Fire safety in dense urban environments, are we meeting the Challenge?

Fire Asia 2018

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Fire shaped the growth of cities in the past and influences them today

Fire is an ever present hazard to society

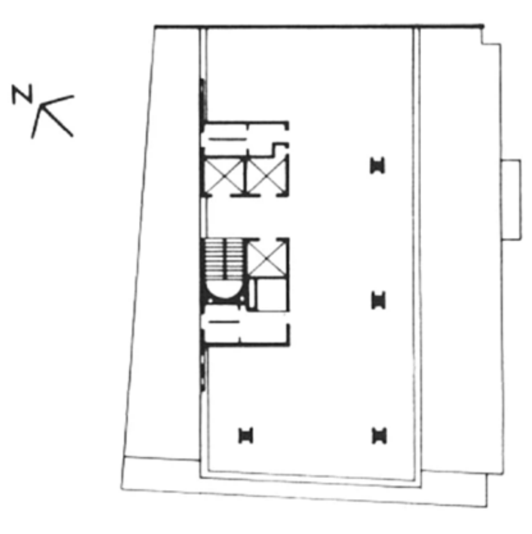
Grenfell Tower, London, 2017
(71 fatalities)

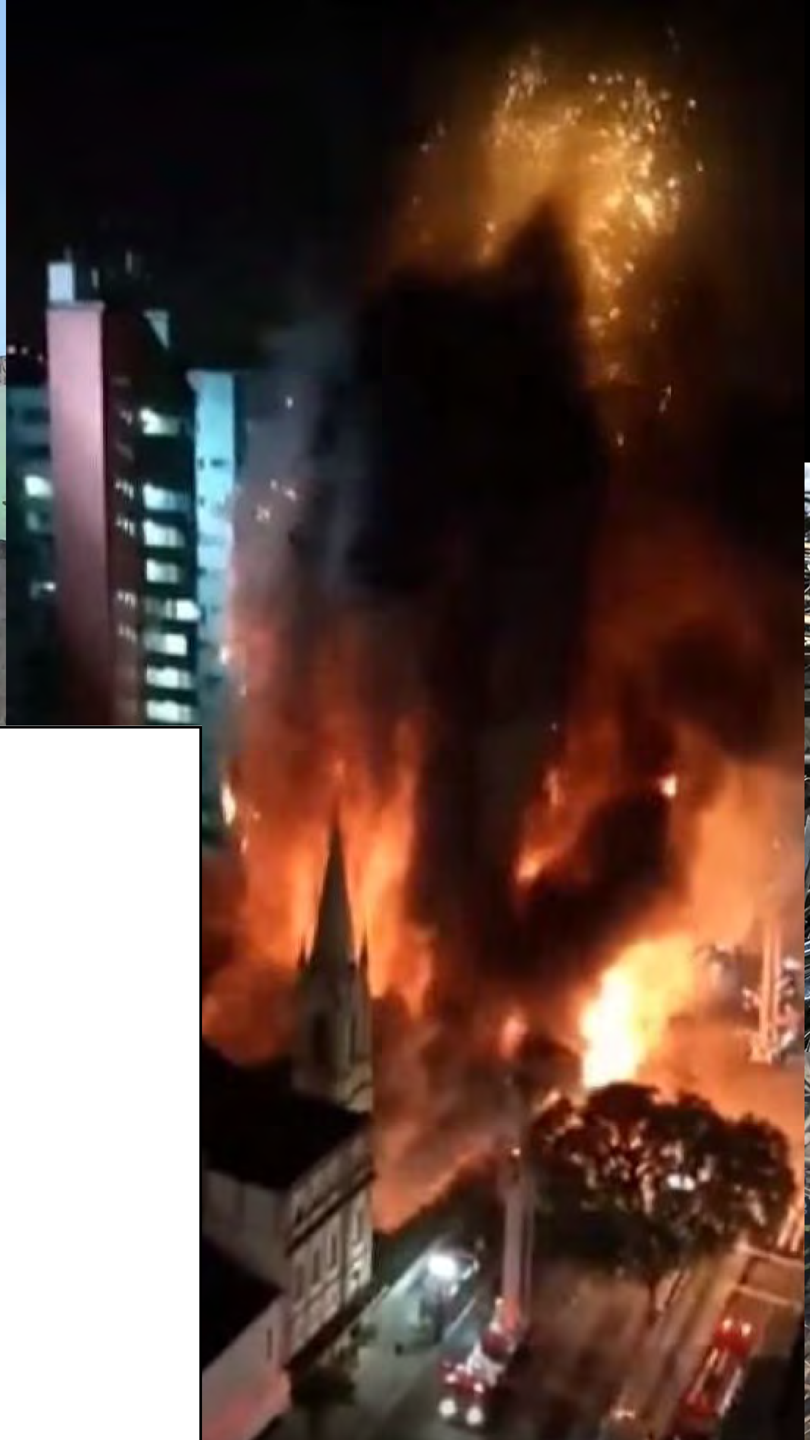
Plasco Building, Tehran, 2017
(22 fatalities inc. 16 firefighers)

Shanghai, 2010
(53 fatalities)

Gretzenbach, Switzerland, 2004
(7 firefighters killed)

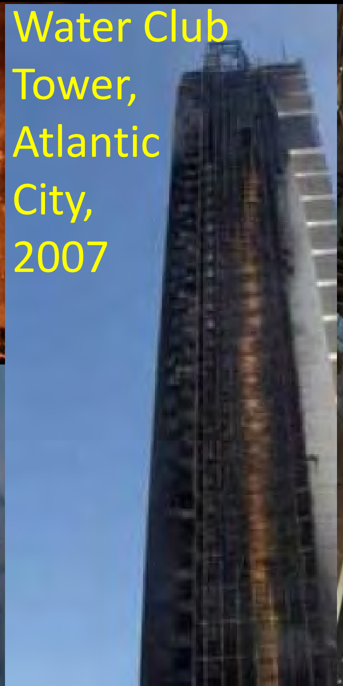
WTC, New York, 2001
(2763 fatalities inc. 343 firefighters)





Edificio Wilton Paes de Almeida, Sao Paulo

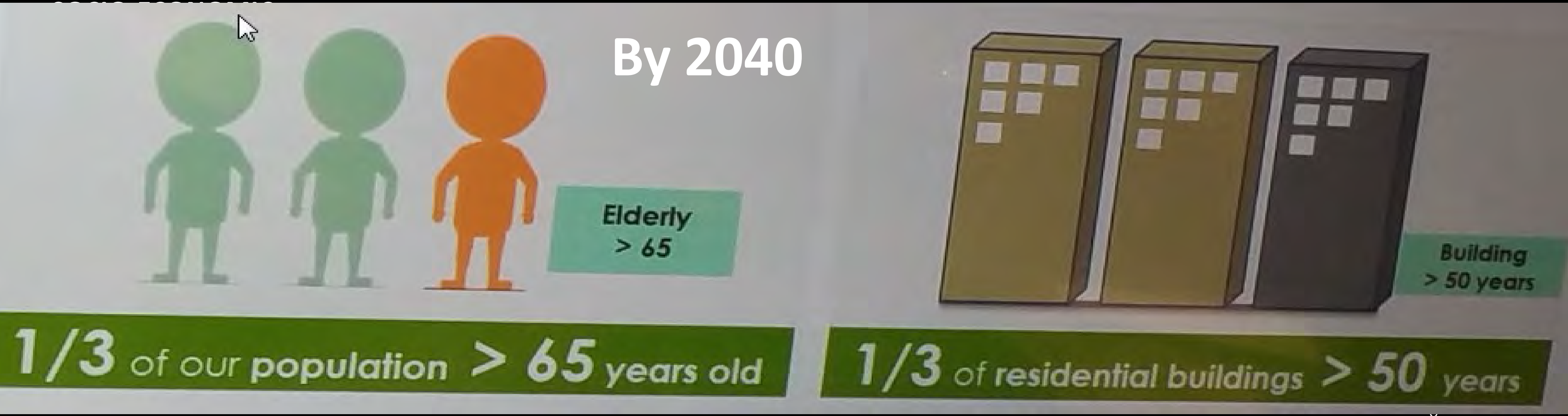
Tall building façade fires across the world



Imperatives driving smart cities/buildings

DEMOGRAPHIC
Proportion of working age population declining in the developed world and increasing demand for services to support the old and infirm;

INFRASTRUCTURAL
The building stock in highly developed economies and cities such as Hong Kong is rapidly aging and requires innovative solutions for safe and sustainable retrofit and rehabilitation



Mission or BSE department at PolyU

To imagine, engineer and promote
sustainable, salutogenic and safe
environments for human habitation

Building Energy

Building Environment

Building Safety and Resilience


Challenge of fire safety in tall buildings in dense urban environments
How many similarly vulnerable buildings are there in your city ?

Why are tall building fires different?

