based segmentation to Lidar point cloud



72+ outdoor vegetation species with the 49 Lilly Pilly samples

Geometry – UAS-Based Remote Sensing and Artificial Intelligence




remote sensing

MDPI

Article

Prediction of Thermal Response of Burning Outdoor Vegetation Using UAS-Based Remote Sensing and Artificial Intelligence

Pirunthan Keerthinathan [1,*], Imanthi Kalanika Subasinghe [2], Thanirosan Krishnakumar [2], Anthony Ariyanayagam [2], Grant Hamilton [3] and Felipe Gonzalez [1]

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Highlights

What are the main findings?

- Developed a UAS-based framework to identify and delineate Lilly Pilly vegetation using ML, watershed, and point cloud delineation tool.
- Built a predictive model estimating simulation-based Lilly Pilly vegetation thermal responses with >99% validation accuracy.

Vegetation point clouds were used to record the diameter and height range to generate the synthetic dataset

Ref: QUT Wind and Fire Lab publications - https://research.qut.edu.au/wafel/publications/

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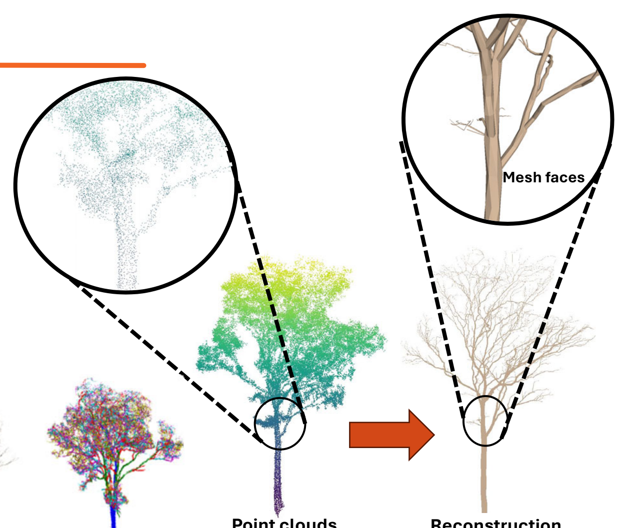
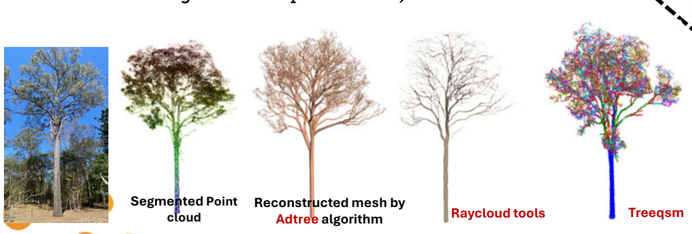
Geometry – LiDAR-Based Vegetation Geometry

Vegetation recorded within the Premises
(Height, Diameter and Breast height and the Species name)

Eucalyptus siderophloia





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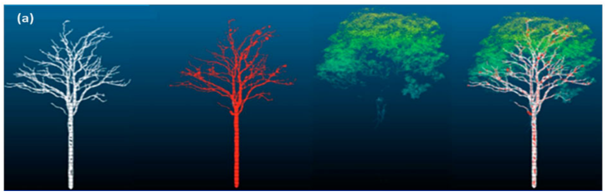
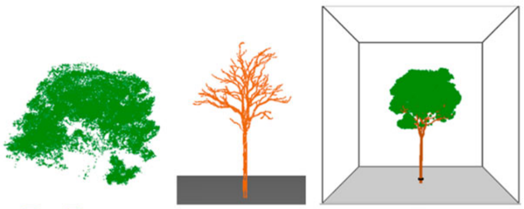
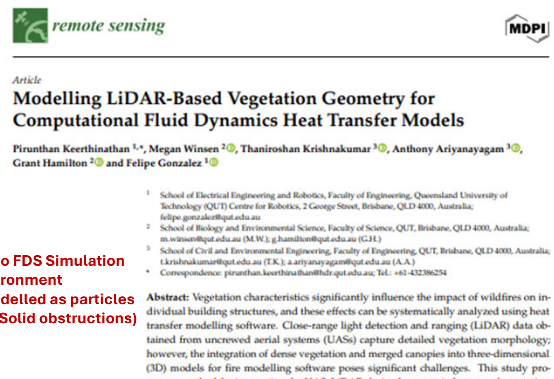
Geometry – LiDAR-Based Vegetation Geometry





