# IMPACT OF BUILDING GEOMETRY ON FIRE SPREAD RATE

**Timothy Onyenobi[1], J.Hudson[2], and M Ormerod[3]**

*School of Construction and Property Management, University of Salford, M5 4WT, UK*

In order to encourage sustainable construction practices, the renewability and low embodied energy of timber could be harnessed through its increased use in the building industry. This can be done through timber substitution and hybrid approaches of which the Building Research Establishment in Japan is currently carrying out a Research and Development Project. Timber being a combustible material increases concerns on fire behaviour among other issues. From the above context, this research explores the impact of the building geometry on fire spread rate. This paper contains first, a validation of the Fire Dynamic Simulator code (adopted for this experiment) with UK's Building Research Establishment real fire test program (TF2000) and secondly, an experiment carried out using the three primary forms to explore the possibility of an impact of building geometry on fire spread rate. Three fire domain samples were generated with uniform parameters differing only in their morphology: triangular, circular and square plans. These were each subjected to fires of equal heat release rate and fuel loads. It was observed that none of the three samples had equal fire spread rates. When applied to the building sector this could help designers reduce adoption of fire prone geometries when designing open plan buildings with fire prone material specification like timber.

Keywords: building geometry, fire, fire dynamic simulator, timber, validation.

## INTRODUCTION

Over the past years there have been introduction of new building materials into the construction industry driven by either economic, availability or high performance factors or all the above mentioned criteria. Such materials might have a low fire performance rating, for example timber which is a sustainable material but requires a high level of fire consideration when specified in a project as it has a low fire rating.

Various protection approaches like sprays, boards, preformed casings, intumescents etc are currently being used to mitigate rapid fire growth in the event of a fire incident. In addition to additive or subtractive fire protection measures, the experiment carried out in this research seeks to address the fire safety issue from the building design conceptualisation stage which will take advantage of the natural capability of the design form to mitigate fire spread. The experiment aimed at ascertaining zero, minor or major impact of building morphology/fire interaction without consideration of the fire domain materials. This approach of fire spread mitigation could have a positive impact on the whole life cycle of a building which contributes to construction management. To ensure a reliable result, a validation exercise of the Fire Dynamic Simulator (FDS) using the TF2000 natural fire test project was carried out. Parameters

[1] T.C.Onyenobi@pgr.salford.ac.uk
[2] J.Hudson@salford.ac.uk
[3] M.Ormerod@salford.ac.uk

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provided by British Research Establishment BRE were adopted as input for the FDS code though not enough was acquired.

## CFD (COMPUTATIONAL FLUID DYNAMICS) PROGRAM VALIDATION

The objective of this research phase is to provide empirical data needed to validate the proposed simulation technique for this research. The proposed package to be used is FDS (Fire Dynamics Simulator) application put together by NIST (National Institute of Standards and Technology) 2004 version which works in synergy with Smokeview (a visualisation software). In order to accept results using this application, a validation process was carried out see below. (Other researchers who adopted this application have carried out various validation exercises for their adoption of the FDS). TF2000 test compartment was chosen for this validation exercise for this research as it involves timber as a building material.

## TF2000 FIRE TEST COMPARTMENT AND FDS MODEL DOMAIN DESCRIPTION.

**TF2000 Test Compartment Description:**
The fire test compartment consisted of a single flat in the South West corner on the third level of the building. The walls were built of timber studs, OSBs, plaster board lining, external brickwork cladding. Ceiling lining was made of plasterboard beneath timber floor joist for the flat above, the same arrangement occurred for the floor of the test compartment. The ventilation conditions involved two windows, the living room and kitchen (Lennon, 2000) see fig 2. The fire load was provided by timber cribs spread over the floor area of the flat. Approximate box dimensions 6.0m east, 3.0m south, 2.4m height dimensions. (Deduced from TF2000 second floor plan drawing see Fig1).

