OpenFIRE: An Open Computational Framework for Structural Response to Real Fires

Aatif Ali Khan

University of Canterbury
Te Whare Wānanga o Waitaha
Christchurch New Zealand

The Hong Kong Polytechnic University
香港理工大學

SiF 2022, Hong Kong

Structure Fires

- Nearly 500,000 building fires reported each year in US
- Each year property damage of nearly $10 billion
- Bridge fires: Direct and Indirect cost

What fire scenario to use for structural response simulation?

Forensic analysis of disasters:

WTC Towers

Plasco Building

Design Scenarios for PBD

CFD SIMULATIONS

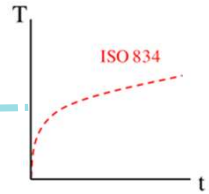
Prescriptive and Performance based designs:

Fire curves from codes and standards

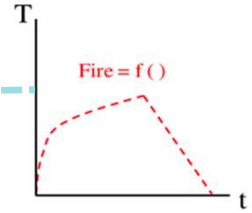
Idealised fire scenarios

IDEALISED UNIFORM FIRES

- Standard fires

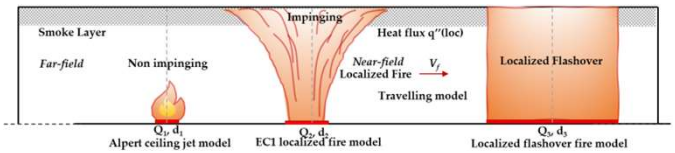


- Parametric fires

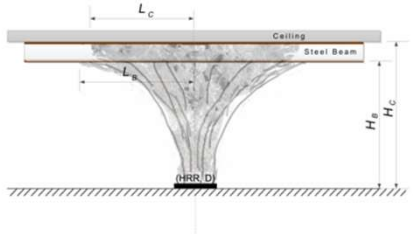


IDEALISED NONUNIFORM FIRES

- Continuous fuel distribution

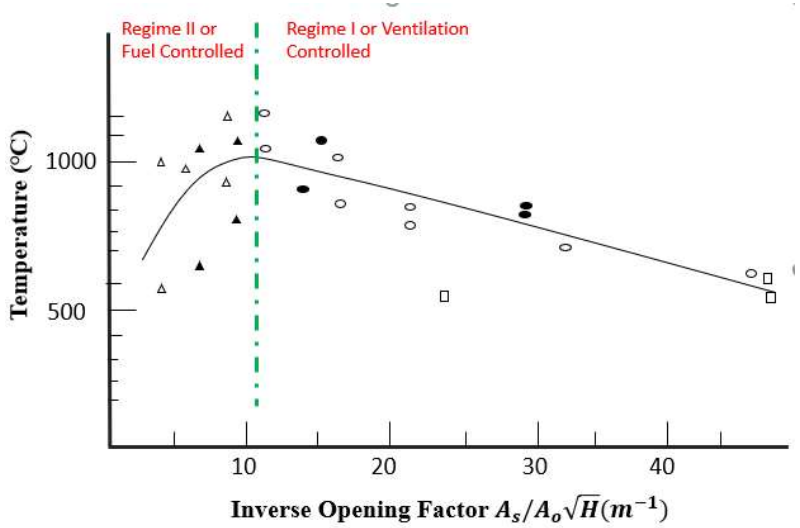


- Discontinuous fuel distribution



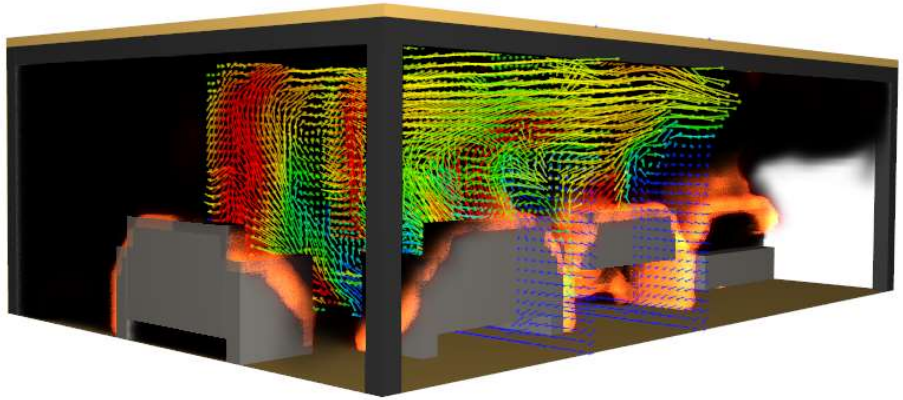
Why we need CFD ?

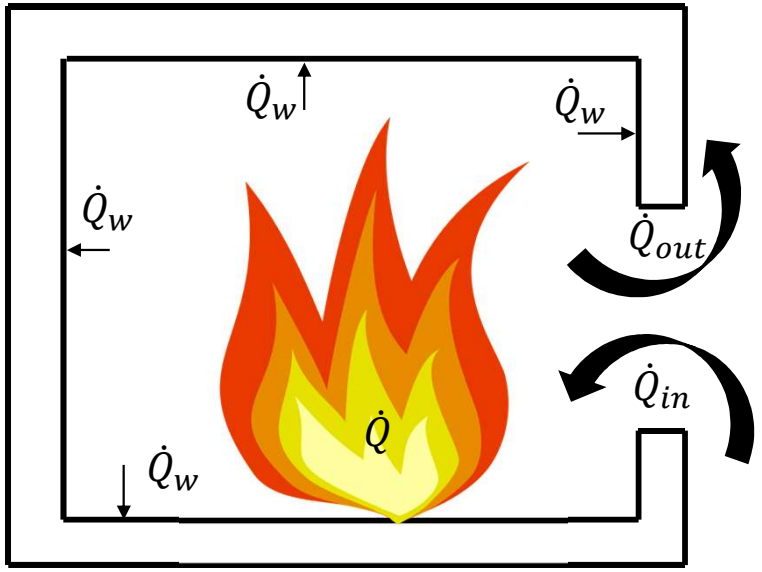
- Experiments:
  - Costly
  - Sometimes not feasible
- Idealized Fire Model for Design
  - No material information (Chemical Composition)
  - Suitable for ventilation-controlled fire
  - No information on the distribution of fuel
- PBD: Requires design fire scenarios
  - CFD can generate realistic fire scenarios



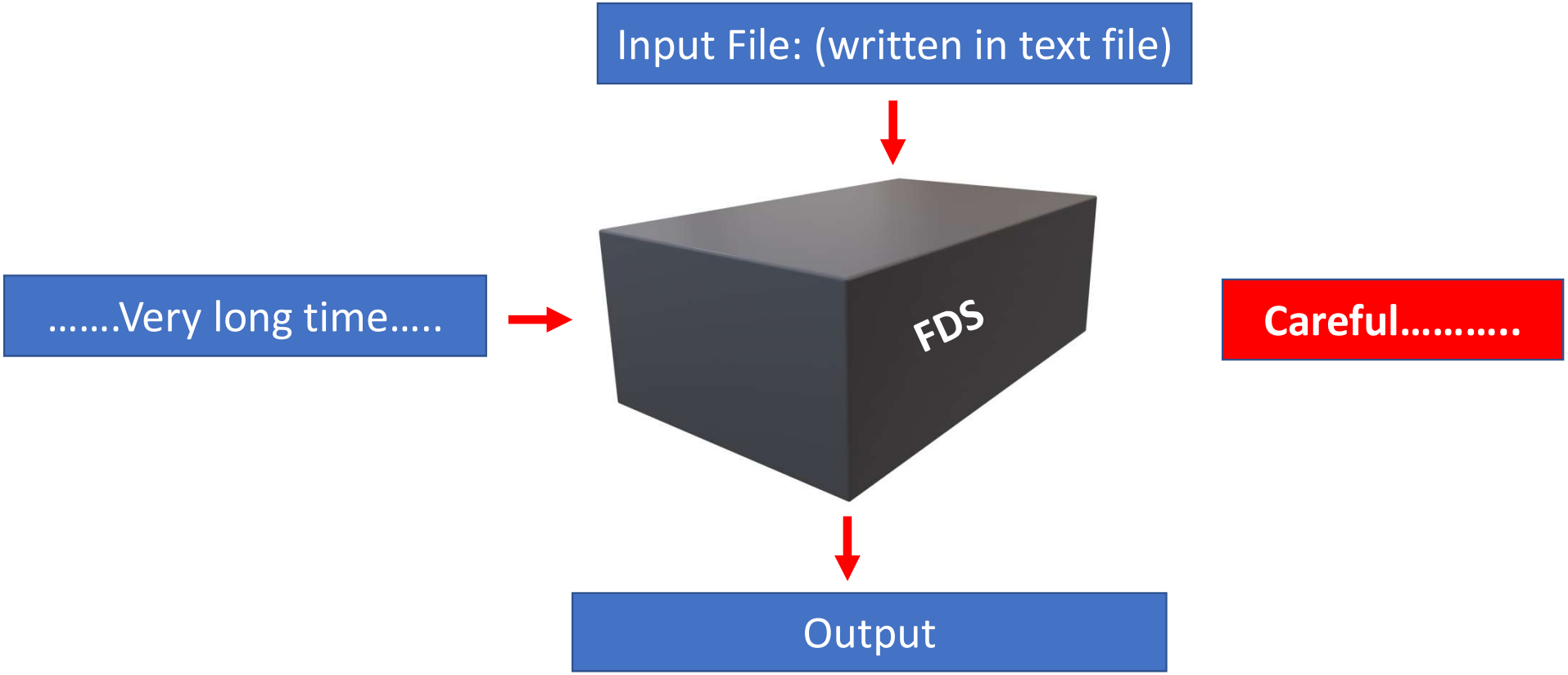
FDS… What is it?