Taller buildings → Multiple-floor fires

More adventurous architecture → Complex structural response

Open plans offices → Non-uniform “travelling” fires

Larger number of occupants → Extended evacuation times

City centre locations → Delays in emergency response

↓

Significantly increased risk
(probability x consequence)

NO CURRENT REQUIREMENT FOR TREATING TALL BUILDINGS DIFFERENTLY

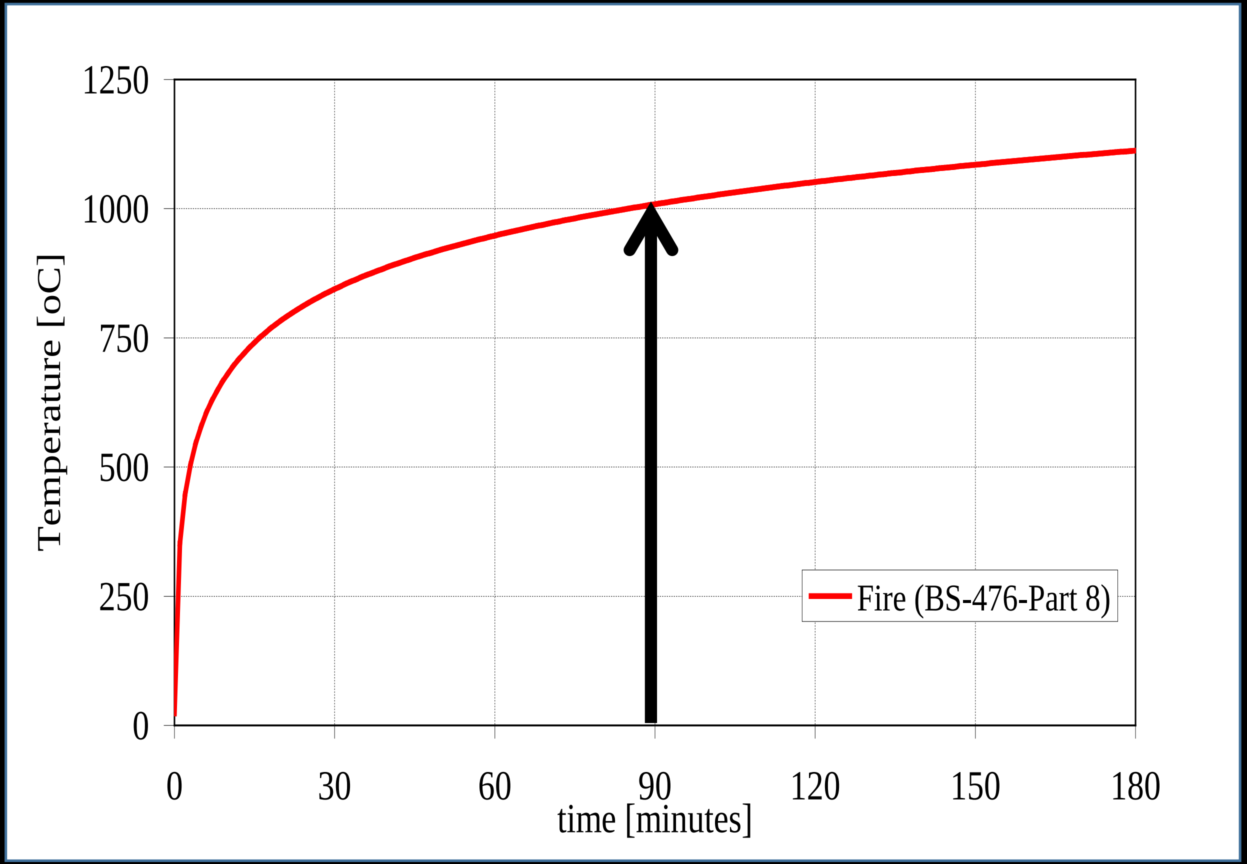
Except that usually higher fire resistance times are specified

or

the recommendation to use

PERFORMANCE-BASED DESIGN (or P-B ENGINEERING)

Universal design basis (standard fire curve)



Standard fires specify a fixed temperature-time curve (originally developed over 100 years ago in USA in a 2.9mx2.9mx4.4m compartment to reach 926 Celcius in 30 mins).

Real fires are complex and non-uniform

Fire tends to travel in large spaces

Therefore, Compartment fire Models are invalid

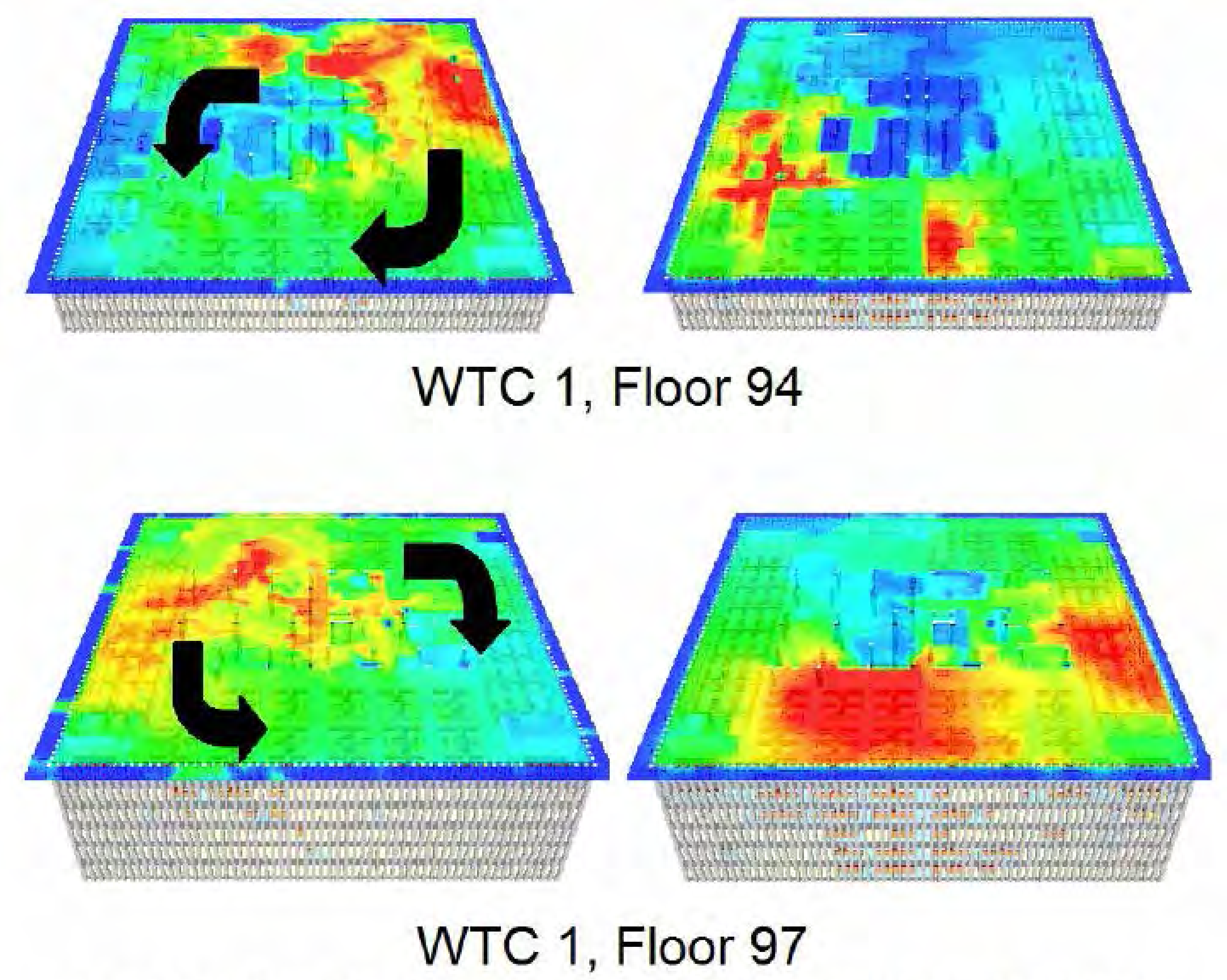


Figure 6–29. Direction of simulated fire movement on floors 94 and 97 of WTC 1.

Source:

NIST NCSTAR 1-5

Emerging research on "travelling fires"

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A critical review of "travelling fire" scenarios for performance-based structural engineering

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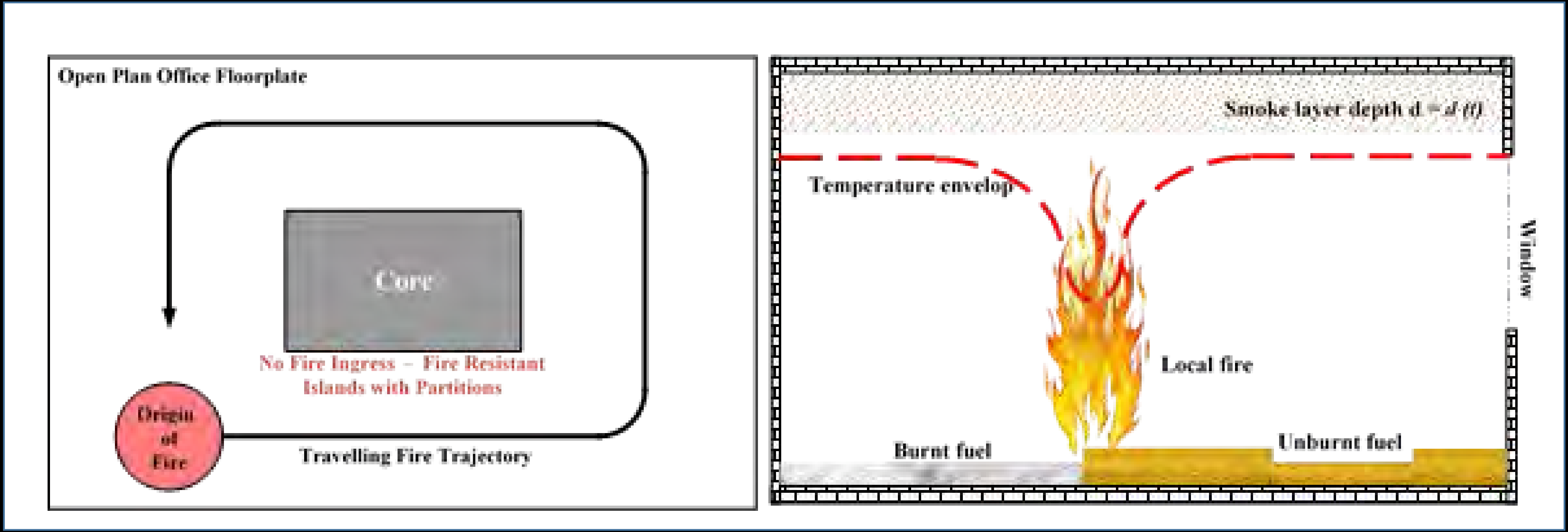
Performance-based design