**FDS Model Computational Domain:**
For this validation exercise the researcher chose the nucleus of the TF2000 fire test (ignition domain) a) the living b) the kitchen and for triangulation purposes also included c) the ceiling void. The ventilation conditions involved two windows, the living room and kitchen. The fire load was provided by upholstery and timber boxes spread over the floor area of the flat. Approximate box dimensions 6.0m east, 3.0m south, 2.4m height dimensions. (Deduced from TF2000 second floor plan drawing see Fig3).

Door leading to the TF2000 lobby was present in the compartment but was shut This door wasn't included in the FDS model because it was shut during the test though the door linings could have acted as vents and contributed to the test result values, but this wasn't done because it would require relatively minute grid cells which might greatly slow down the simulation process for an insignificant difference in empirical output values. The simulation of the FDS generated fire domain was carried out producing result similarities to the TF2000 fire test program.

# TF2000 AND VALIDATION MODEL DESCRIPTIVE ANALYSIS

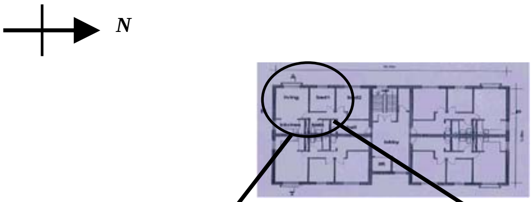


**Figure 1:** BREs TF2000 3rd floor of test facility (Lennon 2000)

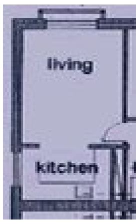


**Figure 2:** Research focus BREs TF2000 Compartment Enlarged (Lennon 2000)

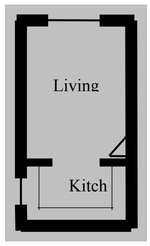


**Figure 3:** Research focus simulation compartment enlarged

**Table 4**: Comparison of observations between the TF2000 test and generated FDS model

| TF plan / TF2000 fire test | FDS plan / validation model |
|---|---|
| Fire progressed to flashover after 24minutes from ignition | Fire gradually progressed to flashover between 20 and 30 minutes from ignition |
| Fire Brigade were asked to intervene by breaking single Window pane in kitchen area 21minutes 30secs from ignition | The simulation was stopped at its highest temperature 80 minutes into the simulation (1000degC) |
| Following flashover, the fireline boards over windows to the floor above were subjected to heat flux of approx. 30kw/m^2 | Following flashover the temperatures stayed between 900 and 1000deg C |
| Window frame in the living area burnt away 35minutes into test | There was no information on the wood input parameter as regards windows |
| Peak temperatures in living area reached 1000°c and remained there until the test was stopped at 64minutes from ignition. | Peak temperatures in living area reached 1000°c and remained there until the test was stopped at 80minutes from ignition |
| Based on the measurements taken of fuel mass loss, the peak rate of heat release is estimated as approximately 6MW(MW=Megawatts) | Not yet determined |
| Ceiling boards began to come down 54minutes into the test | No such observation was made as this research focussed on the temperature |
| Maximum temperatures in the structural voids forming the Boundaries of the compartment remained below 100°c | Maximum temperatures in the structural voids forming the Boundaries of the compartment remained below 140°c |
| The coolest temperature recorded close to the window in the TF2000 test exercise. Data demonstrates intense period of heat flux after flashover | The coolest temperature recorded close to the window parameter as regards window in the FDS model data demonstrates intense period of heat flux after flashover |

During TF2000 fire test, it was observed that the effect of natural fire is approximately 10% higher that that of a standard (BS476: Part 20 furnace) fire test. (Lennon 2000) Only the test on a real structure under natural fire may evaluate the forthcoming model of the actual temperature development in fire compartment that's why this research seeks to validate the major tool by comparing with a natural fire (TF2000) see table 2 below. For this program to be valid the relative differential factor should not exceed 11 %, this percentile is taken from the TF2000 natural fire charring test results analysis when compared with the (BS476: part 20 furnace) charring test results. See table 2 below and analysed in Table 3.