- Widely used fire simulation tool
- Solved governing equations
  - Conservation of mass, energy, momentum, species

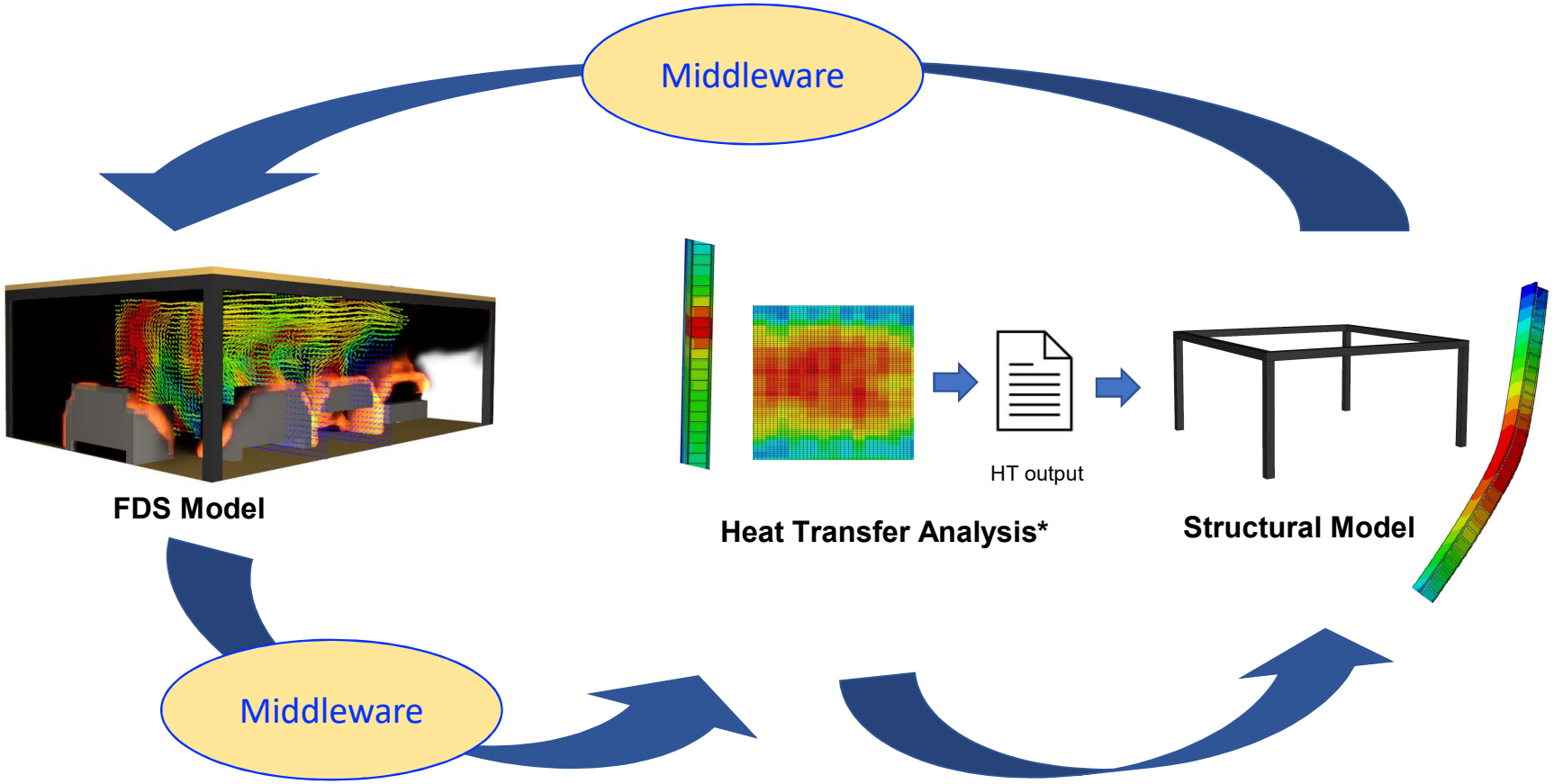




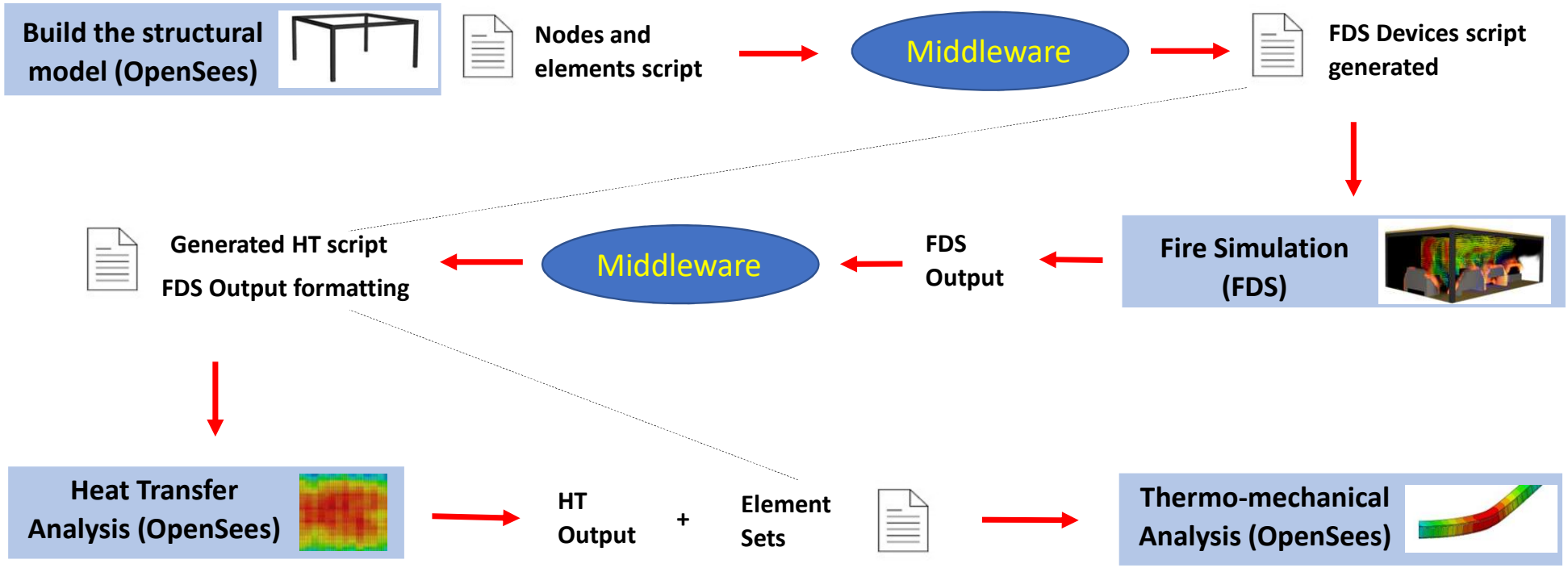
FDS


Input File: (written in text file)
.....Very long time.....
FDS
Careful.....
Output

FDS-OpenSees (OpenFIRE)