ABSTRACT

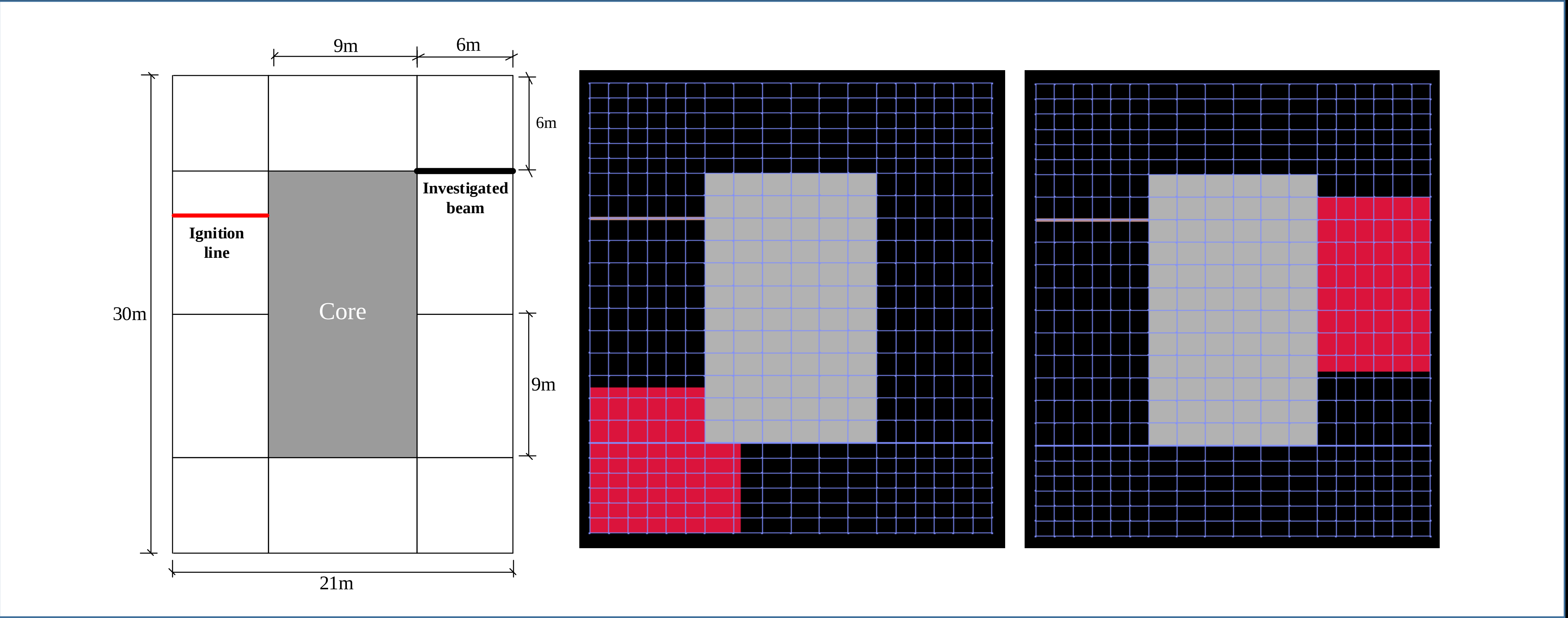
Many studies of the thermal and structural behaviour for large compartments in fire carried out over the past two decades show that fires in such compartments have a great deal of non-uniformity (e.g. Stern-Gottfried et al. [1]), unlike the homogeneous compartment temperature assumption in the current fire safety engineering practice. Furthermore, some large compartment fires may burn locally and tend to move across entire floor plates over a period of time. This kind of fire scenario is beginning to be idealized as *travelling fires* in the context of performance-based structural and fire safety engineering.

This paper presents a literature review of the travelling fire research topic and its state of the art, including both the experimental and theoretical work for the past twenty years. It is found that the main obstacle of developing the travelling fire knowledge is the lack of understanding of the physical mechanisms behind this kind of fire scenario, which requires more reasonable large scale travelling fire experiments to be set up and carried out. The demonstration of the development of a new travelling fire framework is also presented in this paper, to show how current available experimental data hinder the analytical model development, and the urgent need that the new travelling fire experiments should be conducted.

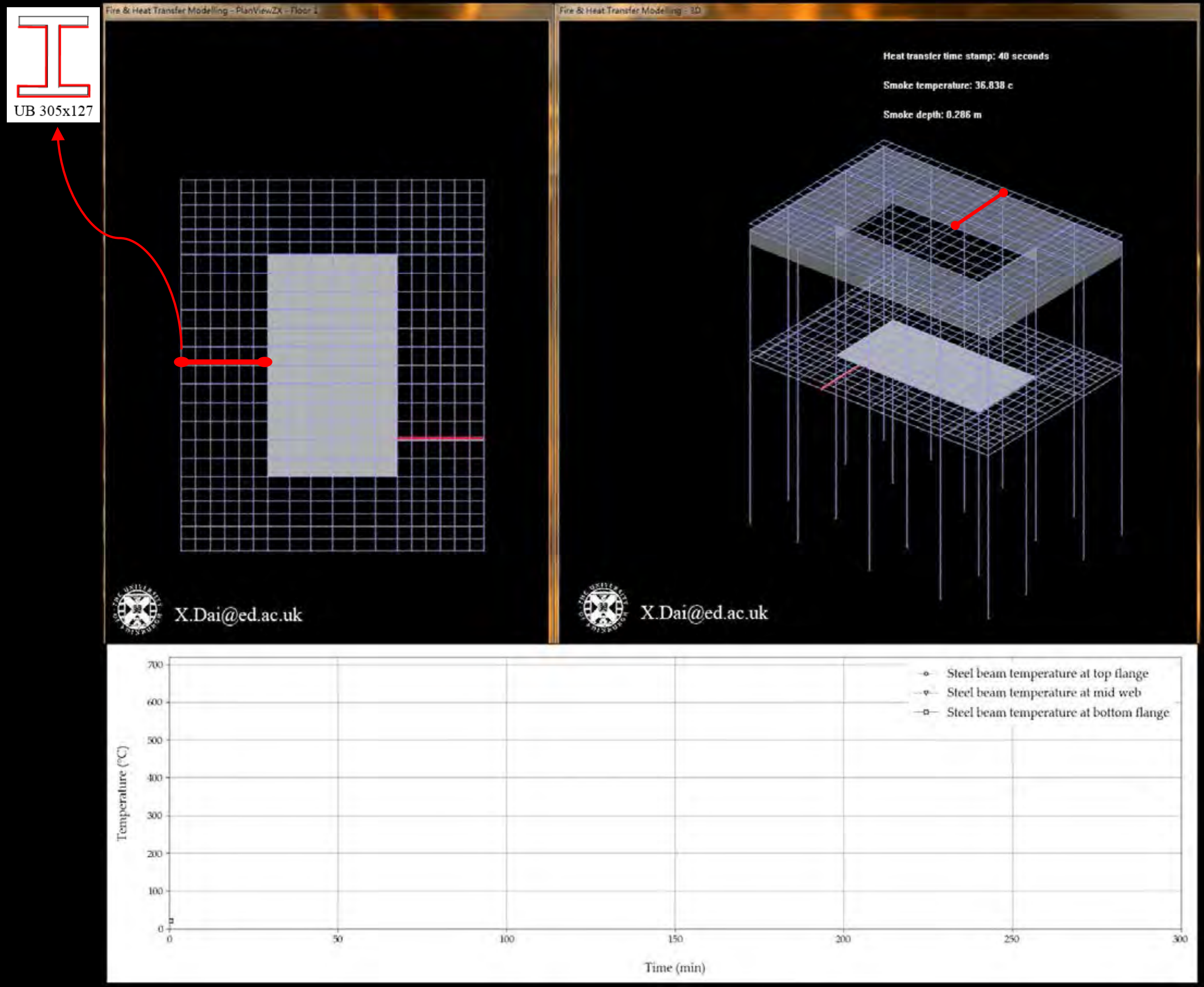
Travelling fire model



Implementation in structural analysis software OpenSees for automated response simulation



Case study using ETFM framework



Visualization output of OpenSees-SIFBuilder during heat transfer analysis

Fire scenario:

