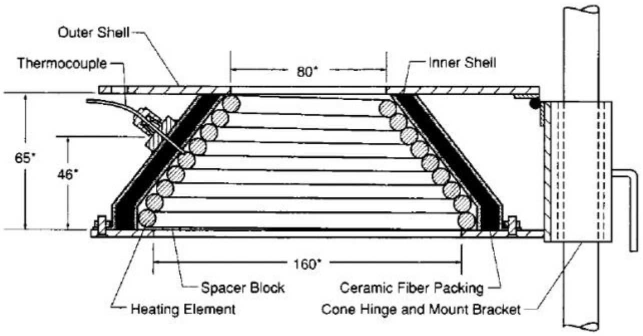
Project title: Firebrand-Timber Interaction and Ignition Dynamics in Wildfire Spread

About the Project:

Participants in this project will conduct hands-on research on timber -as a sustainable construction material- ignition in wildfire scenarios, with a particular focus on spotfire development. This phenomenon occurs when firebrands -burning embers transported by wind- remotely ignite new fires at a distance from the main fire front, often with minimal to no direct flame interaction. Spot fires pose a significant threat to communities in the Wildland-Urban Interface (WUI), where urban development meets fire-prone landscapes. This study explores and examines thoroughly the thermal interaction between firebrand depositions and timber surfaces, aiming to establish a quantitative relationship between firebrand heat transfer and timber ignition behavior. Experiments will be conducted using a specialized cone calorimeter setup at Carleton University's fire engineering lab.

The cone calorimeter is a fundamental experimental apparatus in the field of fire safety engineering, primarily used to quantify the heat release rate (HRR) of materials -a critical parameter in fire science that reflects the energy released during combustion. In addition to measuring HRR, the cone calorimeter enables the determination of the minimum incident heat flux required for ignition, providing insight into a material's ignitability. The test operates on the principle of oxygen consumption calorimetry, which states that the heat released during combustion is directly proportional to the amount of oxygen consumed (13.1×10^3 J of heat are released er 1 kg of oxygen consumed). This relationship is assessed through a gas analysis system that continuously samples combustion gases to determine the reduction in oxygen concentration, thereby quantifying the oxygen consumption and, consequently, the heat release. The entire procedure is conducted in accordance with ASTM E1354, a standardized testing protocol that specifies guidelines for sample preparation, testing conditions, ignition methods, and the measurement of key fire properties, including HRR, time to ignition, mass loss, and gas concentrations.



NOTE 1—All dimensions are in millimetres.
NOTE 2—* Indicates a critical dimension.

Figure 1: Cone Coil Heater Structure.

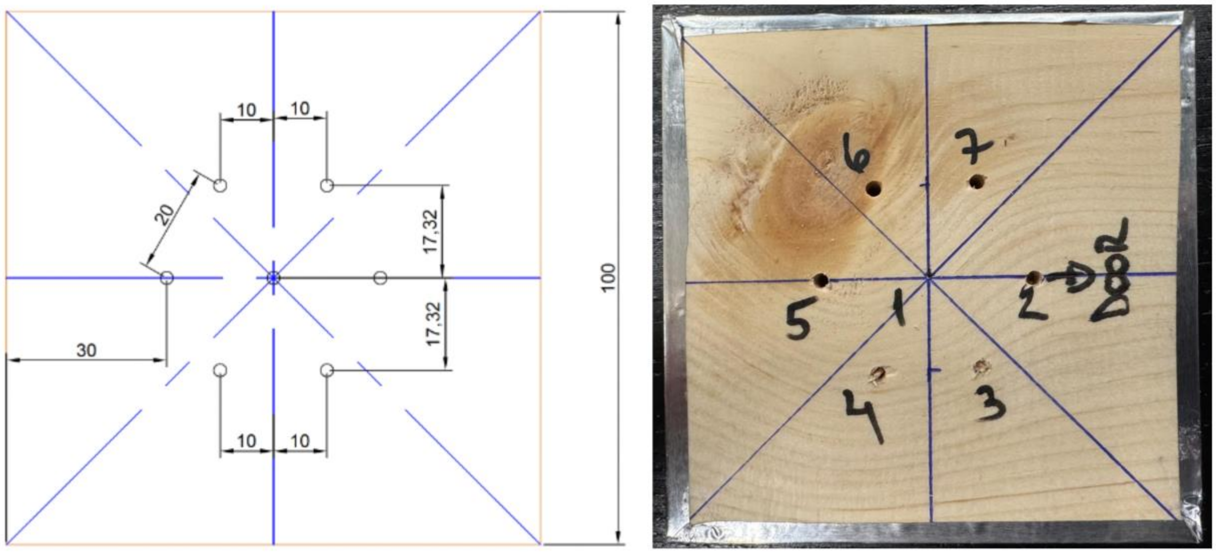
In this test, specimens are burned under ambient air conditions while exposed to a predetermined external heat flux delivered by a cone-shaped coil heater. The heat flux can be adjusted within a range of 0 to 100 kW/m^2 and is monitored and regulated using a thermocouple, as illustrated in Figure 1. Ignition may occur either with the assistance of a spark (piloted ignition) or without it (spontaneous ignition), depending on the experimental setup. For this project, the experiments are conducted in a non-standardized piloted manner; however, they take advantage of key features of the cone calorimeter, including the uniform radiative heating provided by the cone heater and the thermal insulation benefits offered by the ASTM E1354 procedures.