**Table 2**: Measured depth of charring (mm) TF2000 and BS476 part 20 furnace comparisons. BRE report (Lennon 2000)

| Cube Location | Cube type | TF 2000 | Furnace | Relative severity | Percentage difference |
|---|---|---|---|---|---|
| Living room | H | 33 | 24 | 1.375 | -2.2 |
| Living room | S | 45 | 41 | 1.098 | -8.8 |
| Kitchen | H | 20 | 23 | 0.87 | 15.0 |
| Kitchen | S | 36 | 39 | 0.923 | 8.3 |
| Corridor | H | 15 | 23 | 0.652 | 53.3 |
| Corridor | S | 26 | 39 | 0.667 | 50.0 |

*H* hardwood cube samples during the TF2000 fire test
*S* softwood cubes samples during the TF2000 fire test

**Table 3:** Result of analysis of relative severity and percentage magnitude of charring depth (Lennon 2000)

| Compartment | Mean severity | Percentage magnitude |
|---|---|---|
| Living room | 1.237 | 11 |
| Kitchen | 0.897 | 23.3 |
| Corridor | 0.66 | 103.3 |

These values in table 3 derived from the TF2000 Natural fire and BS476 Part20 furnace standard test will empirically define the numerical range within which the FDS simulation results should fall for this research to adopt the program.
Below are graphical illustrations of the results of both tests exercises placed side by side for both visual and numerical comparisons

Three points of time against temperature will be selected and compared for both tests for each of the test criteria and results will be tabulated of which a relative severity factor will be recorded. This method was used in the TF2000 project when test results were compared with that of the BS476:Part20 furnace test (Lennon 2000).

These results were comparatively analysed for the validation exercise. See Table 4

**Table 4:** Comparative analysis of FDS and TF2000 temperature value results

| Compartment | Time (mins) | FDS (˚C) | FDS (˚C) |
|---|---|---|---|
| Living room | 20 | 665 = (t1) | 480 = (t4) |
| | 40 | 751 = (t2) | 980 = (t5) |
| | 60 | 943 = (t3) | 940 = (t6) |
| Kitchen | 20 | 580 | 400 |
| | 40 | 692 | 750 |
| | 60 | 774 | 800 |

*t* recorded temperature readings from thermocouples during the test

Based on TF2000 report review, for simulation to be valid it has to comply with the equation in Fig 4 below.

$$\frac{\left(\frac{t4 + t5 + t6}{3} - \frac{t1 + t2 + t3}{3}\right) \times 100}{\frac{t1 + t2 + t3}{3}} \leq 11\%$$

**Figure 4**: Validation equation

The percentage '*difference*' between the '*mean*' of the TF2000 readings and the FDS simulation readings should not exceed 11%.

This percentage value was chosen because during the test, the Charing results of TF2000 (natural fire) and BS476 (standard fire test) differed by 11%. See Tables 2, 3, 4 and Fig 4.

**Explanation of the equation**

The percentage '**difference**' between the '**mean**' of the TF2000 readings and the FDS simulation readings should not exceed 11%. This percentage value was chosen because during the test, the Charing results of TF2000 (natural fire) and BS476 (standard fire test) differed by 11%. See Table 5 and 6.

Mean of temperature readings at 20, 40, and 60 mins into test:

TF2000 = 800, FDS = 786,

Percentage difference

= (800-786)/800 x 100 = 1.75 %

Percentage difference = 1.75, this is less than 11%

Hence the fire spread rate exploratory research will be carried out using the FDS fire simulation code.