Fire starts on: the first floor

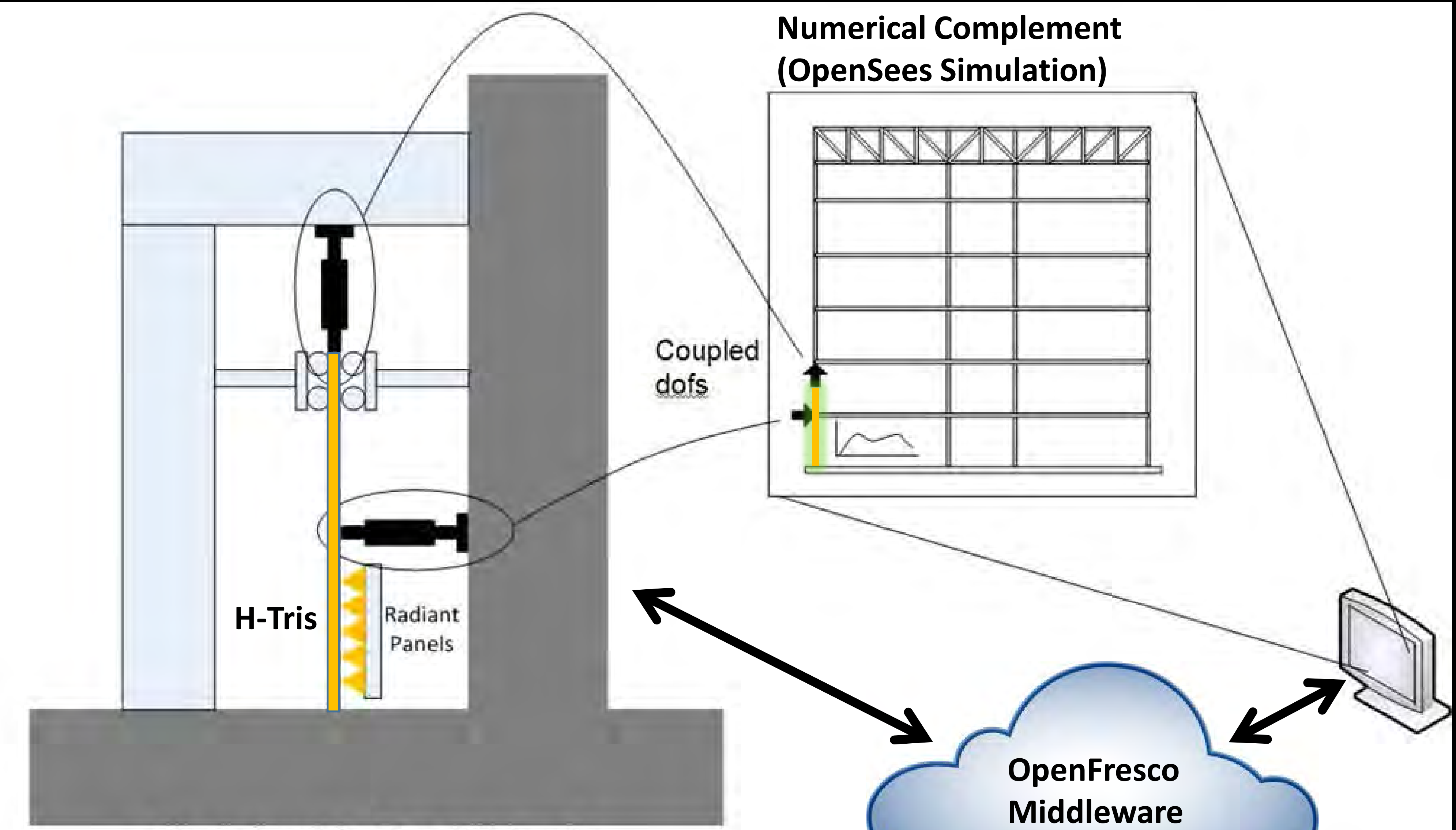
Fire spread rate: 5 mm/s

HRR per area: 300 kW/m^2

Fuel load density: 570 MJ/m^2

WTC towers collapse simulation

Hybrid testing and simulation



Physical model at Tongji University
structural fire engineering laboratory

Hybrid testing and simulation equipment

MTS SilentFlo™ 515 Hydraulic Power Units

293 Hydraulic
Service Manifold

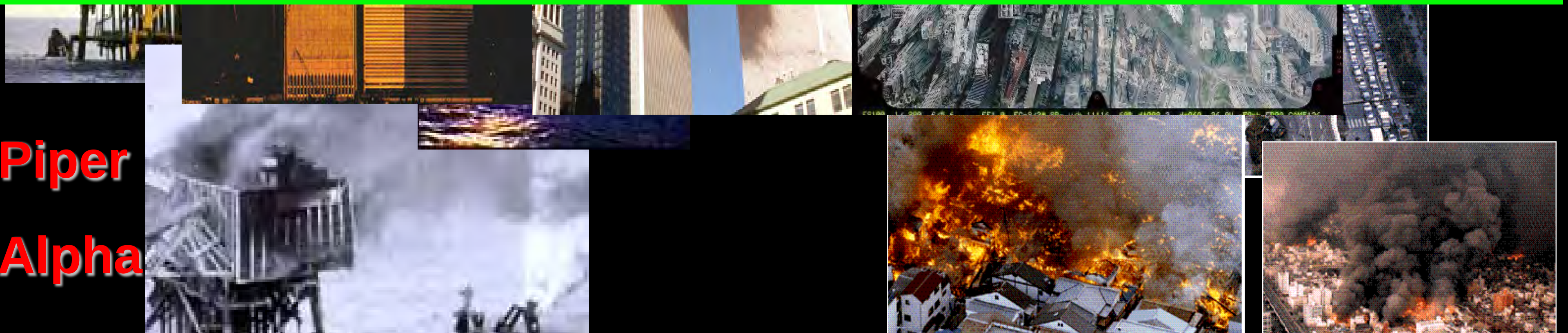
Model 244 Hydraulic Actuators

MTS FlexDAC™ 20 Data Acquisition System

MTS FlexTest® Controller Family

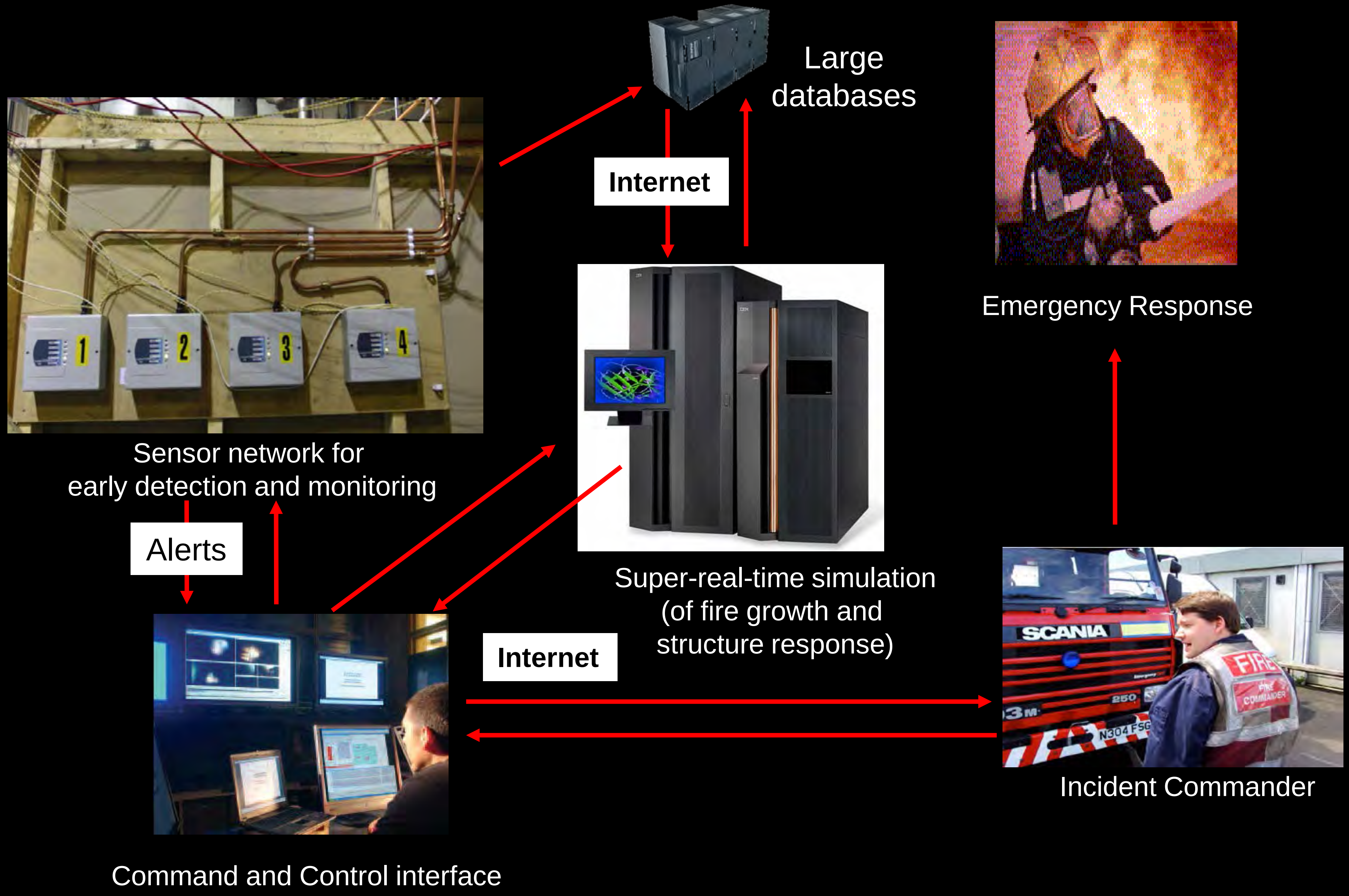
Emergency response in dense urban environments

Forensic investigation of every major disaster shows that given better information response could have been more effective




Emergency services lack even the very basic information when responding to most emergencies
Is this acceptable if we live in the so-called “Age of Information”