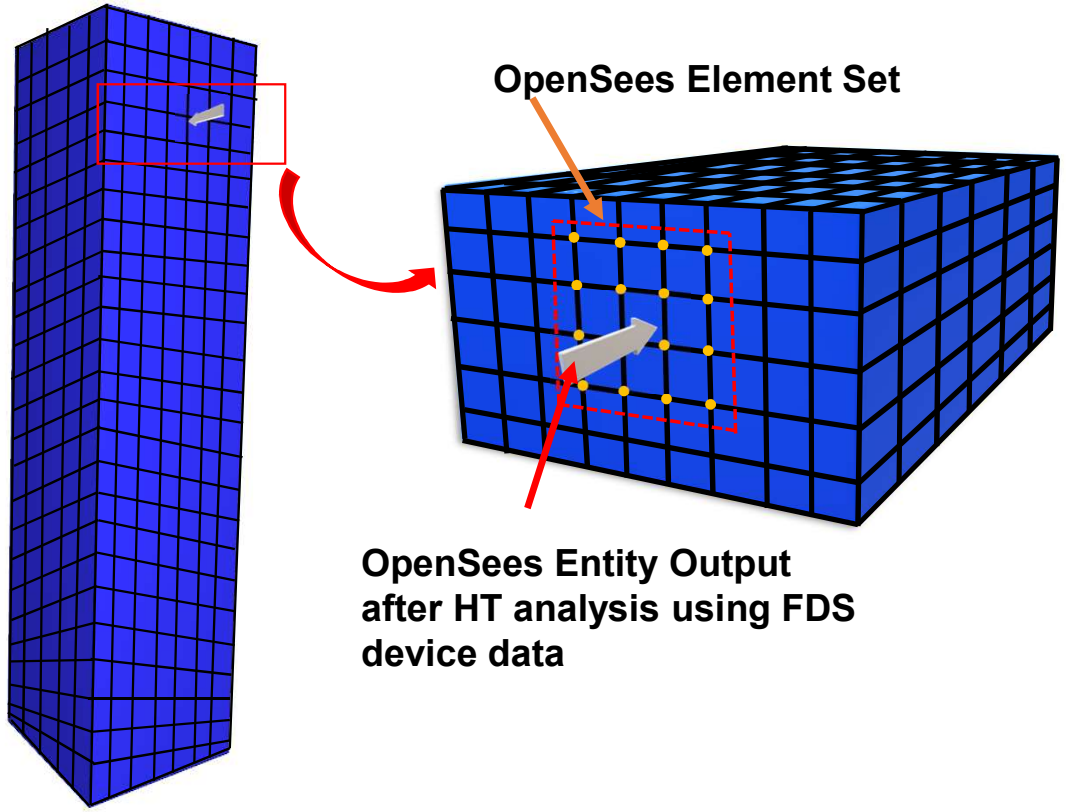
OpenFIRE


Build the structural model (OpenSees)
Nodes and elements script
Middleware
FDS Devices script generated
Fire Simulation (FDS)
FDS Output
Middleware
Generated HT script
FDS Output formatting
Heat Transfer Analysis (OpenSees)
HT Output
+
Element Sets
Thermo-mechanical Analysis (OpenSees)

OpenSees Entities

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

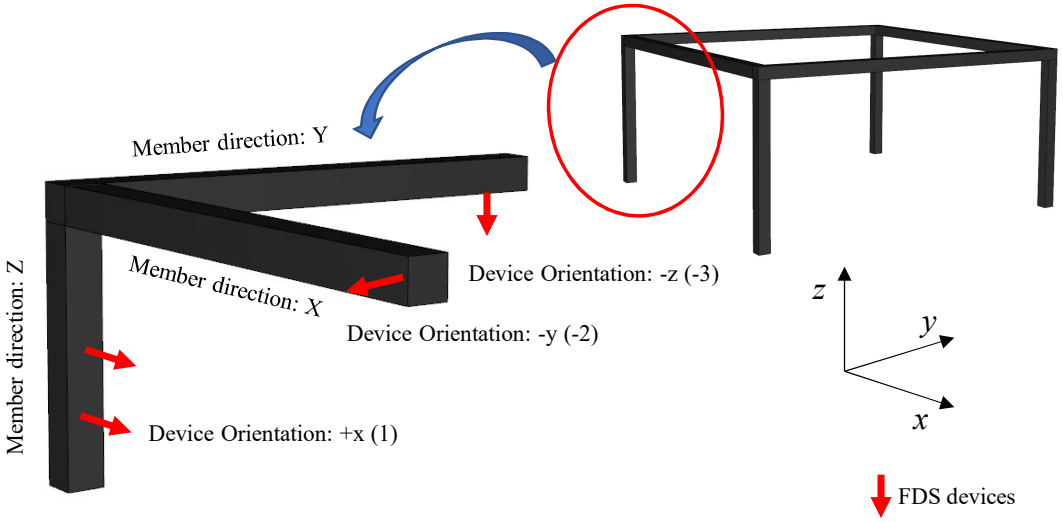
Spatio-temporal scale



FDS and OpenSEES

- While defining the models ..
  - Only fire room is present in FDS
  - Global coordinates should be same
  - “Z” axis as vertical direction
  - The link between OpenSees and FDS:
    - Device location

Devices



Method	Boundary condition
1	AST
2	HF
3	HTC
4	GAS*

Measuring quantity

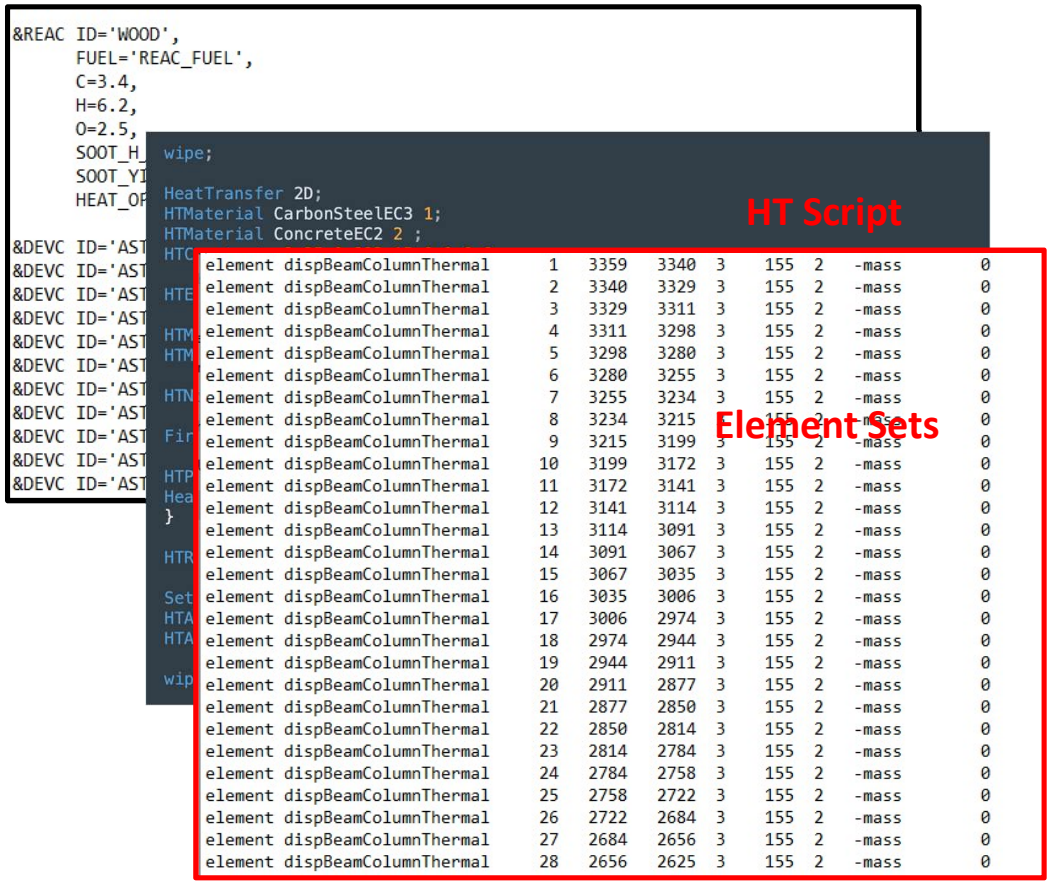
Location of device

```
&DEVC ID='AST01', QUANTITY='ADIABATIC SURFACE TEMPERATURE', XYZ=0.15,2.5,2.1, IOR=1/
&DEVC ID='AST04', QUANTITY='ADIABATIC SURFACE TEMPERATURE', XYZ=0.5,2.5,2.85, IOR=-3/
```