## SIMULATION TEST ON FIRE DYNAMICS IN RELATION ENCLOSURE MORPHOLOGY

With the FDS simulation software validated its subsequent empirical results will be adopted which leads to the next stage, does the geometry of a fire domain (enclosure) have any impact on the rate of fire spread? A pilot simulation was carried out to investigate this. Three test domains were generated. The domain geometry consists of:

| | |
|---|---|
| A square | 6720 x 6720mm |
| A triangle | 9500mm height and 9500mm base |
| A circle | 3790mm radius |

As temperature values are closely related to heat fluxes this could be a pointer if the flow field within the domain is identical or not. Therefore differing temperatures within the domain could most likely symbolise difference in fire spread rate. Note: all other computation input parameters remain uniform. *The prime unifying input parameter is the floor area (45m²) and flow field volume (108m³).* There was no ventilation to ensure unaffected plume propagation. Below are temperature readings for the three geometries. For a reliable figure temperatures of six levels were taken:

600mm, 900mm, 1500mm, 1800mm, 2200mm above floor assumed floor level see graph figs 1 to 10.

**Triangular plan Computational Domain** (*Readings when exposed to a 60 sec flame*).

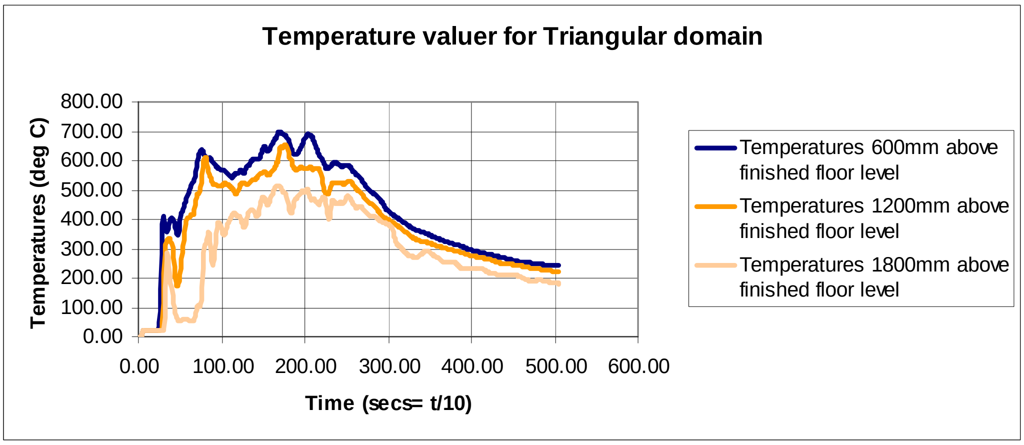


**Figure 5:** Temperature reading for levels 600mm, 1200mm, 1800mm (triangular)

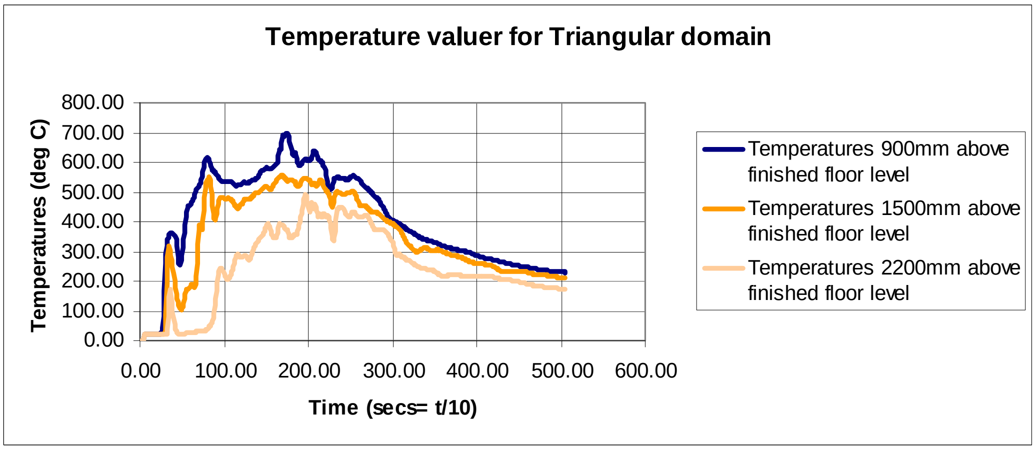


**Figure 6:** Temperature reading for levels 900mm, 1500mm, 2200mm (triangular)

**Square plan Computational Domain**:*(Readings when exposed to a 60 sec flame)*

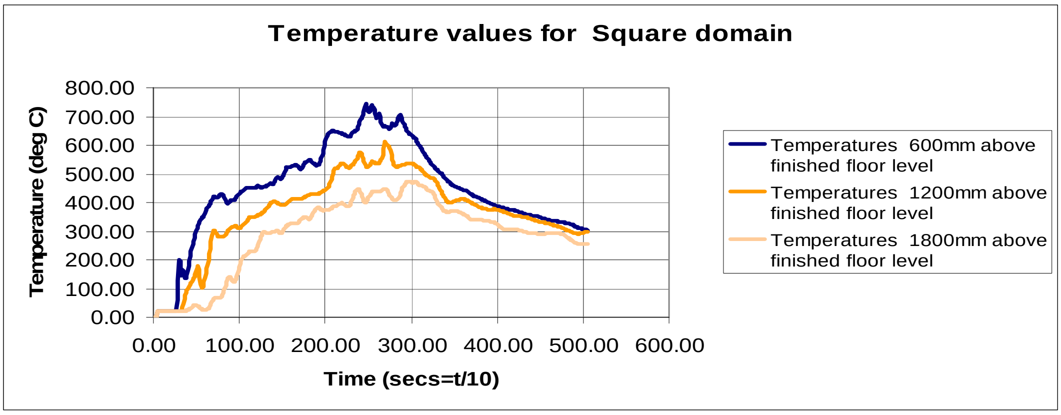


**Figure 7:** Temperature reading for levels 600mm, 2100mm, 1800mm (square)

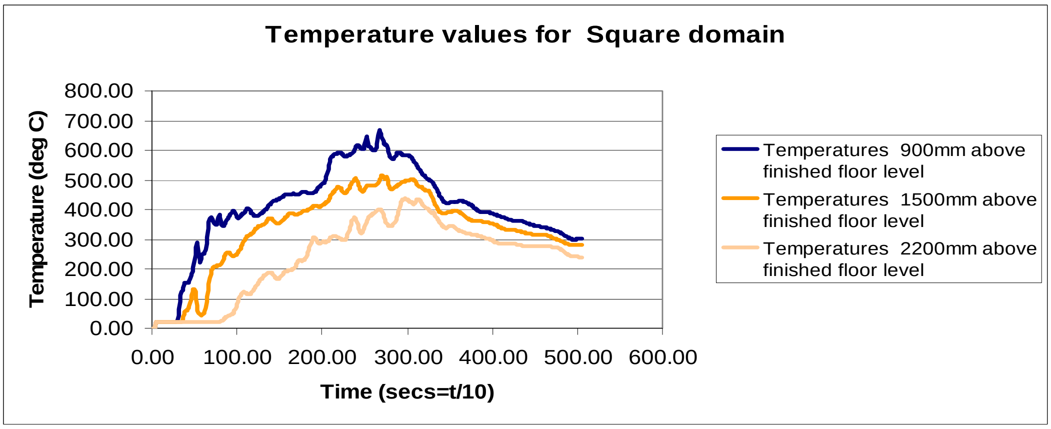


**Figure 8:** Temperature reading for levels 900mm, 1500mm, 2200mm (square)

**Circular plan Computational Domain**:*(Readings when exposed to a 60 sec flame)*

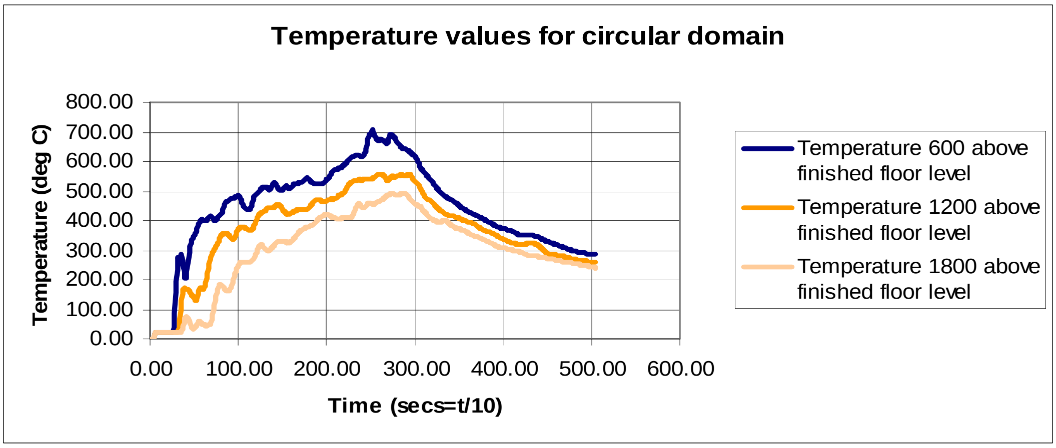