A vision for resilience of cities against fire:
FireGrid Project (2006-09), UK



Generic system architecture

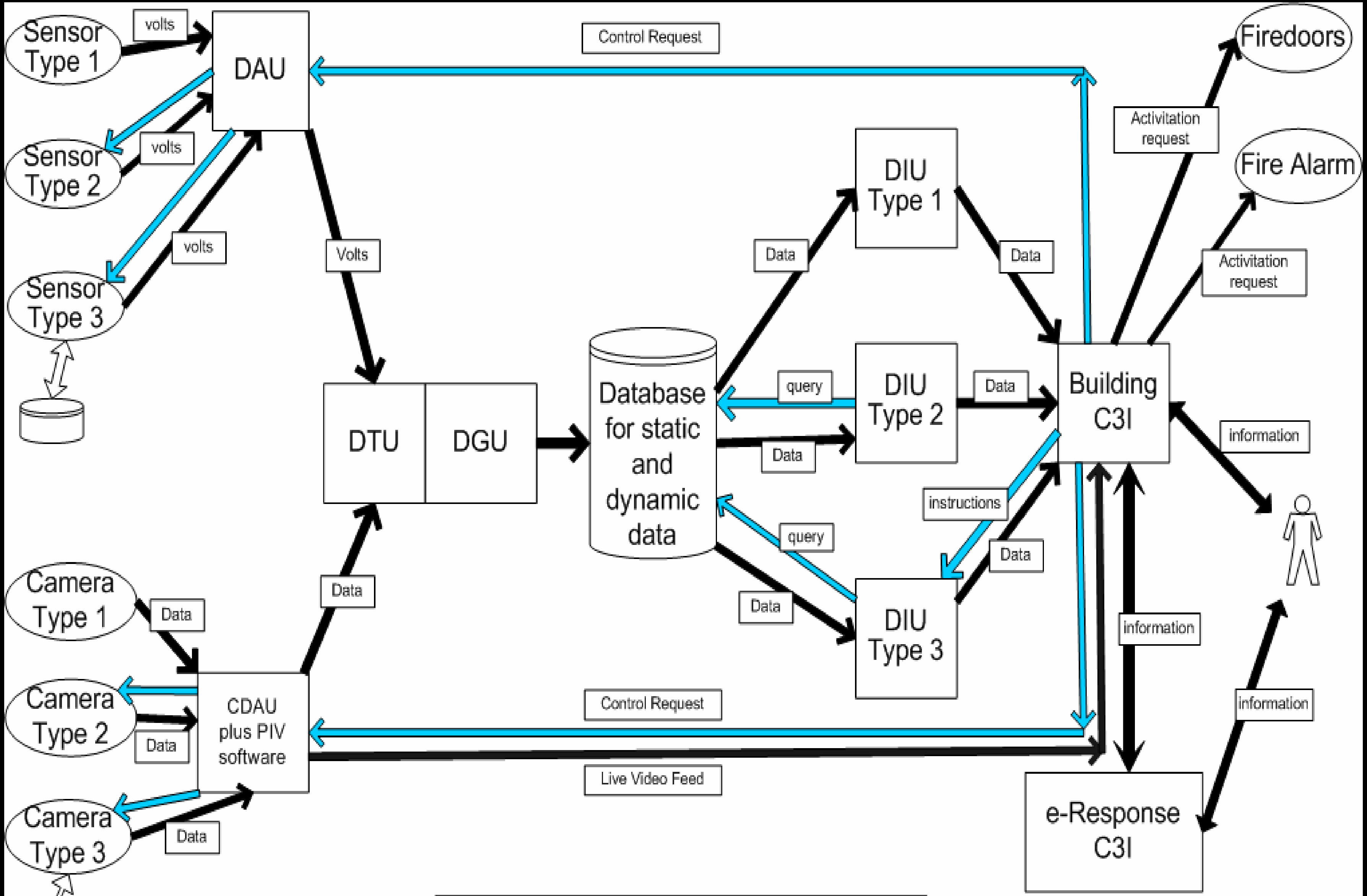
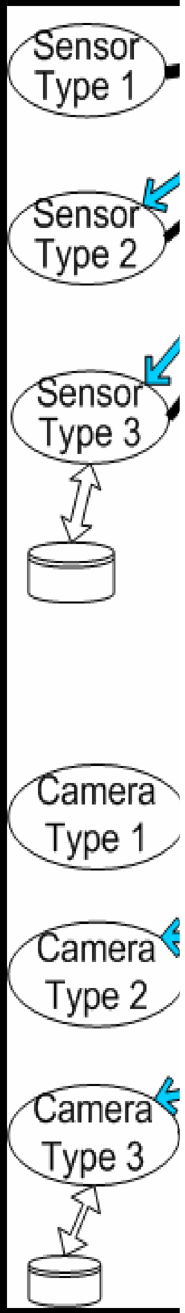


Figure 1: Component layout of basic FireGrid System, where each single object may represent multiple components

Generic system architecture

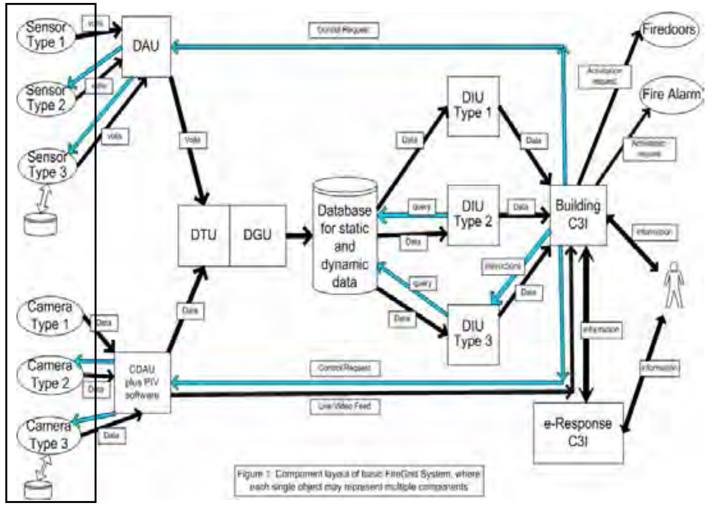


Sensor types

1 data pulled at constant rates (i.e. thermocouples)

2 variable data rates and action requests

3 type 2 with local memory



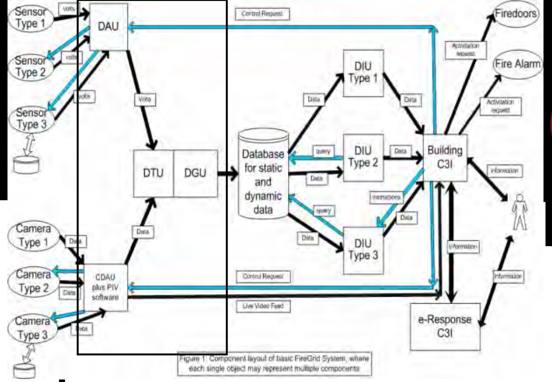
Camera types

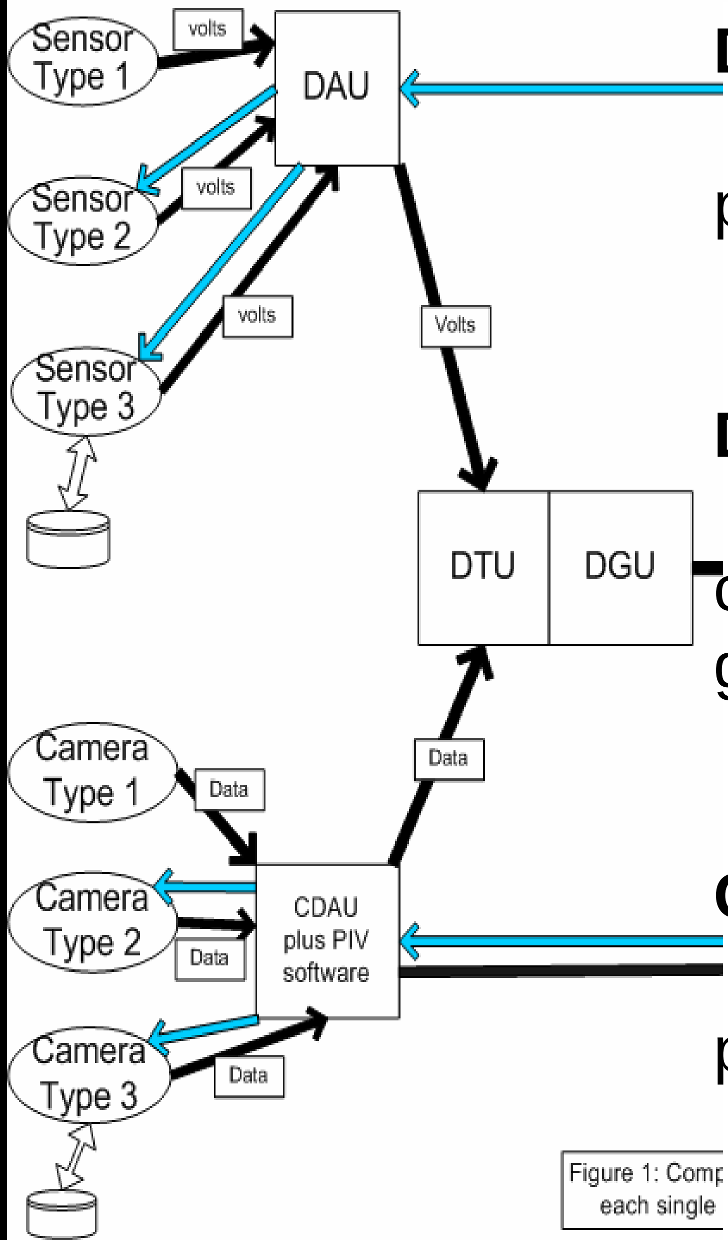
1 fixed direction feed

2 allows action requests and changes direction

3 type 2 with local memory

Generic system architecture





DAU (data acquisition unit)

pulls raw data from sensors as volts

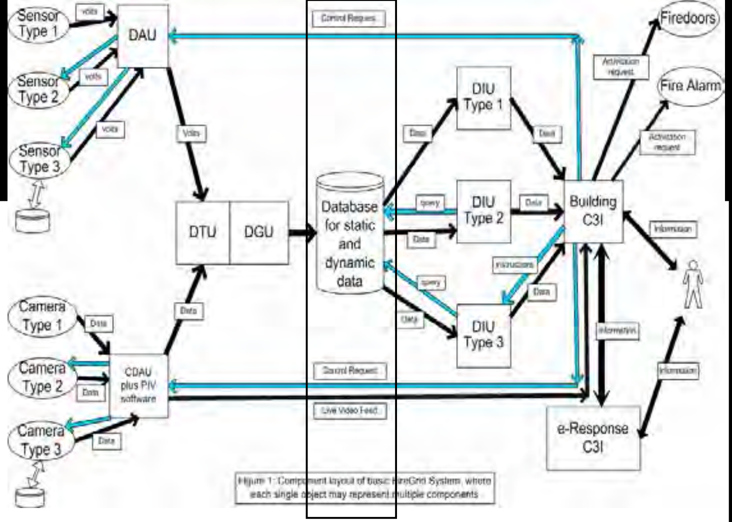
DTU/DGU (data translation and grading)