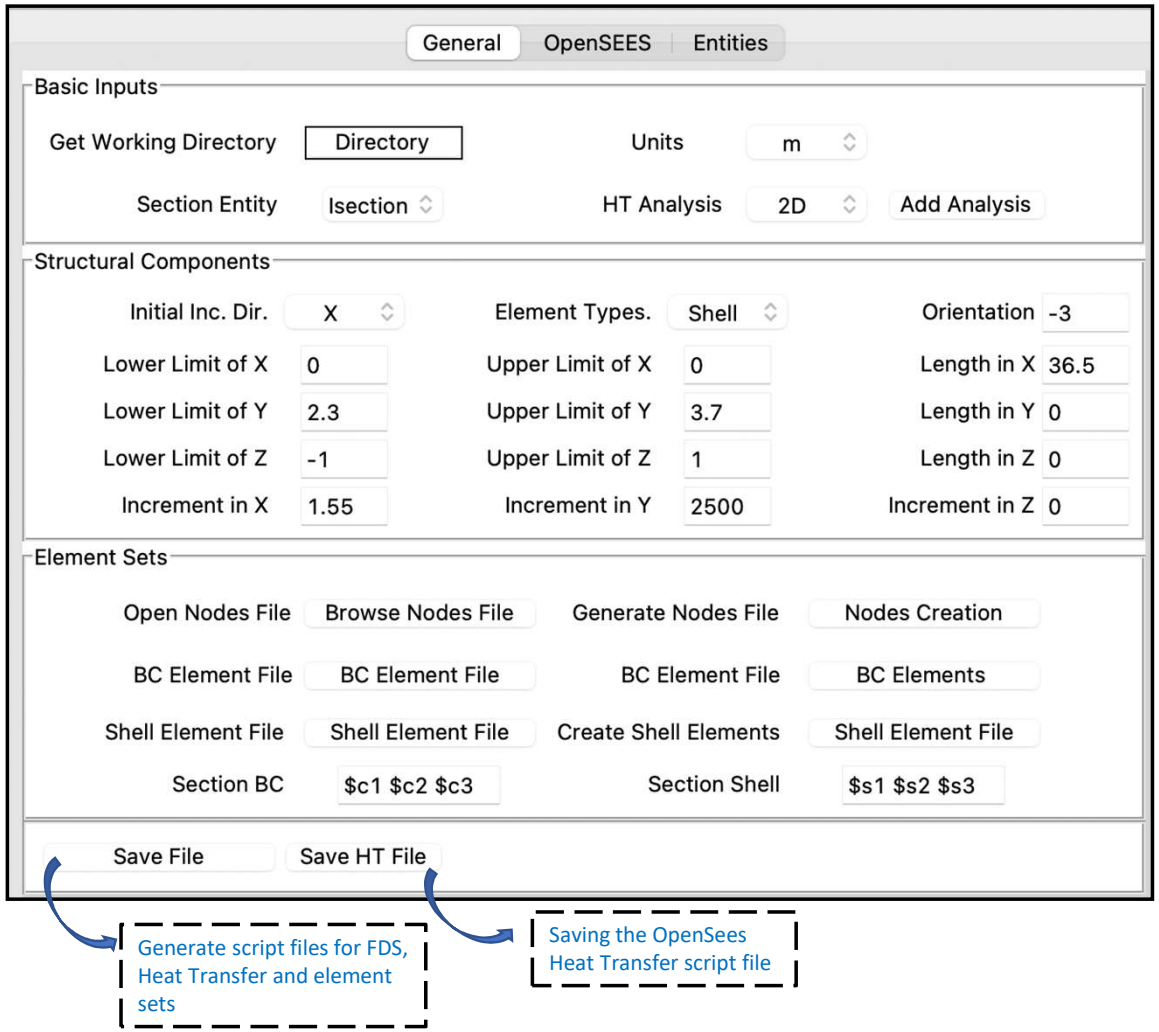
Index of orientation

Middleware

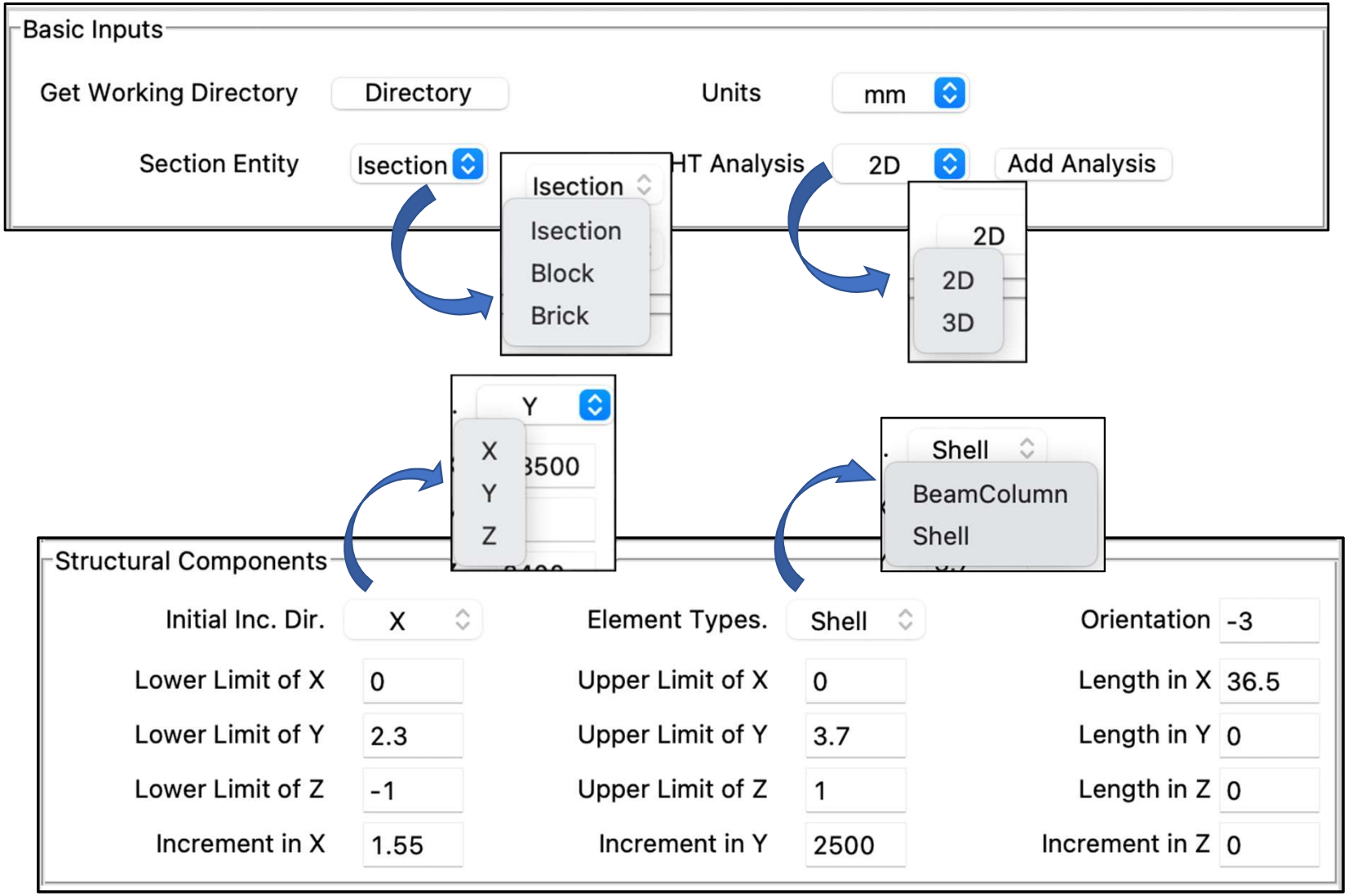
- Few modules
  - Generating scripts
  - Data conversion
- Data input GUIs