Foliage, wooden core and bark, and a comprehensive view of the whole tree

Exportation to FDS Simulation Environment
(Canopy is modelled as particles and bark is as Solid obstructions)



remote sensing

MDPI

Article

Modelling LiDAR-Based Vegetation Geometry for Computational Fluid Dynamics Heat Transfer Models

Pirunthan Keerthinathan [1,*], Megan Winsen [2], Thaniroshan Krishnakumar [3], Anthony Ariyanayagam [3], Grant Hamilton [2] and Felipe Gonzalez [1]

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Abstract: Vegetation characteristics significantly influence the impact of wildfires on individual building structures, and these effects can be systematically analyzed using heat transfer modelling software. Close-range light detection and ranging (LiDAR) data obtained from uncrewed aerial systems (UASs) capture detailed vegetation morphology; however, the integration of dense vegetation and merged canopies into three-dimensional (3D) models for fire modelling software poses significant challenges. This study pro-

Ref: QUT Wind and Fire Lab publications - https://research.qut.edu.au/wafel/publications/

Decomposition of Vegetation

- Vegetation subjected to fire - response involves a series of interconnected thermal and chemical processes (Both its external morphology and its internal thermochemical composition)

The initial stage involves **Moisture Evaporation**.

Wet vegetation → ν_{moist} **Moisture** + $(1 - \nu_{\text{moist}})$ **Dry vegetation**

The second stage is the **Pyrolysis** of the dry fuel.

Dry vegetation → ν_{char} **Char** + $(1 - \nu_{\text{char}})$ **Volatile**

The final stage is the **Oxidation of the char** residue.

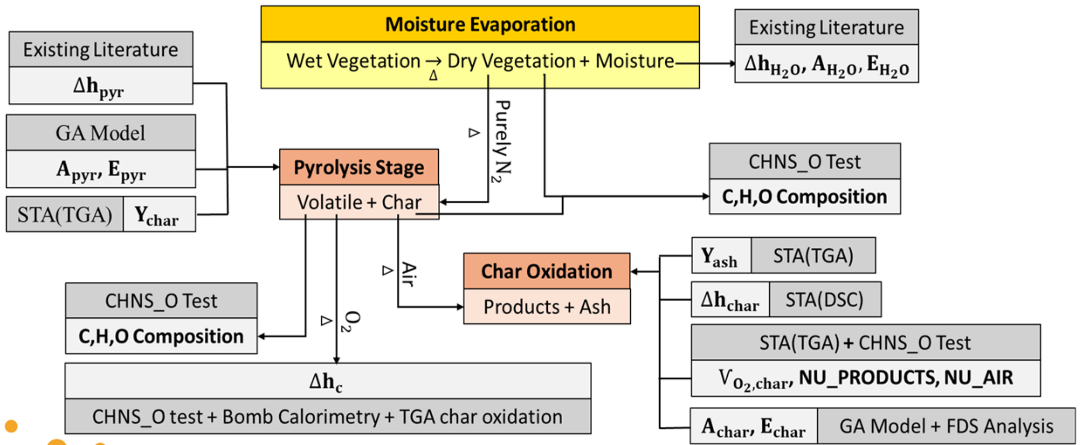
Char + $\nu_{O_2,\text{char}}$ O_2 → $(1 + \nu_{O_2,\text{char}} - \nu_{\text{ash}})$ CO_2 + ν_{ash} **Ash**

The rates of these transformations are typically characterised using **Arrhenius-type kinetics**.

$$\frac{d\alpha}{dt} = A\exp\left(-\frac{E}{RT}\right).f(\alpha)$$

Where,
α - conversion of the reacting fraction,
A - pre-exponential factor,
E - activation energy,
R - is the universal gas constant,
T - absolute temperature,
f(α) - selected conversion-dependent reaction model.