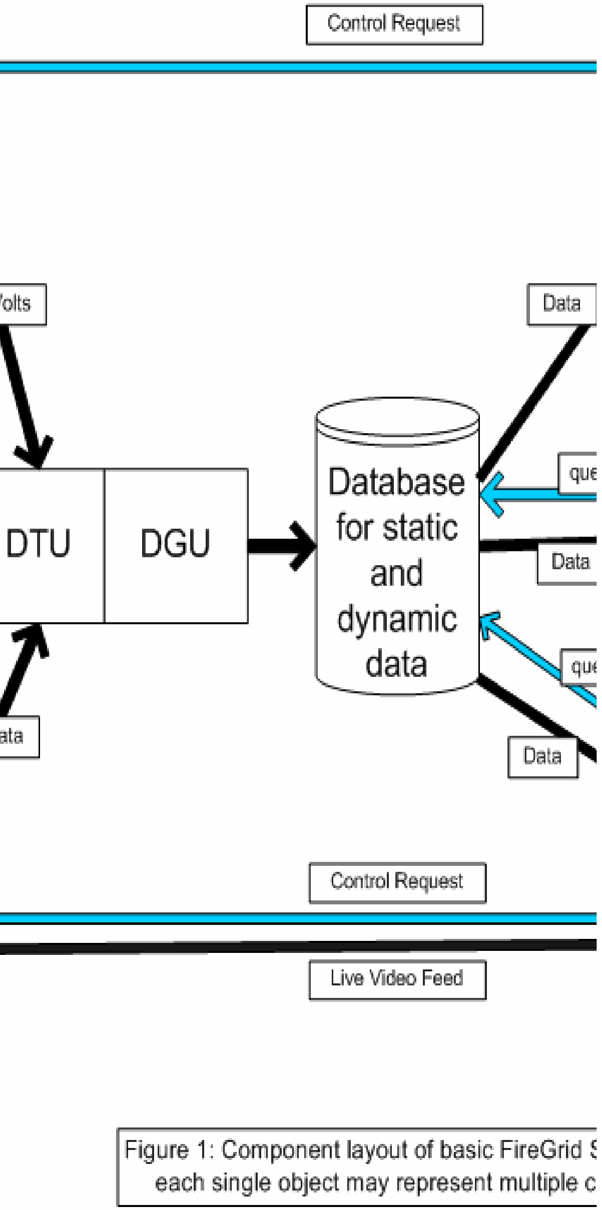
converts data into digital formats, time stamps and grades (assign a reliability or accuracy index)

CDAU (camera data acquisition unit)

pulls images from cameras

Generic system architecture

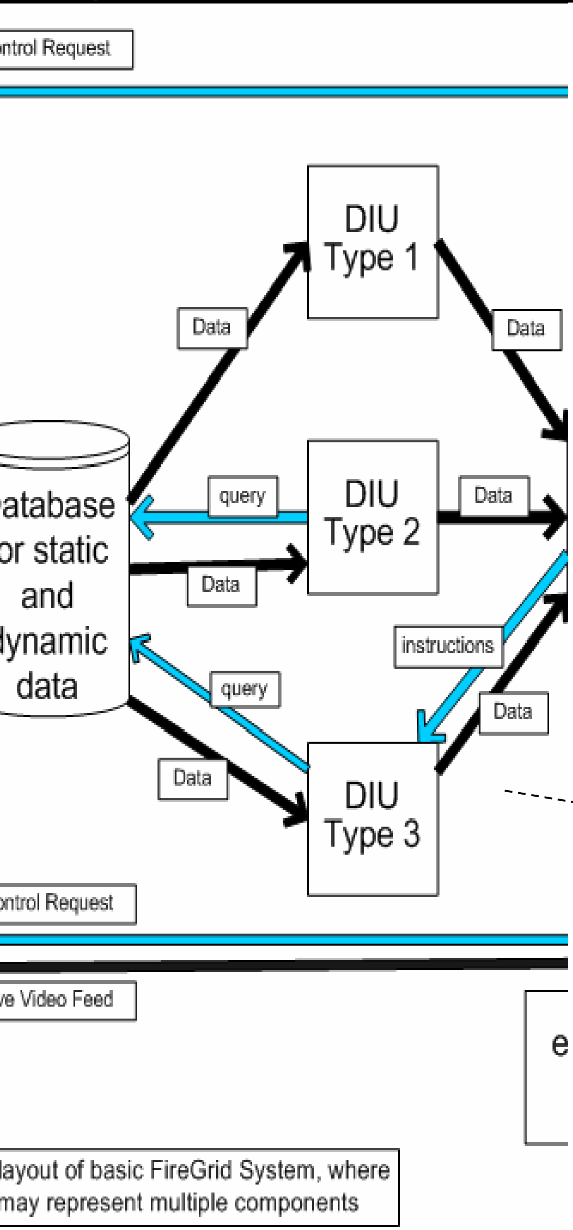


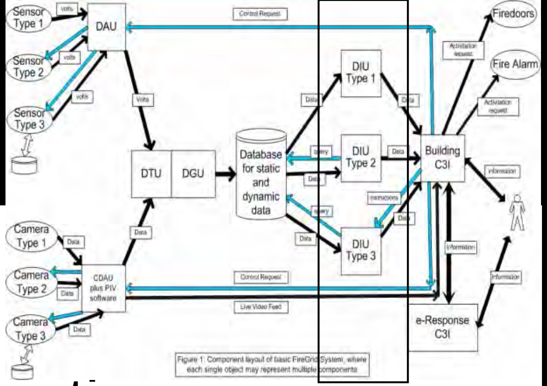


Main database

Repository of all static and dynamic data. Static data could be digitised building plans, computational grids and all material, boundary and constraint information, and pre-run scenarios for rapid actuation and response. Dynamic data will include the sensor outputs and other information generated by the system.