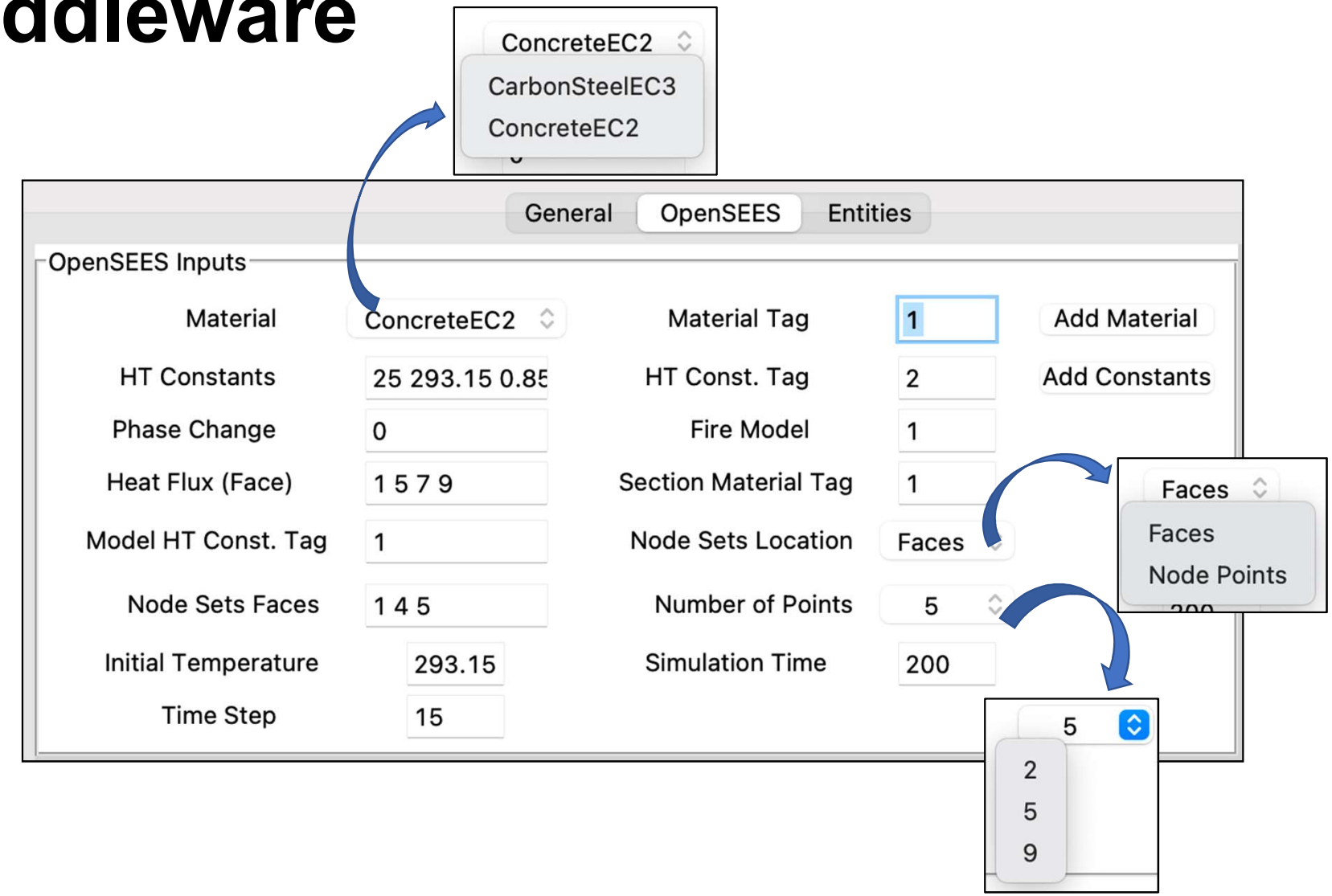
Middleware: Scripts generation



Middleware

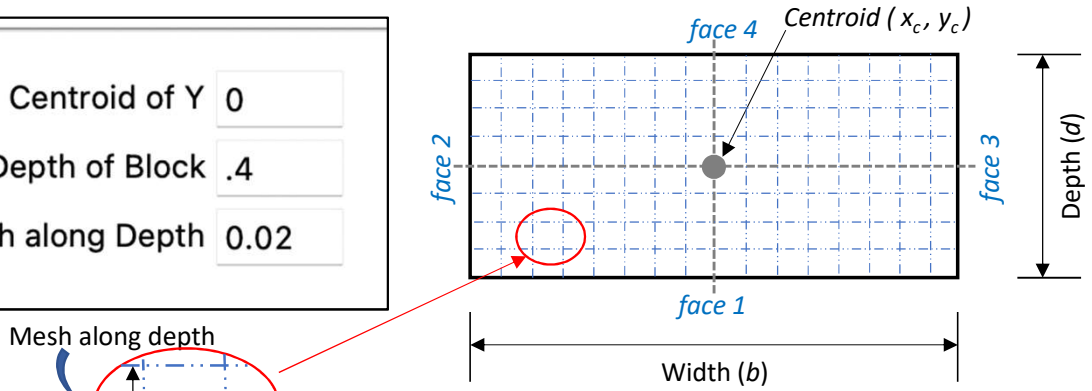

Basic Inputs
Get Working Directory
Directory
Units
mm
Section Entity
Isection
HT Analysis
2D
Add Analysis
Isection
Isection
Block
Brick
2D
2D
3D
Y
X
Y
Z
Shell
BeamColumn
Shell
Structural Components
Initial Inc. Dir.
X
Element Types.
Shell
Orientation
-3
Lower Limit of X
0
Upper Limit of X
0
Length in X
36.5
Lower Limit of Y
2.3
Upper Limit of Y
3.7
Length in Y
0
Lower Limit of Z
-1
Upper Limit of Z
1
Length in Z
0
Increment in X
1.55
Increment in Y
2500
Increment in Z
0

Middleware


ConcreteEC2
CarbonSteelEC3
ConcreteEC2
General
OpenSEES
Entities
OpenSEES Inputs
Material
ConcreteEC2
Material Tag
1
Add Material
HT Constants
25 293.15 0.85
HT Const. Tag
2
Add Constants
Phase Change
0
Fire Model
1
Heat Flux (Face)
1 5 7 9
Section Material Tag
1
Model HT Const. Tag
1
Node Sets Location
Faces
Node Sets Faces
1 4 5
Number of Points
5
Initial Temperature
293.15
Simulation Time
200
Time Step
15
Faces
Faces
Node Points
5
2
5
9

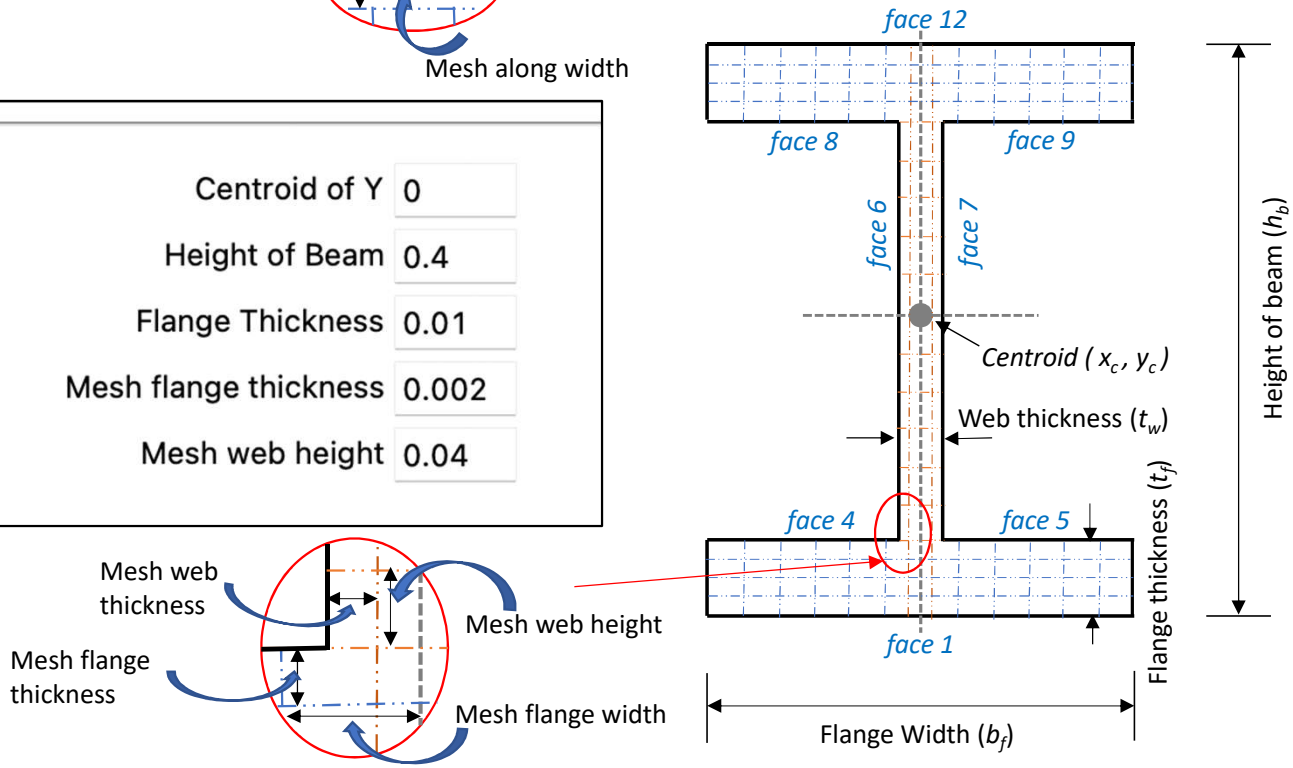
Block Entities

Centroid of X	0	Centroid of Y	0
Width of Block	.4	Depth of Block	.4
Mesh along Width	0.04	Mesh along Depth	0.02