**Figure 9:** Temperature reading for levels 900mm, 1500mm, 2200mm

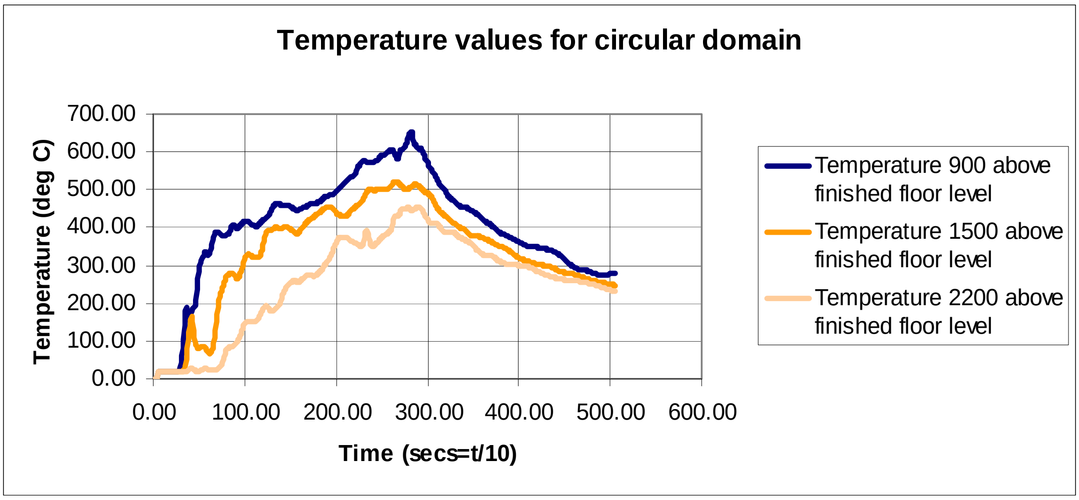


**Figure 10:** Temperature reading for levels 600mm, 2100mm, 1800mm (square)

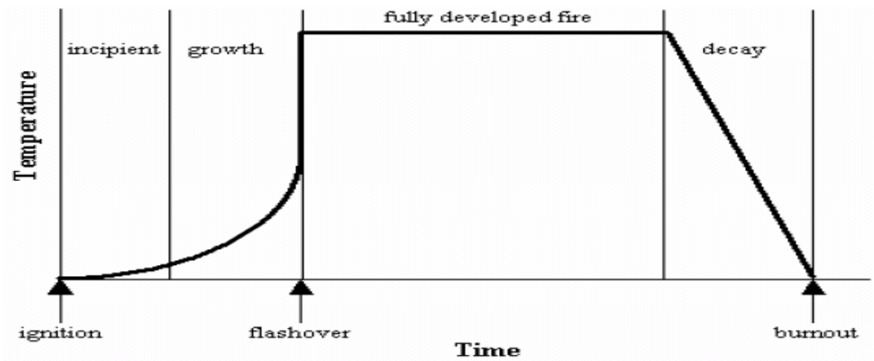


**Figure 11:** A typical temperature / time fire curve and various stages of fire development

From the output data values there were identical temperature readings for all six thermocouples 2 seconds into the fire and though near close readings after the during the decay period of the flame. From the graphs in Figs 5, 6, 7, 8, 9, and 10 this can also be noticed in the pattern. Analysing these shape one could say hypothetically that the spread rate during the incipient and growth stage of the flame, for the three experiments were identical. This is likely to be as a result of lack of contact of the plumes with the domain boundaries. During the full developed fire stage which for this experiment occurred between 2.5 and 25 seconds into the fire.