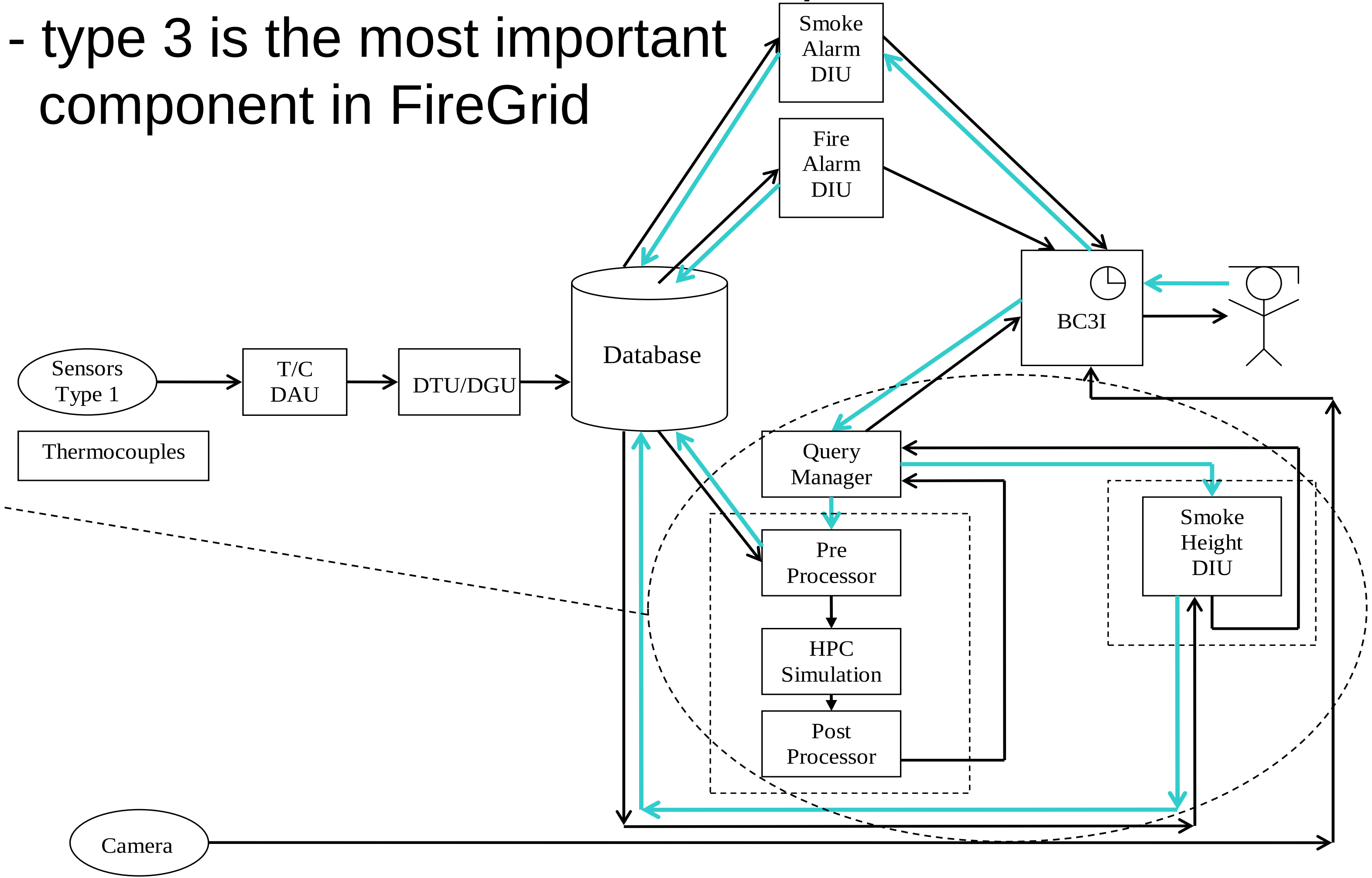
Generic system architecture



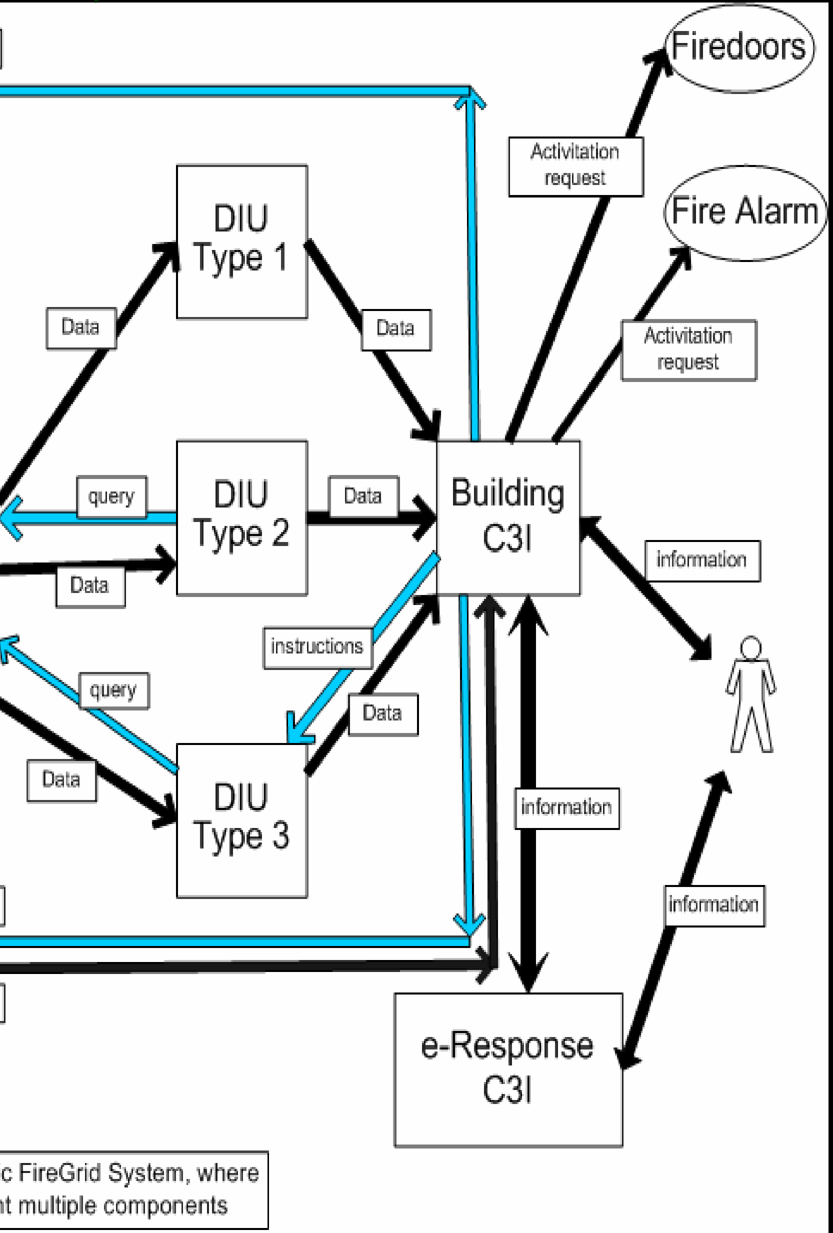


DIU (data interpretation unit)

- types 1& 2 are essentially detection devices of different levels of sophistication
- type 3 is the most important component in FireGrid

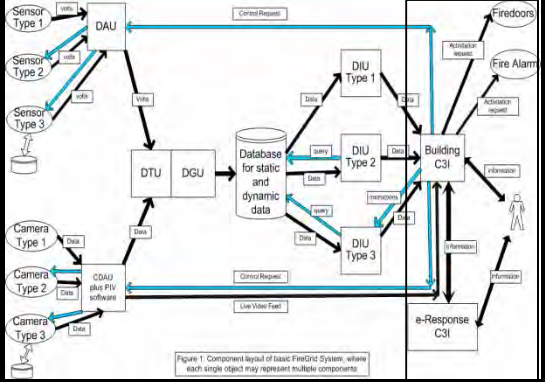


Generic system architecture



Actuators

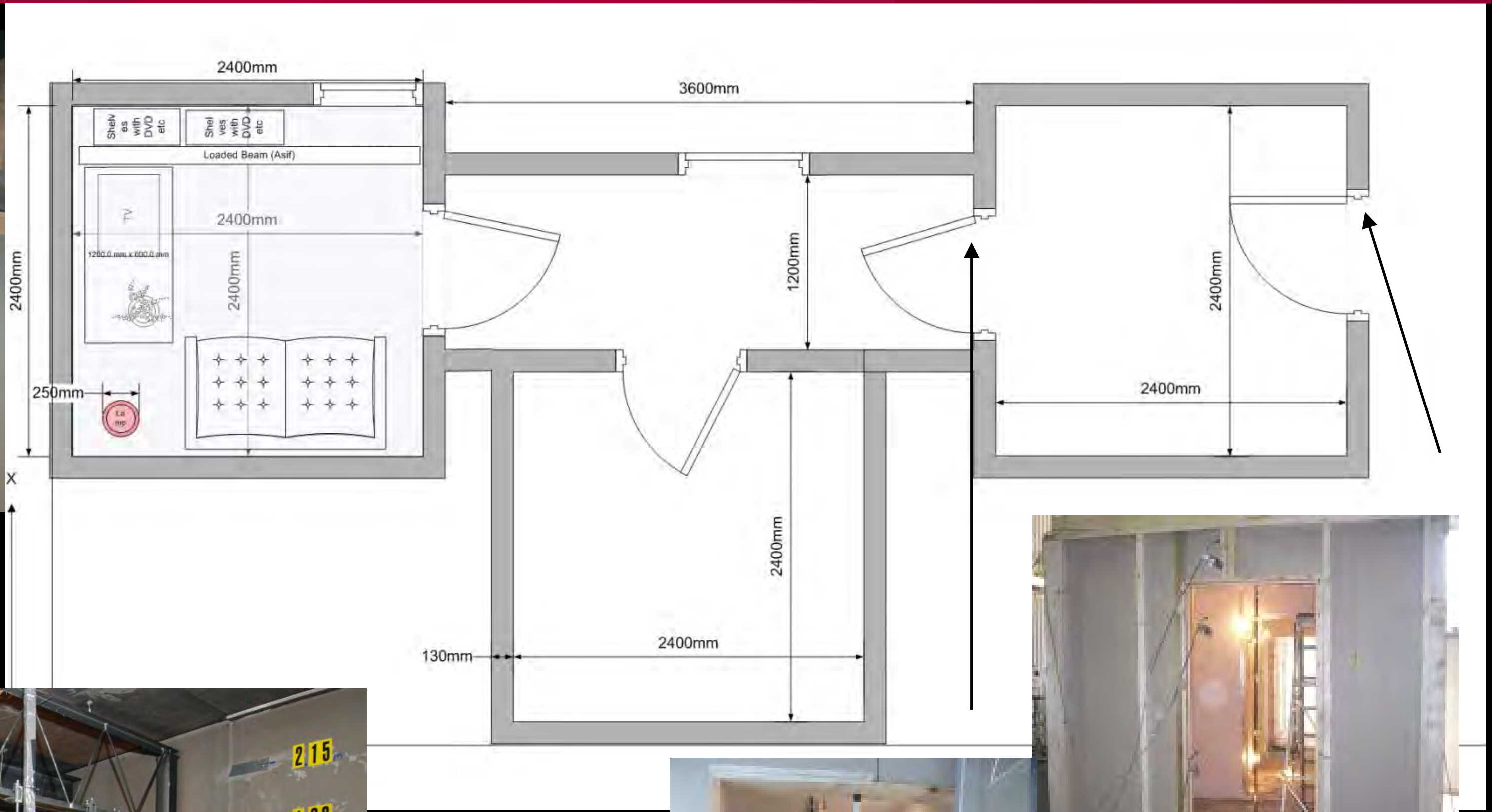
automated building protection systems

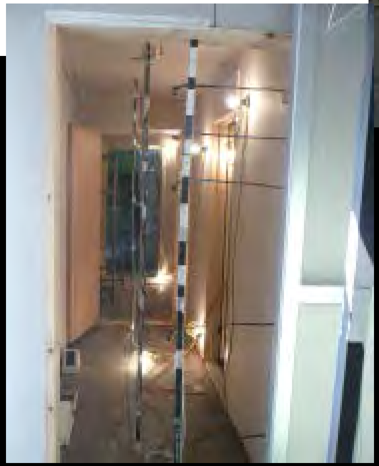


BC3I (building command, control, communication and intelligence)