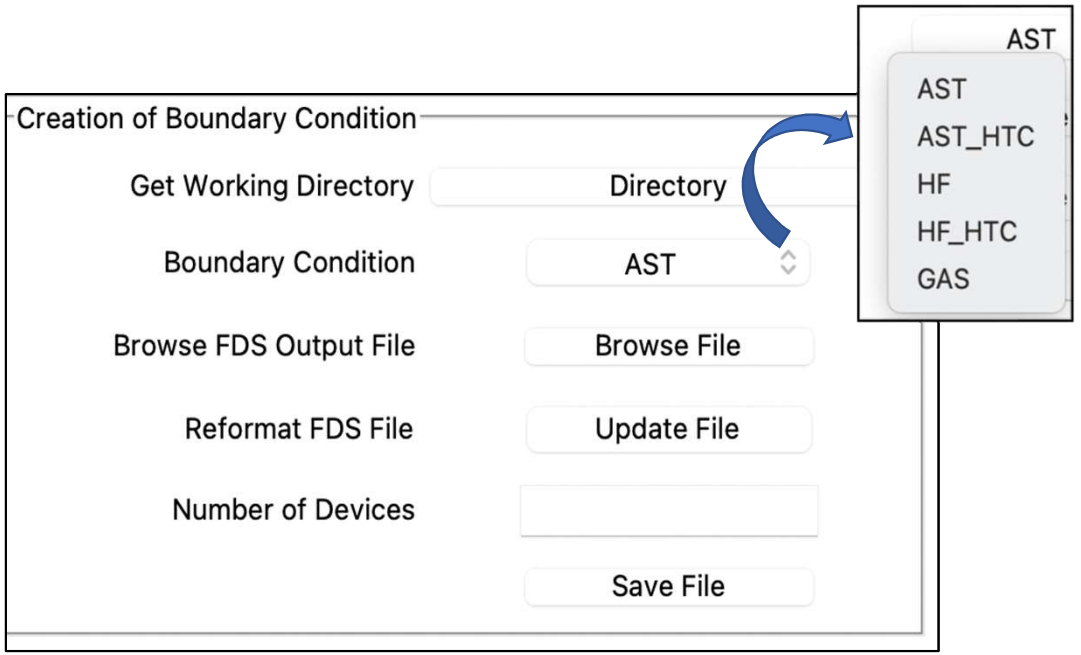
I Section Entities

Centroid of X	0	Centroid of Y	0
Width of Flange	0.4	Height of Beam	0.4
Web Thickness	0.008	Flange Thickness	0.01
Mesh flange width	0.04	Mesh flange thickness	0.002
Mesh web thickness	0.002	Mesh web height	0.04



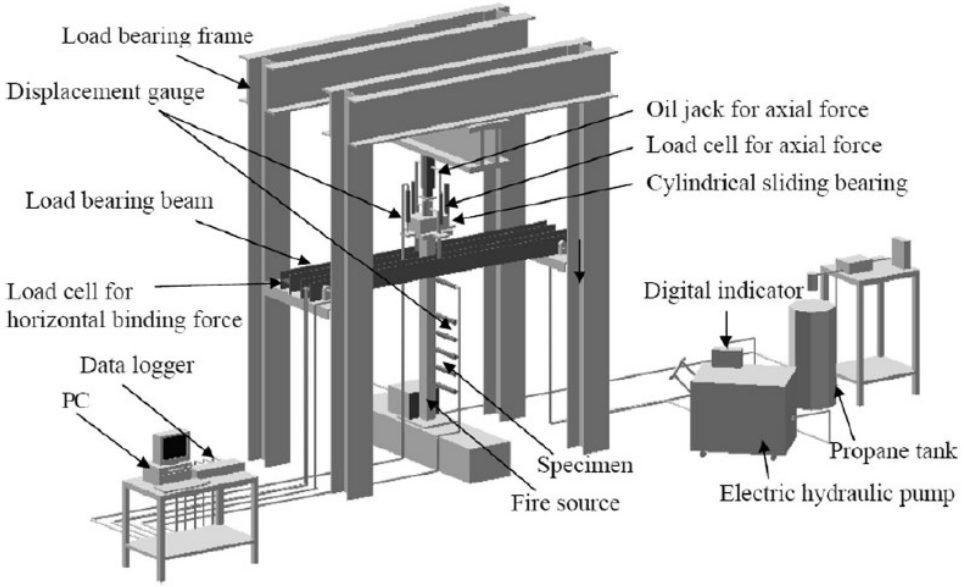
Boundary conditions: HT analysis

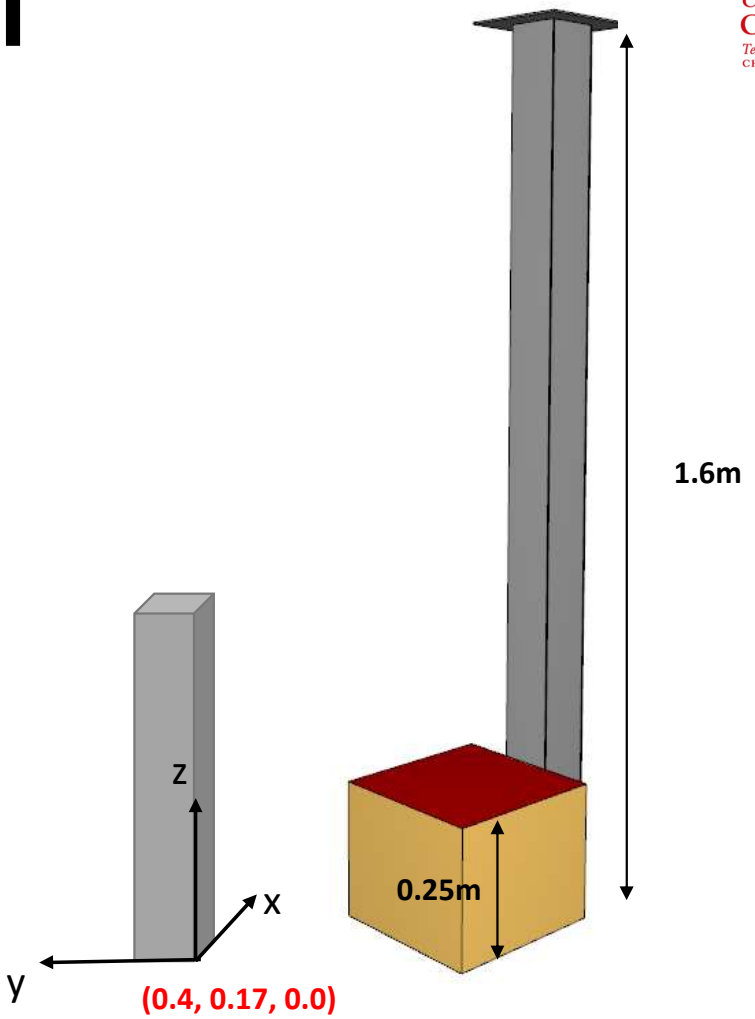
Method	Boundary condition	Value of convective heat transfer Coefficient
1	AST	Fixed
2	HF	Fixed
3	AST+ HTC	Varying
4	HF + HTC	Varying
5	GAS	Fixed
6	GAS + HTC	Varying