The design of this internship's experimental work builds upon previous investigations conducted in our laboratory, which focused on the interaction between firebrands and pine wood. Pine wood was selected due to its high ignitability relative to other commonly used building materials, attributed to its high resin content, low density (as a softwood), and porous internal structure. In the earlier experiments, we analyzed the thermal response of pine wood surfaces subjected to combined heating effects: radiant heat from a cone coil heater -simulating the dominant radiative heat transfer from a firebrand pile- and conductive heat transfer resulting from direct contact with accumulated touching firebrands layer. The incident heat flux was systematically varied between 10 and 40 kW/m^2, while the firebrands touching layer count flux ranged from 400 to 1000 firebrands/m^2. To capture the surface and subsurface thermal behaviors of the wood specimens, an array of thermocouples was embedded 2 mm beneath the surface and connected to a data acquisition system or a data logger device. Real-time temperature data were collected and processed using a custom Python script, which will be made available to support your analysis. In parallel, each experiment was video recorded to enable synchronization with the thermal data, allowing for accurate identification of flaming ignition onset, including its timing, location, and orientation in relation to the applied heat flux and firebrand interaction.

This work aims to improve the accuracy of ignition point identification by refining the threshold criteria that define ignition as a function of both incident heat flux from the cone heater and the firebrand contact density. The goal is to establish a physical correlation between the surface heating profile of the material and the total incident energy delivered by a firebrand pile under representative deposition conditions.

Methodology:

Preparing the Sample: pre-machined pine wood samples, each measuring 10 × 10 cm in surface area and 19.5 mm in thickness, will be provided and labeled for hole positions as illustrated in Figure 2. Each sample will then be aligned with pre-marked hole positions, which are centered using a screwdriver to facilitate precise drilling to a depth of approximately 17 mm using a drilling tool with a diameter of 7/64 inch, leaving about 2 mm from the surface to ensure accurate thermocouple placement. Following this, the lateral surfaces of the samples will be insulated using aluminum Cangfort tape to minimize edge heat losses during testing. Each drilled position will be labeled with the corresponding thermocouple number to streamline the installation and data acquisition process. Finally, weigh and record the insulated sample after drilling the holes.



(a) (b)

Figure 2: (a) A schematic showing the positions and orientations of drilled blind holes in the back of the specimens. (b) Sample being labelled and drilled as mentioned.

Thermocouple Assembly: Thermocouples are then inserted into the pre-drilled holes from the back side of the sample and secured in place using Scotch tape to ensure they remain firmly positioned within the cavity as shown in Figure 3. Care should be taken to ensure that the thermocouple junction (i.e., the sensing tip) is pushed to the maximum possible depth within the hole to maintain consistent thermal contact and accurate temperature measurement.

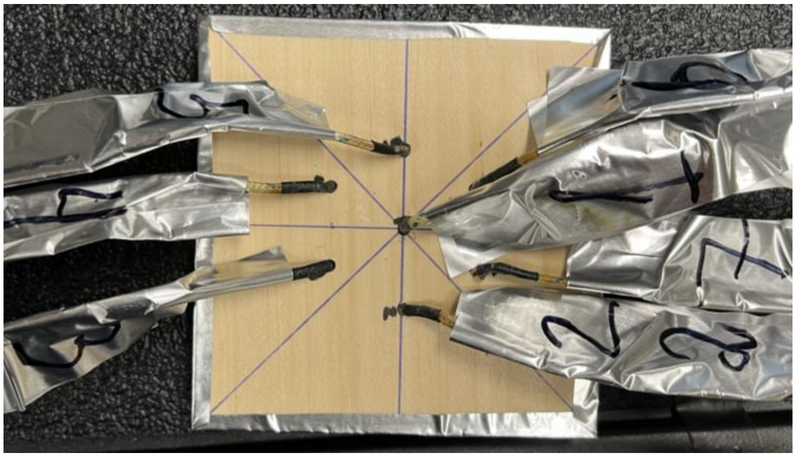


Figure 3: Thermocouples being inserted inside the holes at the back of the sample to be then scotch taped.