Thermo-Chemical Properties



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Thermo-Chemical Properties

Moisture Evaporation

Wet Vegetation $\xrightarrow[\Delta]{}$ Dry Vegetation + Moisture

Δh_{H_2O} = 2 259 kJ/kg [1]

A_{H_2O} = 600 000 /s [1]

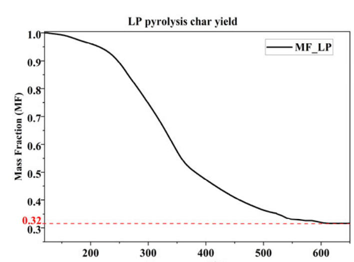
E_{H_2O} = 48 200 J/mol [1]

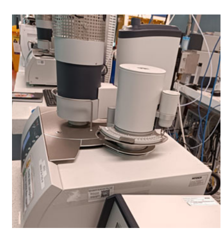
Pyrolysis of dry vegetation

Dry vegetation $\xrightarrow[\Delta]{}$ $(1 - Y_{char})$ Volatile + Y_{char} Char

Δh_{pyr} = 418 kJ/kg [1]

Y_{char} ?





NETZSCH STA 449 F3 Jupiter instrument

[1] B.Porterie, J.L. Consalvi, A. Kaiss, and J.C. Loraud. Predicting Wildland Fire Behaviour and Emissions Using a Fine-Scale Physical Model. Numerical Heat Transfer, Part A, 47:571–591, 2005. 245, 246, 248

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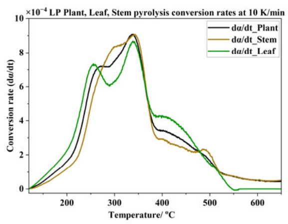
Thermo-Chemical Properties

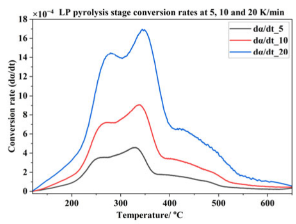
Pyrolysis of dry vegetation contd….

A_{pyr}, E_{pyr} Arrhenius Equation for the pyrolysis phase

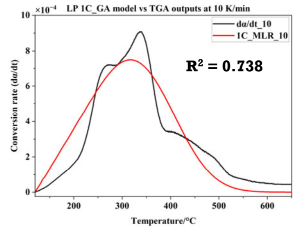
First-order decomposition reaction (conversion rate)

$$\frac{d\alpha}{dt} = A_{pyr}.\, e^{\left(-\frac{E_{pyr}}{RT}\right)}.\,(1-\alpha)$$





Genetic Algorithm



A = 0.387848 E = 27051.79

$$J(A,E) = \frac{1}{N}\sum_{i=1}^{N}\frac{\left[\left(\frac{d\alpha}{dt}\right)_{model,i} - \left(\frac{d\alpha}{dt}\right)_{exp,i}\right]^2}{\left(0.5\max\left|\left(\frac{d\alpha}{dt}\right)_{exp}\right|\right)^2}$$

The single-component (1C_GA) model is widely popular among researchers and used in many existing studies.

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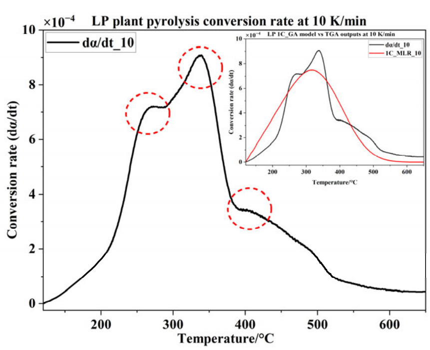
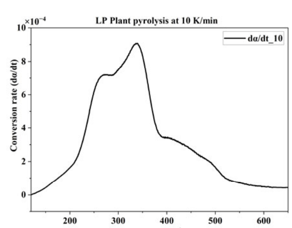
Thermo-Chemical Properties

Pyrolysis of dry vegetation contd….

Genetic Algorithm



- Vegetative fuel decomposition is complex because these fuels often contain several distinct components, such as hemicellulose, cellulose, and lignin, which react at different temperatures.
- This study considers these components as components 1, 2, and 3 for modelling purposes.