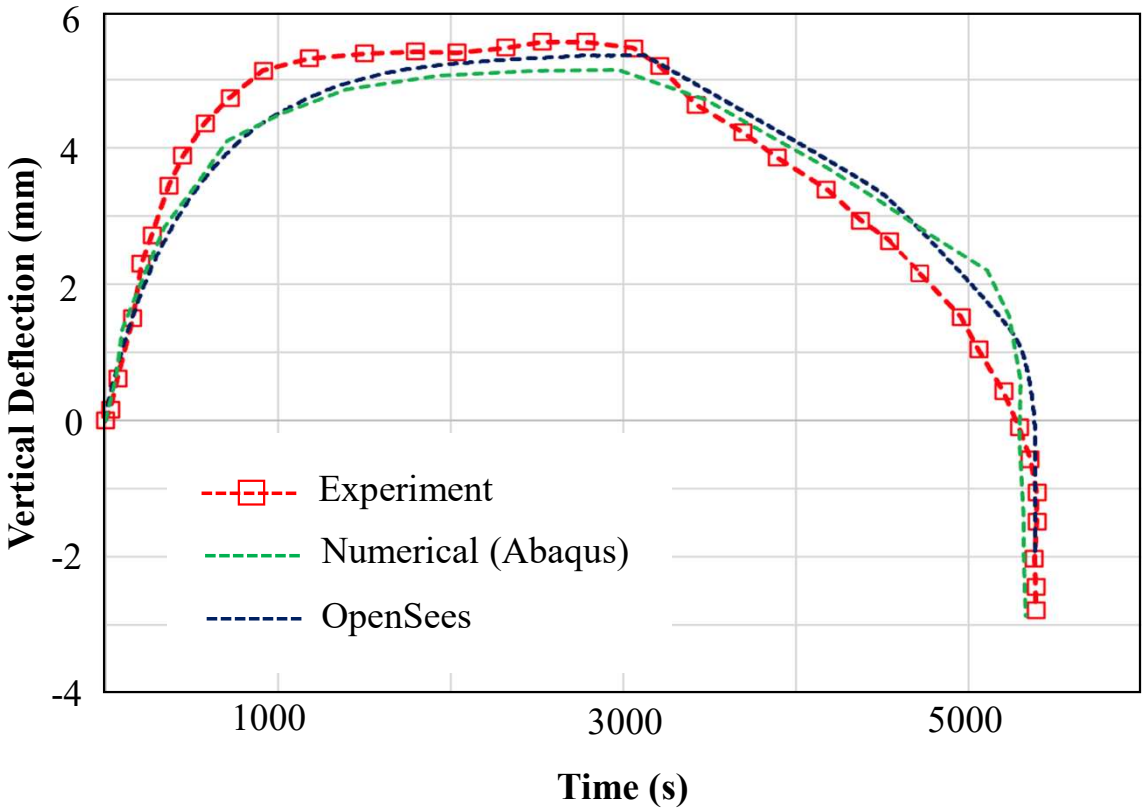
Data transfer from FDS to OpenSees

Validation Cases: Case 1

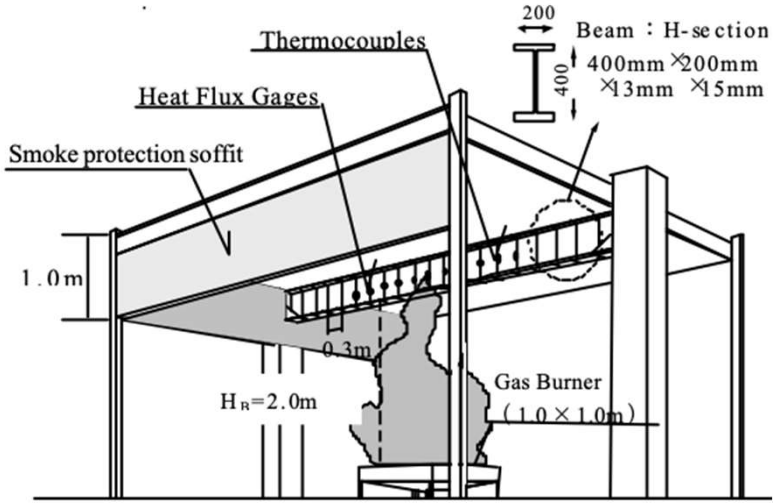


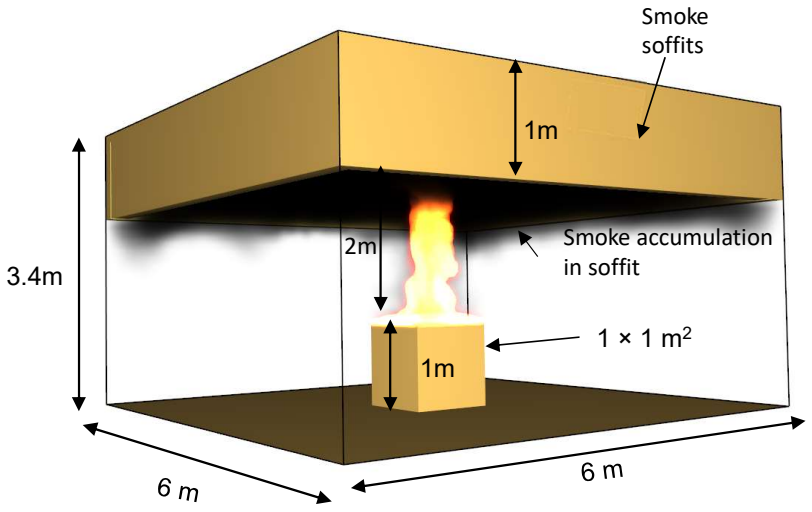


Validation Cases: Case 1

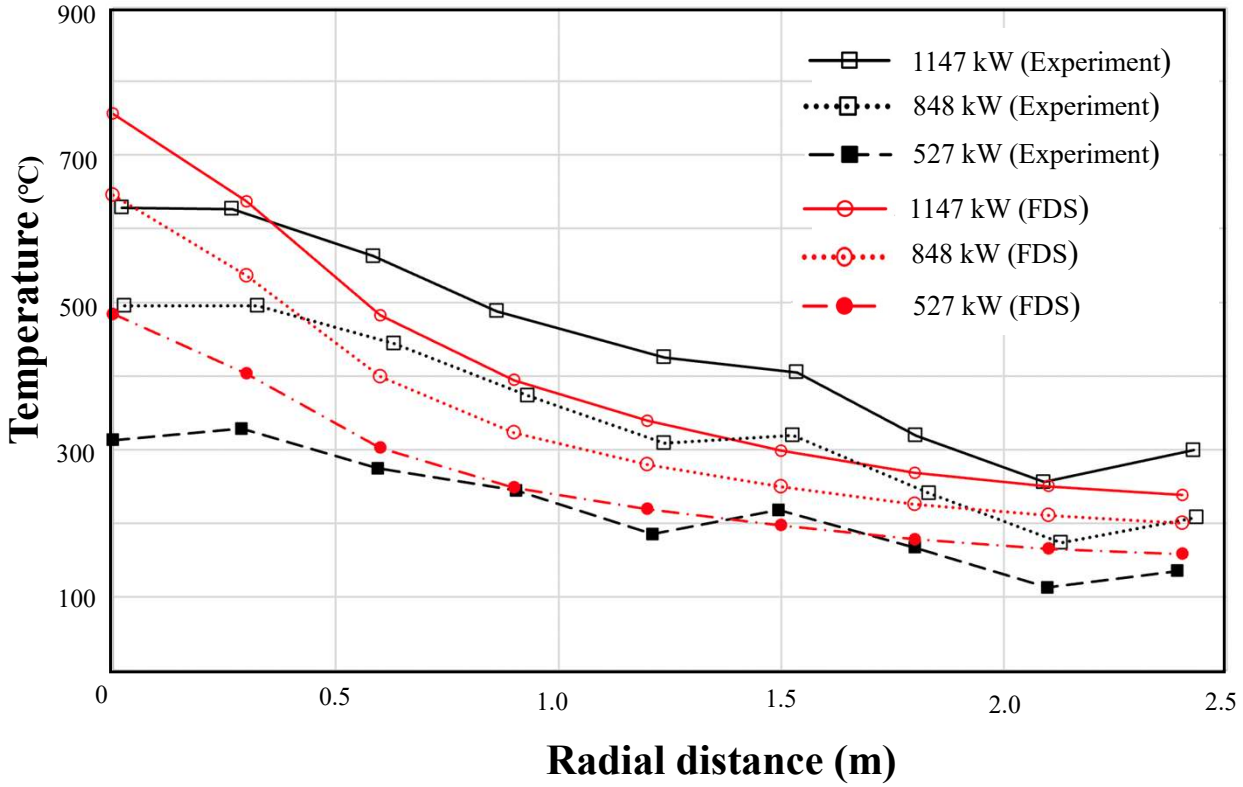


Case 2: Smoke Layer Effects

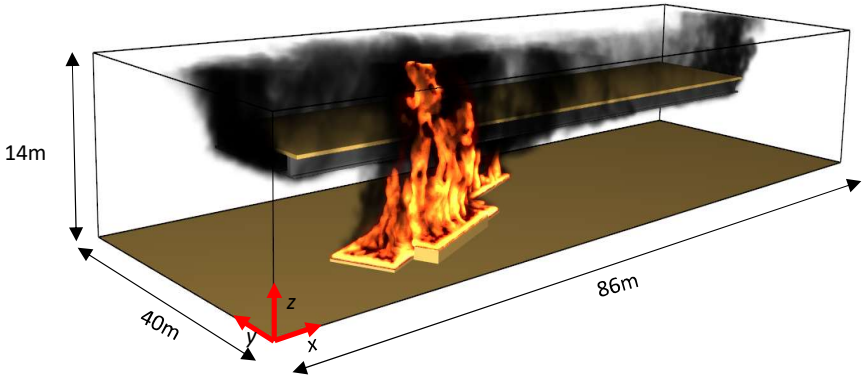


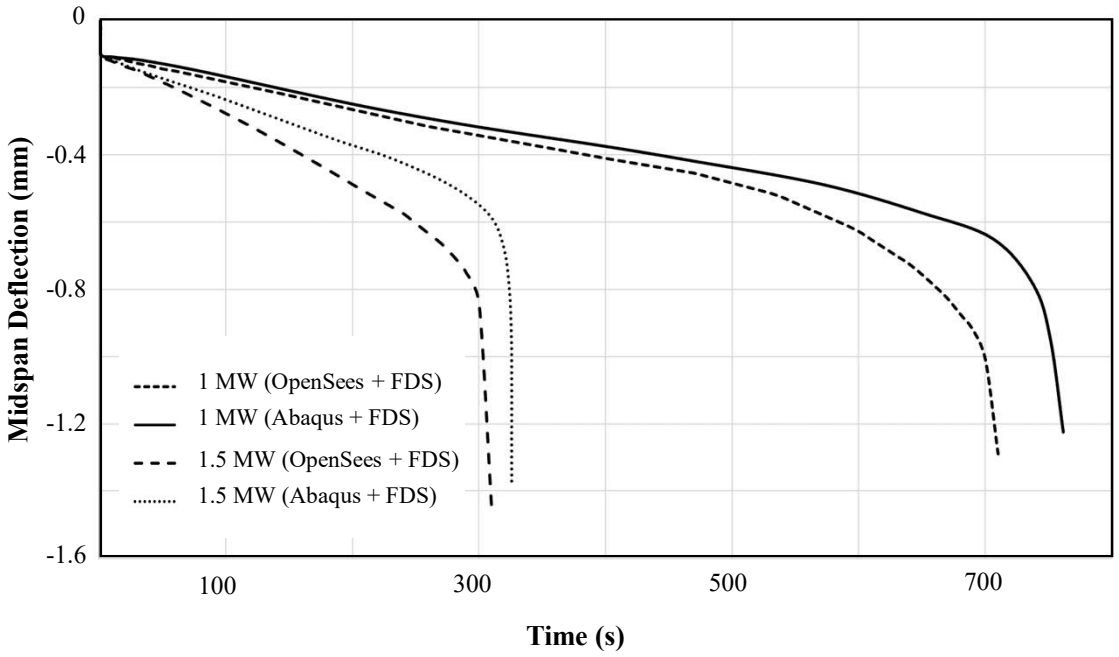


Smoke Layer Effects



Case 3: Real Accident

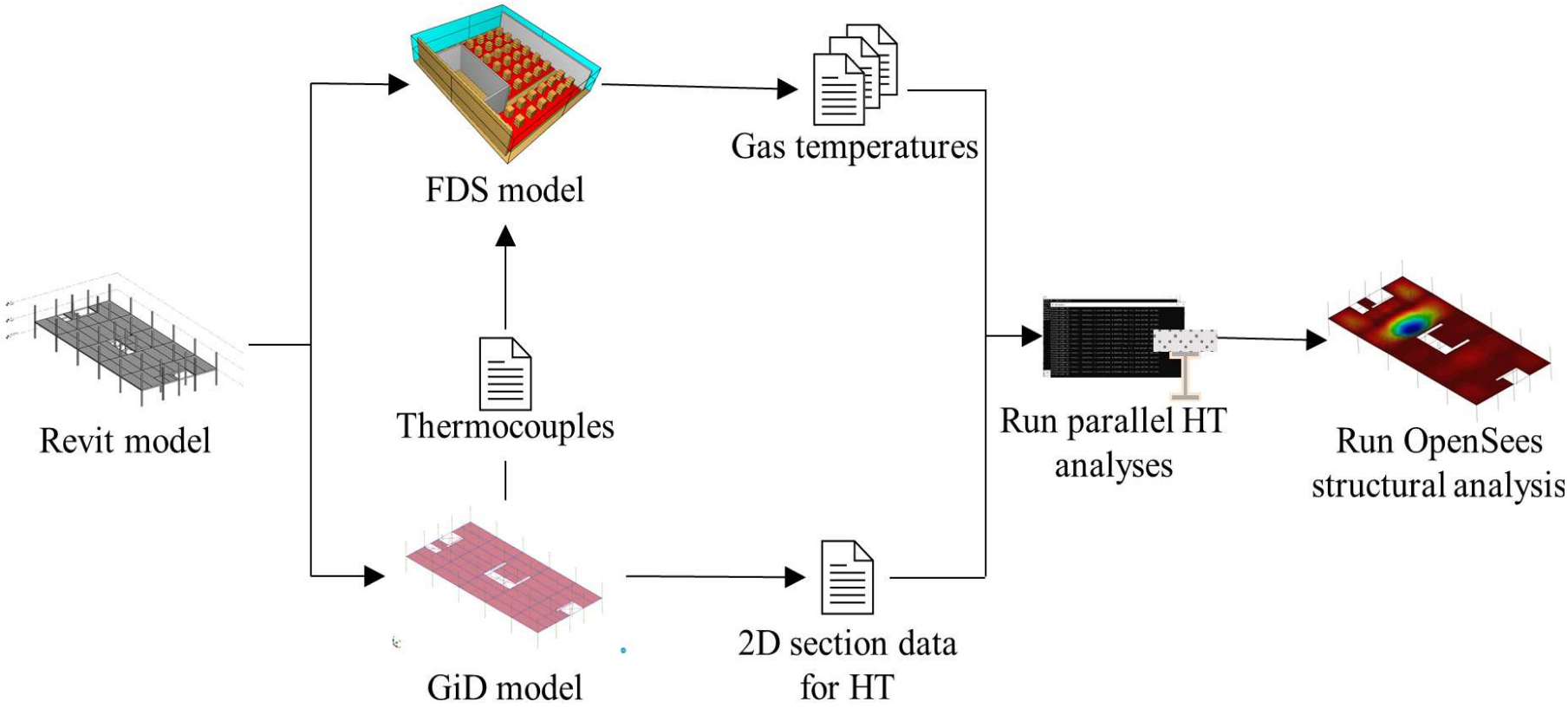




Limitation of Current Tools

- Mesh size of the CFD domain must be smaller than the spatial resolution required for the structural analysis.
- No cavity radiation
- Only a few entities available: "*user-defined*" entity needs to be generated

OpenFIRE with GiD



OpenFIRE and OpenFIRE with GiD

OpenFIRE	OpenFIRE with GiD
No need to buy licences (open source and freeware)	Need to buy a licence for large geometry
Script based	Have pre and post-processor GUI
Number of inputs for boundary conditions	Only gas temperatures