Sample Holder Assembly: The sample holder is prepared by placing two adjacent pieces of ceramic wool wick, each measuring 10 × 5 cm, on top of a ceramic tile substrate, as illustrated in Figure 4(a). The pine wood sample is then flipped and positioned with its rear side facing the ceramic wool wick as illustrated in Figure 4(b). The cover of the sample holder is subsequently placed over the entire assembly, applying uniform pressure to secure all layers in place. The thermocouple wires are routed through the bottom edge of the sample holder cover, as displayed in Figure 4(c), ensuring that the setup remains stable and that the wiring does not interfere with the insulation or testing process.

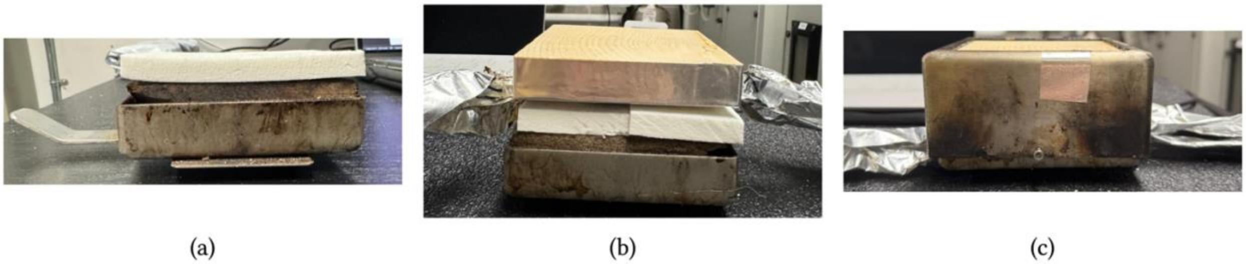
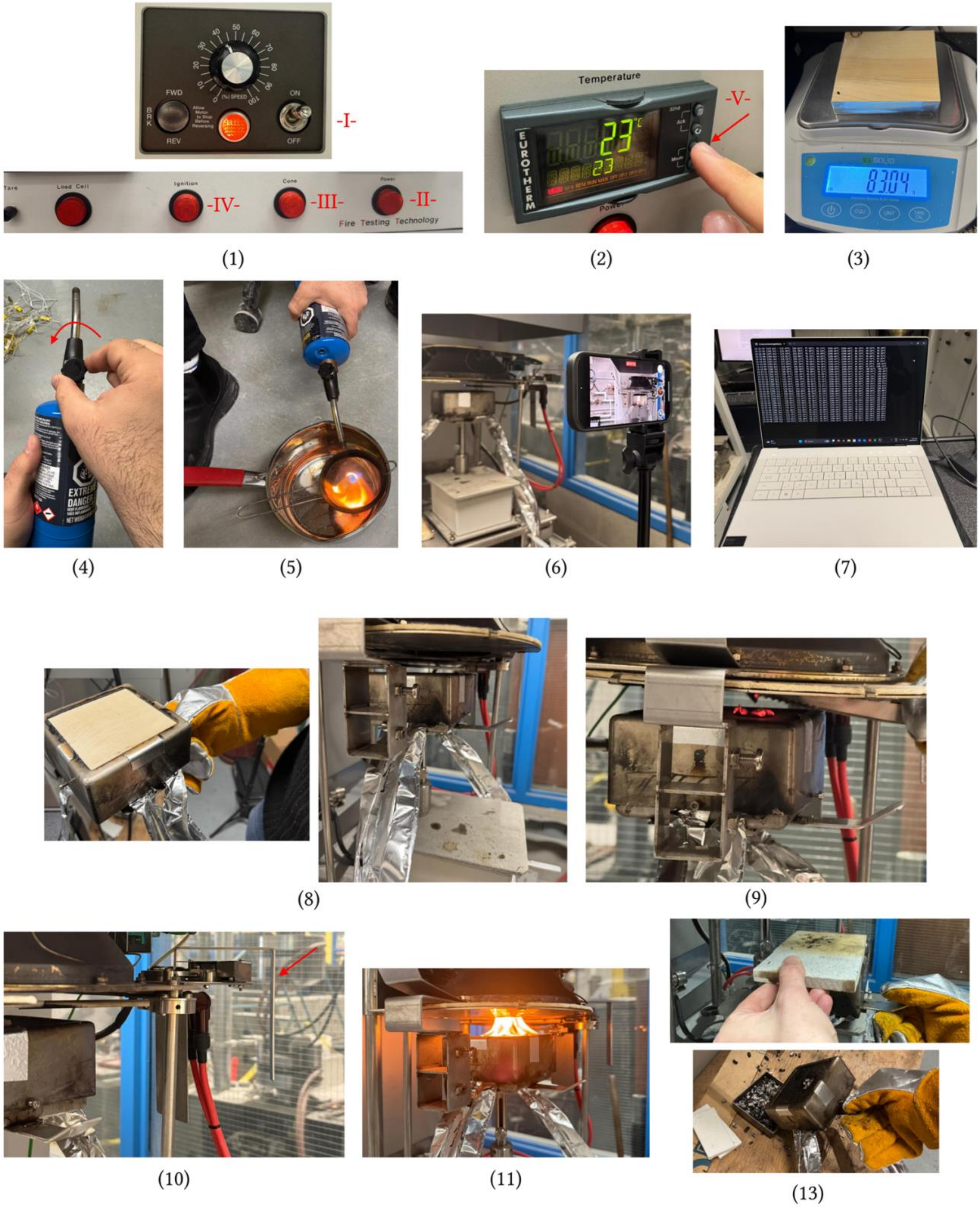