A_1 = 181 834 /s E_1 = 76 657 J/mol

r_1 = 0.20 (hemicellulose)

A_2 = 653 370 /s E_2 = 93 808 J/mol

r_2 = 0.30 (Cellulose)

A_3 = 0.39249 /s E_3 = 31 372 J/mol

r_3 = 0.50 (Lignin)

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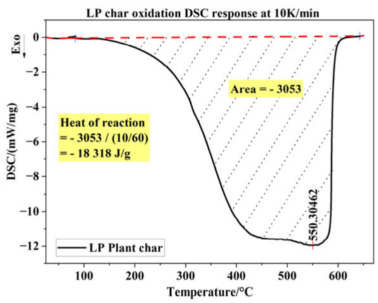
Thermo-Chemical Properties

Char Oxidation Phase

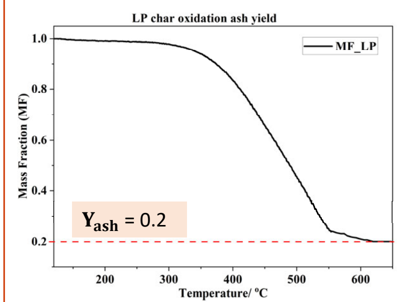
$$\text{Char} + V_{air}\,\text{Air} \xrightarrow[\Delta]{} V_{products}\,\text{Products} + Y_{ash}\,\text{Ash}$$

Heat of reaction of char oxidation — Δh_{char}

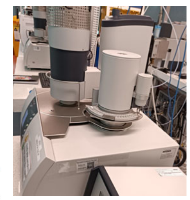


Δh_{char} = -18 318 kJ/kg

Ash yield — Y_{ash}



Y_{ash} = 0.2



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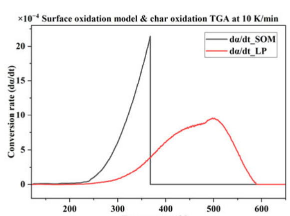
Thermo-Chemical Properties

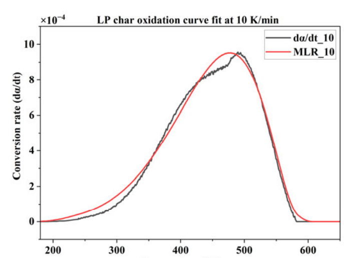
Char Oxidation Phase

A_{char} , E_{char}



SURFACE_OXIDATION_MODEL = T
A = 465 /s [4]
E = 68 000 J/mol [4]

FDS model (Char TGA test) – Trial and Error method and GA



FDS trial runs provided the final A, E, and Ns values that fit the experiment values with the model values as follows,

A_{char} = 500 /s

E = 52 414 J/mol

N_S = 0.7 (How the oxidation rate changes with the remaining amount of reactive char)

[4] *N. Boonmee, J.G. Quintiere, Glowing ignition of wood: the onset of surface combustion, Proceedings of the Combustion Institute, Volume 30, Issue 2, 2005, Pages 2303-2310.*

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Thermo-Chemical Properties

Char Oxidation Phase

$V_{products}, V_{air}$ Ultimate Analysis Test

Species	Sample	N%	C%	H%	O%
Lilly Pilly	Plant	1.54	45.73	5.93	42.49
	Leaf	1.79	47.05	6.24	40.98
	Stem/Twig	1.22	43.94	5.68	43.49
	Plant char	0.93	74.58	0.73	12.54
	Leaf char	0.98	77.88	0.65	10.24
	Stem/Twig char	0.77	68.75	0.86	13.08

Thermo Scientific Flash Smart Elemental Analyzer

	Char	Moles	Composition
C	0.672084	55.9557	1
H	0.006539	6.487594	0.12
O	0.112975	7.061391	0.13

n_{O_2}	54.05
$V_{O_2,char}$	1.73
V_{air}	-7.45
$V_{products}$	8.25

$$n_{O_2} = n_C + \frac{n_H}{4} - \frac{n_O}{2}$$

$$V_{O_2,char} = n_{O_2} * 31.998$$

$$V_{air} = \frac{V_{O_2,char}}{Y_{O_2,\infty}}$$

$$V_{products} = 1 + V_{air} - V_{ash}$$

C, H, O COMPOSITIONS

- $C_1H_{1.55}O_{0.7}A$ – Dry vegetation / fuel
- $C_1H_{3.36}O_{1.42}$ – Fuel gas/ Volatile
- $C_1H_{0.12}O_{0.13}A$ – Char

Thermo-Chemical Properties

Bomb calorimetry test outputs

Species	Sample	Gross Calorific Value (MJ/kg)
Lilly Pilly	Plant	17.6621
	Leaves	18.4115
	Stem	16.5545

Parr 6200 Bomb Calorimeter

$$\text{Dry vegetation} \xrightarrow{\Delta} \boxed{(1 - Y_{char})\ \text{Volatile}} + Y_{char}\ \text{Char}$$

$$+\ O_2$$

The heat of combustion is calculated using two methods and then compared.