Ideal for research and small projects	Ideal for larger and more complex geometry
Boundary files in FDS can be used to avoid redo the fire simulation	Currently have only Device method

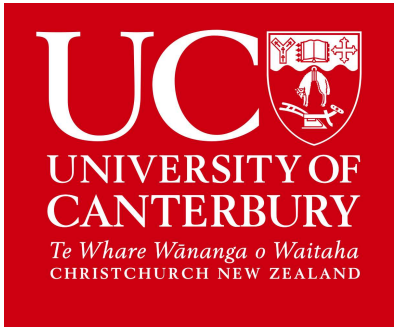
Summarise

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

- Need for CFD for structural analysis
- Coupling of FDS and OpenSees
- **First** and **only** open-source and freeware package for structural analysis
- GUI of middleware makes life easier
- Validation cases shows its capability
- Have some limitations that can be resolved in future
- A version with GiD is developed

Useful Links for OpenFIRE Project

- OpenSEES and OpenFIRE (http://openseesforfire.github.io/openfire.html)
- Instruction manual and source codes (https://github.com/aatif85)
- Video tutorial of all source-codes with instructions to modify (https://firesafetyedu.wixsite.com/aatifalikhan/projects-minimalist)



Aatif Ali Khan

aatif.khan@canterbury.ac.nz