Figure 4: (a) Ceramic Wool Wick over the ceramic tile substrate. (b) Pine wood sample with thermocouples is added on top of the insulative layers. (c) Cover of the sample holder is pressed over the pine wood sample, and insulation layers.

Experimental Procedure: (1) Begin by switching on the system components in the following order: exhaust control, power, cone, and ignition, as illustrated in Figure 5. **(2)** Set the cone heater temperature to the desired heat flux level indicated in Figure 6 using the third button from the top and wait until the cone reaches the target temperature. **(3)** Record the initial mass of the sample and firebrands before the test its initial mass in the Excel spreadsheet. **(4)** Open the gas cylinder valve by turning it counterclockwise and press the trigger button to initiate gas flow. **(5)** Burning the firebrands: Ignite the dowel firebrands by directing the flame toward them from a distance of approximately 10 cm for 30 seconds or until sustained flaming is observed. **(6)** Start video recording using the phone mounted on the tripod, as shown in Figure 5. **(7)** Launch the provided Python script by double-clicking the file to open a command panel displaying real-time temperature readings. **(8)** While wearing thermal gloves, place the sample holder beneath the cone heater as shown in Figure 5. **(9)** Using thermal gloves and tongs, insert the ignited firebrands onto the right side of the sample, preferably above thermocouples 2, 6, and 7, as shown in Figure 5. **(10)** Turn on the igniter handle as shown in Figure 5. **(11)** Allow the experiment to continue until flaming ignition occurs or until a maximum duration of 15 minutes has elapsed, then turn off the igniter handle using thermal gloves. **(12)** Press Ctrl+C to turn off the running code and make sure that the excel file is recorded on your desktop. **(13)** Remove the sample holder, extinguish any remaining flames by pressing the surface against a ceramic tile, and dispose of residual ash and firebrands in the designated ash container, as illustrated in Figure 5. **(14)** Don't forget to rename your extracted temperature excel file before running the next experiment or it will overwrite the older file. **(15)** Finally, weigh and record the final mass of the wood sample while wearing the thermal gloves.



(1) (2) (3) (4) (5) (6) (7) (8) (9) (10) (11) (13)

Figure 5: Experimental procedure of the firebrand timber ignition test.