1. Analysis of CHNS_O outputs + STA(TGA) outputs
2. Analysis of Bomb Calorimetry outputs + STA(TGA+DSC) outputs

SUMMARY

Parameters	Values
Dry vegetation / fuel	$C_1H_{1.55}O_{0.7}A$
Fuel gas/ Volatile	$C_1H_{3.36}O_{1.42}$
Char	$C_1H_{0.12}O_{0.13}A$
A_{H_2O}	$600\,000\ \sqrt{K}/s$
E_{H_2O}	48 200 J/mol
$A_{pyr,1}$	181 834 /s
$E_{pyr,1}$	76 657 J/mol
$A_{pyr,2}$	653 370 /s
$E_{pyr,2}$	93 808 J/mol
$A_{pyr,3}$	0.39249 /s
$E_{pyr,3}$	31 372 J/mol

Parameters	Values
A_{char}	500 /s
E_{char}	52 414 J/mol
$V_{O_2,char}$	1.729
$V_{products}$ (char)	8.25
V_{air} (char)	−7.45
V_{char}	0.32
V_{ash}	0.20
Δh_c	15.32 MJ/kg
Δh_{pyr}	0.418 MJ/kg
Δh_{char}	−18.318 MJ/kg
Δh_{H_2O}	2.259 MJ/kg

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Post-fire Assessment – Test 2

Before

During

After

Leaves and twigs < 6 mm were predominantly consumed; therefore, only fine fuel components were modelled.

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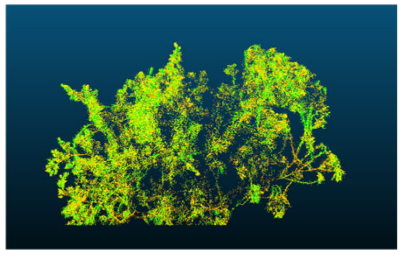
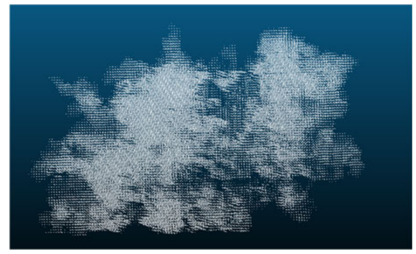
Reconstruction of Geometry – Test 2

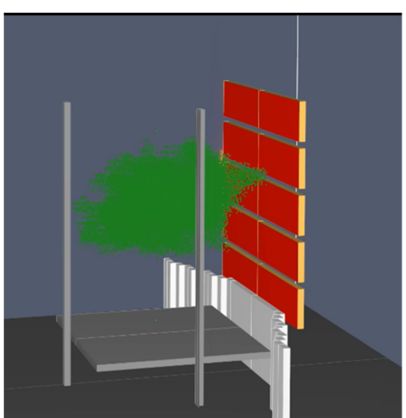

360° video

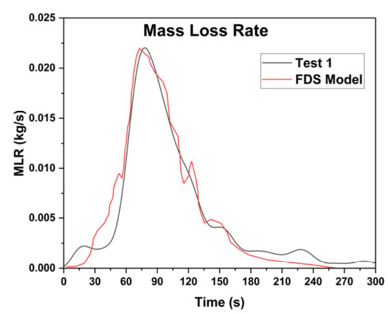

Point Cloud


Filled Point Cloud by keeping 3D Geometry (Algorithm developed)

The reconstructed Lilly Pilly hedge geometry was voxelised at a 50 mm resolution, and particles were distributed uniformly within the voxelised volume for FDS modelling.