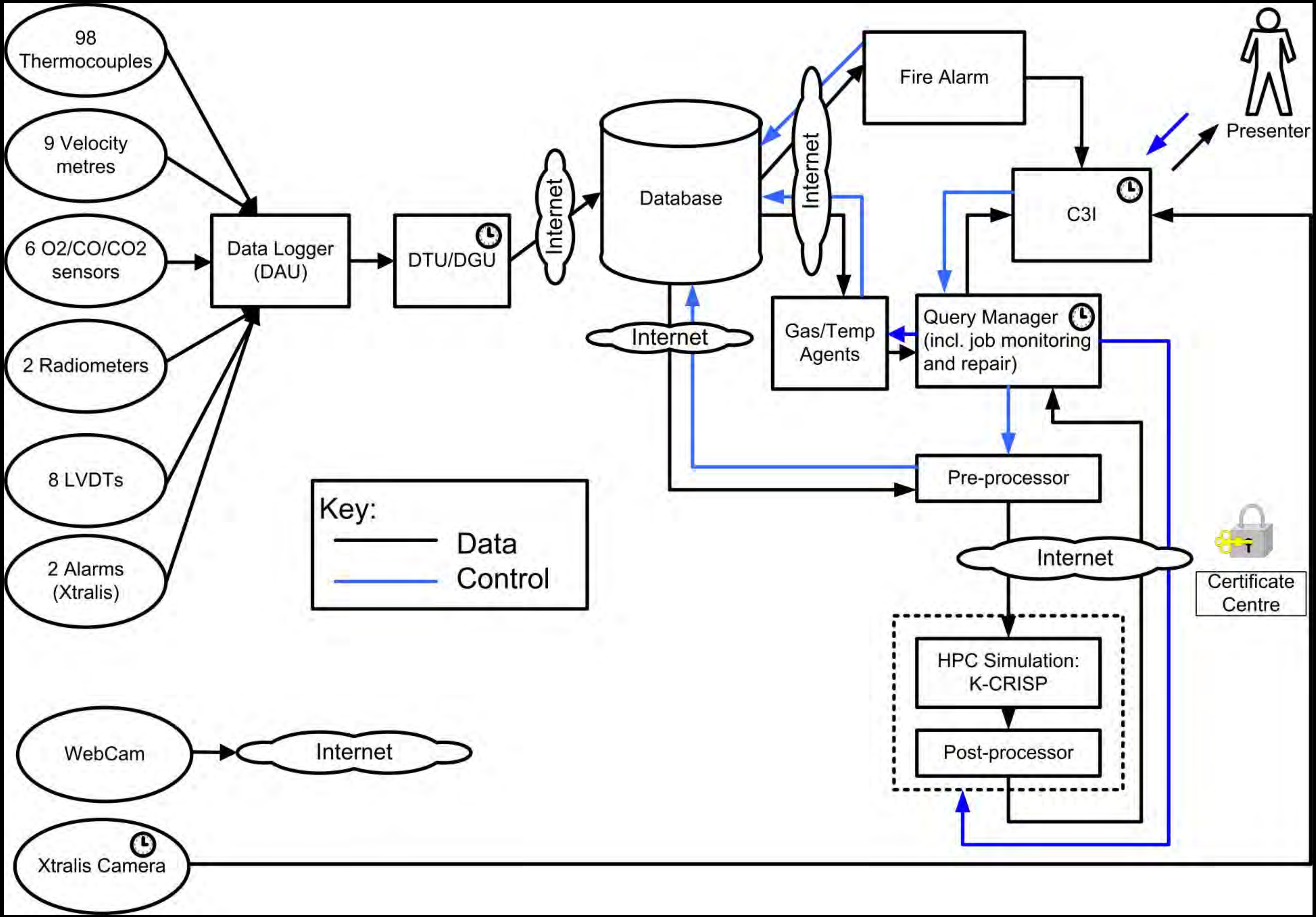
- monitors DIUs type 1 & 2 for signs of fire
- initiates DIU3 query manager to begin super-real-time simulation
- interprets output from DIU3 forecasts for
  - A: initiates automated response using actuators (existing or future active and passive fire protection devices) – in the early stages
  - B: decision support for human intervention – at the later stage (failure of early response), this is done in concert with **e-Response C3I**

Demo in an full-scale apartment mock-up

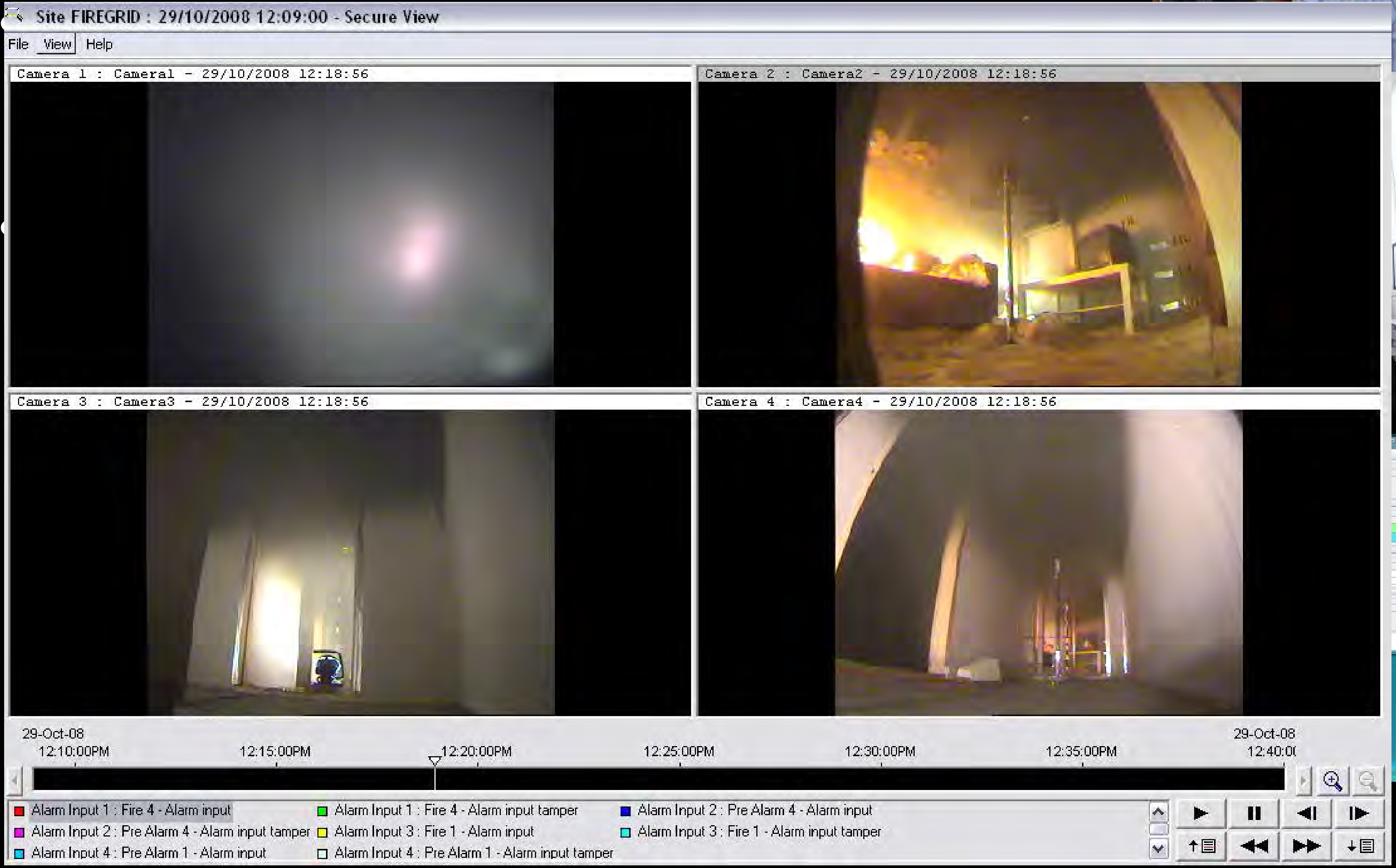




Demo architecture



The demo experiment



Before

After

Results


1000
Temperature(°C)
1000
Deflection (mm); Temperature (°Cx1000)
2400
Time from detection (s)

Full description published in a technical paper

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Journal of Parallel and Distributed Computing

FireGrid: An e-infrastructure for next-generation emergency response support

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A B S T R A C T

The FireGrid project aims to harness the potential of advanced forms of computation to support the response to large-scale emergencies (with an initial focus on the response to fires in the built environment). Computational models of physical phenomena are developed, and then deployed and computed on High Performance Computing resources to infer incident conditions by assimilating live sensor data from an emergency in real time—or, in the case of predictive models, faster-than-real time. The results of these models are then interpreted by a knowledge-based reasoning scheme to provide decision support information in appropriate terms for the emergency responder. These models are accessed over a Grid from an agent-based system, of which the human responders form an integral part. This paper proposes a novel FireGrid architecture, and describes the rationale behind this architecture and the research results of its application to a large-scale fire experiment.

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Concluding remarks

- Cities and high density urban environments are exceptionally vulnerable to fire
- Cities should be resilient against foreseeable hazards to be considered “smart”
- Intelligent building and smart city technologies offer opportunities for FireGrid type systems to be developed and integrated with other services
- It is imperative that researchers, designers and public safety organisations collaborate to mitigate the enormous risk from fire, this is especially true for dense urban environments

Thank you !

Questions?

Cost of fire to society

- Direct costs (from direct consequences of “uncontrolled fire” incidents)
- Continuous costs (from measures taken in anticipation of fire)

} **Core costs**

- Non-monetary losses (may not involve market transactions)
- Indirect costs (relatively difficult to quantify and insure)

} **Other costs**

Total cost of fire (USA)

Core Costs	Billions of Dollars
Economic loss	$14.8
Local fire department expenditures	$42.6
Net insurance (premiums minus NFPA estimate of reported direct damages)	$19.2
New building costs for fire protection	$31.7
Total core costs	$108.4
Other Costs	
Other economic cost	$47.5
Cost of statistical deaths and injuries, civilian and firefighter	$31.9
Cost of coverage by career firefighters of areas now protected by volunteer firefighters	$140.7
Total	$328.4

0.73% of US GDP

2.2% of US GDP

This has dropped from 3.3% of GDP in 1980

Source: National Fire Protection Association (USA), John R Hall, Jr., March 2013

Crude estimate of the core cost of fire

1. Fire is a major cost to an industrialised economy (roughly of the order of 1% of GDP)

2. There is a correlation between economic activity and cost of fire

3. There is potentially also an inverse correlation between human development and fire losses

4. Based on this a simple formula can be used to crudely estimate core fire cost as %GDP

   Cost of fire (% of GDP) = per capita GDP (normalised against USA) / HDI

5. This results in the following numbers for selected countries

Country	Core cost of fire (%GDP)	Cost in Billion USD
United Kindom	0.80	23.6
China	**0.33**	**34.4**
India	0.17	3.5

Validation (UK core cost)

Item	Cost as %GDP
Estimated building fire protection cost	0.23
Insurance administration	0.10
Public fire brigade	0.20
Indirect fire losses	0.01
Direct fire losses	0.13
TOTAL CORE COST	0.67

Source: Bulletin , World Fire Statistics, The Geneva Association, April 2014