Realtime Temperature Profile Measurements: The provided Python script from step number (7) in the procedure is designed to capture a real-time temperature profile using thermocouples connected to a National Instruments (NI) data acquisition system (DAQ). It begins by defining a list of thermocouple input channels distributed across two cDAQ modules. The script then creates a data acquisition task using the nidaqmx library, configuring each channel to read from a Type K thermocouple with built-in cold junction compensation. Once the task is initialized, the script opens a CSV file to log the data, writing a header that includes the timestamp, elapsed time, and channel names. In a loop that runs for up to two hours (or until manually interrupted), it continuously reads the temperature values from all channels every 0.5 seconds. Each reading is timestamped and saved to the CSV file, while also being printed to the console for real-time monitoring. After execution, the script automatically opens the CSV file containing the recorded temperature data in excel format, which you will need to rename and save between after each experiment.

Experimental Domain Mesh: As previously outlined, the primary objective of this project is to refine and characterize the ignition threshold of combustible pine wood building materials under mixed-mode heating conditions that simulate the deposition of firebrands. The experimental matrix explores a range of incident heat fluxes from 14 to 20 kW/m², in 1 kW/m² increments, combined with firebrand quantities of 4, 7, and 10 -equivalent to surface count fluxes of 400, 700, and 1000 firebrands/m², respectively. To ensure statistical relevance and the reliability of the results, each test condition will be repeated three times, resulting in a total of 63 experimental runs.

Important Notes:

1) The prementioned correlation between the cone heater temperature and the corresponding incident heat flux follows an exponential relationship, as derived from calibration tests conducted using the cone calorimeter. This relationship is represented by the equation shown in Figure 6 and can be reliably used to extrapolate the required heater temperature values corresponding to the target heat fluxes defined within our experimental domain.

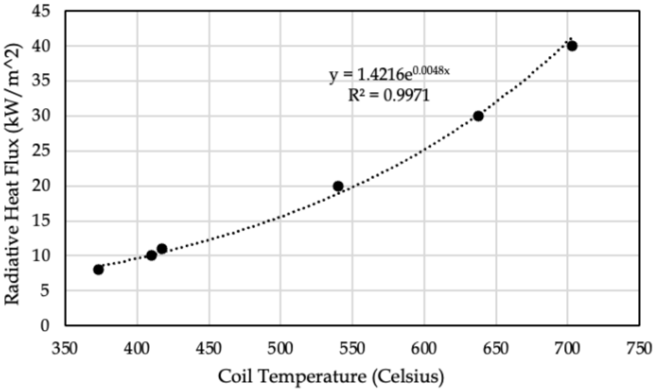


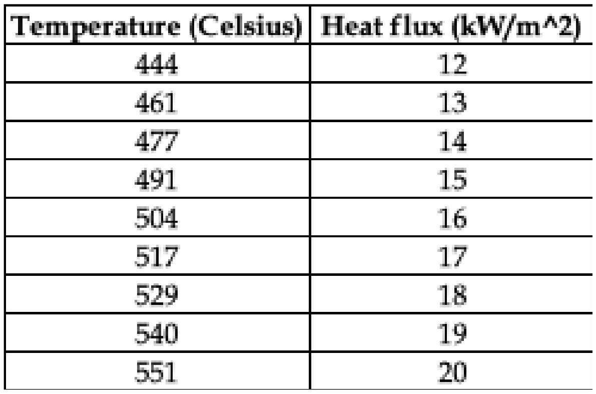
Figure 6: Exponential relationship between the coil temperature and the corresponding induced radiative heat flux.

This correlation yields a positive bound formula of:

$$T(°C) = \frac{\ln\left(\frac{\dot{Q}''\left(\frac{kW}{m^2}\right)}{1.4211}\right)}{0.0048}$$

From which we can extract the corresponding values of radiative heat flux ($\dot{Q}''$) needed for our domain as shown in Table 1.

Table 1: Interpolated values of coil temperature in degrees Celsius from induced radiative heat flux in the cone.



Temperature (Celsius)	Heat flux (kW/m^2)
444	12
461	13
477	14
491	15
504	16
517	17
529	18
540	19
551	20

2) After each test, the resulting CSV or Excel file generated by the Python script must be renamed and saved appropriately before initiating the next experiment. This step is essential to prevent accidental overwriting and potential data loss.
3) Each experimental run should be concluded either upon the occurrence of flaming ignition or after a maximum duration of 15 minutes if ignition does not occur.
4) All safety protocols must be strictly followed throughout the experimental process. Thermal gloves are required when handling high-temperature components, including the cone heater, pine wood samples, and firebrands during heating or transfer. Safety goggles must be worn at all times during the experiment. Additionally, participants should avoid wearing short or skin-exposing clothing, and long hair must be securely tied back, especially when operating equipment such as the hand drilling machine.