## VISUAL RESULTS OF EXPERIMENT

The test domain was sealed up to control external fire friendly factors this accounts for the short ignition – burnout time due to O2 depletion. All three tests from ignition to decay produced a maximum temperature of 820 deg C.
The triangular domain plume burnout time =32.2 seconds from ignition
The circular domain plume burnout time =35.6 seconds from ignition
The square domain plume burnout time =37.0 seconds from ignition
From the visuals with respect to plume spread propensity,
The triangular domain 20seconds from ignition had the fire plume in contact with much surface area of its rear and side left side surfaces (see Fig 12)

The circular domain 20seconds from ignition had a stray fire plume grazing a small fraction of its surface (see Fig 14).
The square domain 20seconds from ignition, the fire plume did not make any visible contact with its surface. (see Fig 13).

Below are the three basic morphologies which were used for to investigate the effect of the building shell or the compartment shell on fire spread rate.

The arrows show the part of the boundary walls that had come in contact with the fire plume within 20 second from ignition

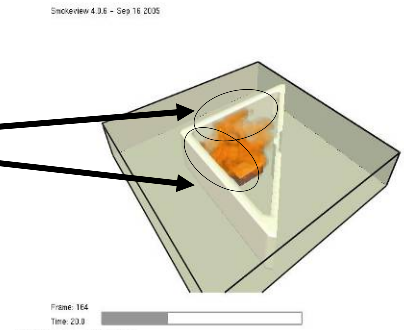

**Figure 12:** The triangular domain

The arrows show the part of the boundary walls that had come in contact with the fire plume within 20 second from ignition.

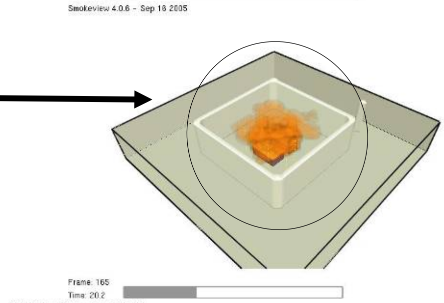

**Figure 13:** The square domain

The arrows show the part of the boundary walls that had come in contact with the fire plume within 20 second from ignition

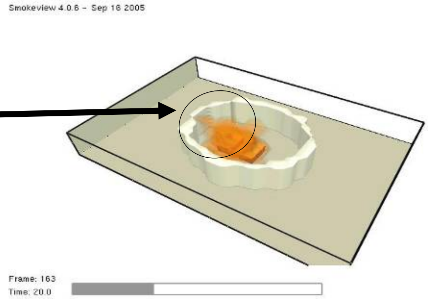

**Figure 14:** The circular domain

## CONCLUSION

With the findings of this experiment, it is observed that there are different fire propagation rates for each sample in the chosen test. The validation process of the FDS simulator increased the reliability of the outcomes when the available input parameters where used. This is simply a pilot experiment and could be taken further through Research and Development programs. The square form showed the highest level of fire mitigation, these are simple forms but complex forms could also be explored in future researches to produce valuable data on fire propagation options which can help Architects, Fire Engineers and other related professionals in making an informed design decision in relation to building form and fire spread especially when increased specification of combustible yet sustainable timber among others. This is expected to reduce heavy dependence on fire protection materials like, boards, preformed casings, intumescents and can in effect reduce the cost of fire protective measures thereby reducing the overall cost of the building and creating an improved life cycle.

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