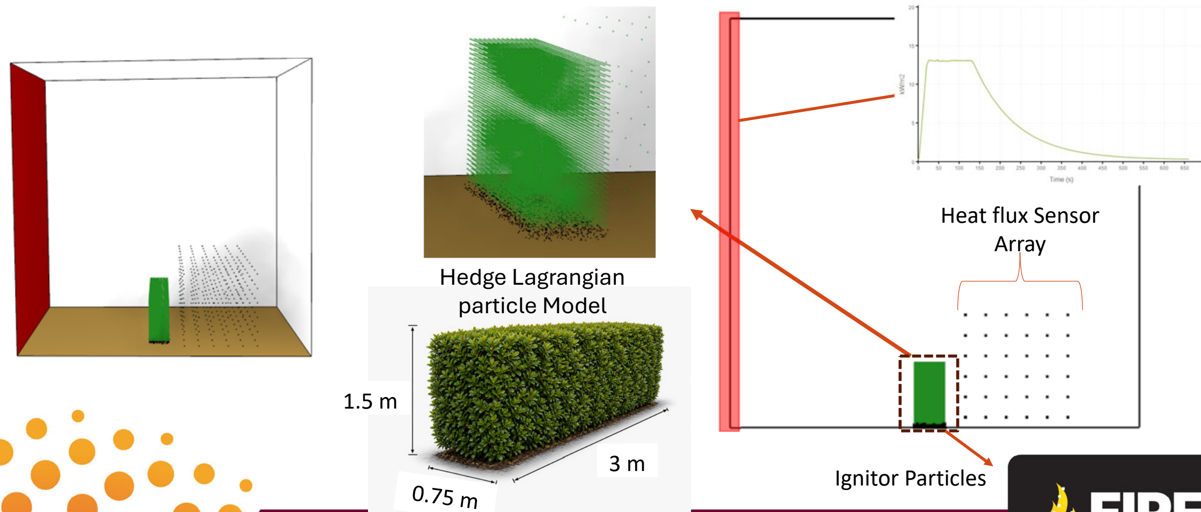
In FDS





	Test 1	FDS Model
Ignition Time	36 s	38 s
Burning Duration	122 s	118 s

Scenario Modelling



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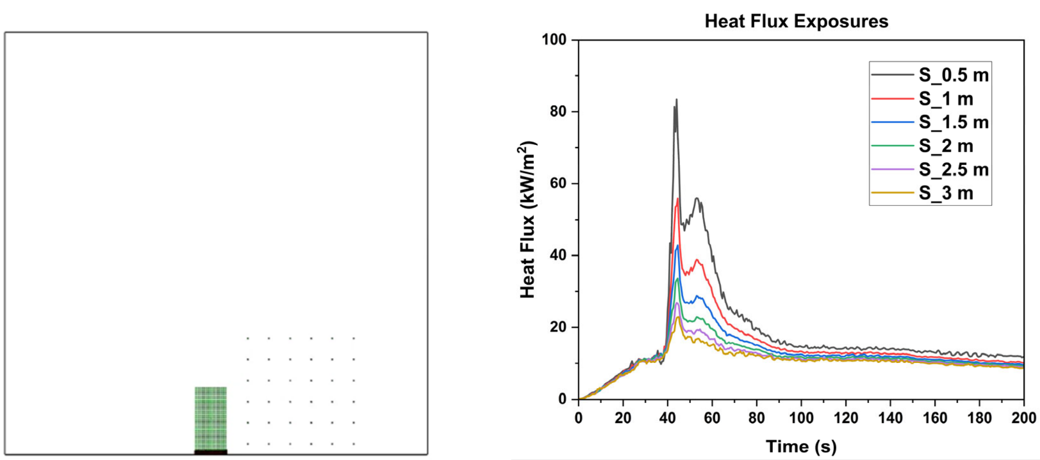
Scenario Modelling



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Thank you

We would like to thank the QUT and the National Recovery and Resilience Agency and Australian Research Council scholarship for the financial support and Natural Hazard Research Australia (NHRA) Postgraduate top-up, **Queensland Fire Department** Live Fire Testing facility and **QUT Banyo PPP** for providing the fire testing facilities; use of the **Central Analytical Research Facility** (CARF) and QUT's High-Performance Computing (HPC) facility for computational resources, and
Our Wind and Fire Lab Research Fellow and our postgraduate and final-year students, for their contributions.

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