Combustion Fundamentals of Fire Safety

The Grenfell Tower Fire: Failing to Understand Complexity in Tall Building Design

José L. Torero
University College London
United Kingdom

Lecture-1
Fire

• Physical phenomenon that evolves in space and time – affect the wellbeing of people and property
How could this happen?

- 100+ buildings tested – 100% failure
- 10+ buildings being evacuated in the UK
- 5+ buildings being evacuated in Germany
- Several buildings being investigated in the US (including several hotels)
- Several buildings being investigated in Australia (including hospitals) ... as you know
- ... this is only the beginning ...
Andraus Building Sao Paulo, Brazil, February 24th, 1974

MOVING MANKIND TOWARD SAFETY FROM FIRE
Neo200 (February 3rd, 2019)

- “Cigarette blamed for Vic apartment fire”
- “Cladding audit found Melbourne apartment tower posed 'moderate' fire safety risk (Victorian Cladding Taskforce)”
- "While most of the building is not clad at all, where any cladding is used it is compliant with VBA [Victorian Building Authority] standards," Neo200 tweeted in June 2017.
- "This building is extremely safe, it's around 90 per cent made out of concrete panel construction, there's only about a 10 per cent mix of ACM panels," Sahil Bhasin (building inspector) told ABC Radio Melbourne”
- "We didn't hear the alarm until about 15 minutes ago. We thought it was a few blocks down"
- "It was smoky through the stairwell and then when we heard it was on the floor that we were supposed to be on we thought, someone's looking after us”
- "The fire occurred, the sprinklers came on and, assisted with the MFB, the fire was doused.”
- Mr Bhasin, who is the general manager of Roscon, said it appeared the building's fire plan had worked "perfectly”
- "I'll be pushing for a nationwide ban on combustible cladding really to further protect Victorians from being exposed to unacceptable fire risk (VCT)"
Are Façade Fires an Unavoidable Feature of Modern Architecture?
The Key Changes

- The building envelope
- New construction methodologies
- Flammable insulation materials – encapsulation
- etc ...

... it is not “one” problem!
The Building Envelope
Fire Safety Strategies

- Prescriptive Design
- Performance Based Design
Life Safety

Compartmentation

Structure

Response
Life Safety

Common Sense Compartmentation

Locate According to manufacturers Specifications

Structure

Specify According to Manufacturers Standard Test Data

Response

Define according to simple rules (Common Sense)
Fire Safety Strategies

• Evacuation
  – Detection
  – Alarm
  – Displacement away from the fire
  – Crowd management

• Compartmentalization
  – Slows fire growth
  – Minimizes smoke spread

• Response
  – Automatic (fire suppression)
  – External
  – Internal

• Structural Integrity
Time Lines

Evacuation Completed
Structural Failure
Untenable Conditions
Structural Failure
The Objectives
Why is this important?
Impact of External Fire Spread

Adequate Travel Distances
Protected Egress Paths

Effective Detection
Compartmentalization

Fire Brigades: Defend in Place

Structural integrity – Given a 1 Floor Fire
How do things change?

- Detection
- Egress
- Protection of egress paths – compartmentation
- Active fire suppression: Sprinklers
- Structural integrity
- Fire Brigade operations
- etc ...
Is it possible for firefighters to identify when this will happen?

Shepherds Bush Court, August 19th 2016

Grenfell Tower Fire, June 14th 2017
No Vertical Flame Spread

Well defined procedures → One Compartment Fire

All Comes Back to Fire Fighting Operations

Acceptable Vertical Flame Spread

Disclosure of what this means in regards to Vertical Flame Spread and the implications for the specific building safety is not clear

Undefined Procedures → Unknown

Performance Criteria
How is this different?
Why is this the outcome?
What has truly changed?
A fundamental change of the problem ...
Filling the opening?

- Relative displacement
- Construction Detailing
Complex Building Systems

- **Complex**: Building systems are “multi-purpose” (energy, stability, durability, comfort, life cycle, fire barriers, etc.)
- **Dependent on labour skill and cost**: Tolerances, installation times, modification during construction, etc.
- **If the objective is to guarantee encapsulation** then this is the problem that needs to be solved!
Encapsulation
Encapsulation
Protective Layers

How do we establish performance for encapsulation/protective layers?
Complexity

- External fires change everything and severely expose building occupants
- The fire safety strategy is designed for “no” external flame spread
- How can performance be assessed?
Flammability to Encapsulation = Complexity

- Challenged our understanding of how to achieve quality, safe, robust, resilient infrastructure
  - Design principles
  - Design practises
  - Performance assessment
  - Regulatory frameworks
  - Professional boundaries
  - Integrated design
  - Definition of competence
  - ... etc.
“The Wake Effect”

... or the unintended consequences of our actions
Why are we back to the 1970’s?

Joelma fire, Sao Paulo, Brazil, Friday, February 1st, 1974
Drivers and Constraints
Energy: Quantifiable Performance

- Energy conservation targets

Note: Figures are 2010 averages for electrified households
Source: Enerdata via World Energy Council
Social Housing: 1960’s – 1970’s
Grenfell Tower, Notting Hill

Architect: Studio E

Client: Royal Borough of Kensington & Chelsea

Main contractor: Rylar Group

Scope of works: over-coating with ACM cassette rainscreen, windows replacement, curtain walling, cladding, feature metalwork

Harley contract value: £2.6m

Harley Facades Limited

Harley House

Brooklands Park

Pimlico Road

Crawley

East Sussex

TN1 2JD

T: 01892 669704
F: 01892 669705

harleyfacades.co.uk

Grenfell Tower
How do we quantify performance?
Compliance

Materials of limited combustibility

9 Materials of limited combustibility are defined in Table A7:

a. (National classes) by reference to the method specified in BS 476: Part 11:1982; or

b. (European classes) in terms of performance when classified as class A2-s1, d2 in accordance with BS EN 13501-1:2007, Fire classification of construction products and building elements, Part 1 – Classification using data from reaction to fire tests when tested to BS EN ISO 1182:2002, Reaction to fire tests for building products – Non-combustibility test or BS EN ISO 1716:2002 Reaction to fire tests for building products – Determination of the gross calorific value and BS EN 13823:2002, Reaction to fire tests for building products – Building products excluding floorings exposed to the thermal attack by a single burning item.
Is this a solely a material flammability issue?
Flammability Tests

Reaction-to-fire Classification: A1, A2, B, C, D, E

- Heat of combustion (ISO 1716)
- Non-combustibility test (ISO 1182)
- Ignitability test (ISO 11925-2)
- Room corner test (ISO 9705)
- SBI (ISO 13823)

Are we truly testing “system” behaviour?
Does this test provide system performance?
Does this test assess true mechanical behaviour?
Spill Plumes

$L_f$

![Graph showing incident heat flux vs. height above window soffit]
Are these the right tests?

BS 8481

NFPA 285

PASS

FAIL
ANSI FM 4880
... we know perfectly well how to do it ...

... but it requires “bespoke” performance protocol for each particular system ... there is no standardize test because we are testing “system behaviour”: Building + Envelope

... Past: One test for all materials

... Today: A bespoke performance protocol for each system
How do we bring attention to the “wake”?

- Safety is not a constraint
  - It is not the bad test
  - It is not the bad material
- It is the lack of understanding of the consequences of our actions
Today: Design for Implicit Performance

Standardization of Space
Means of Escape
Compartmentation
Geometry

Loss of Function
Compromised Aesthetics

One Size Fits All
Consequence: Enormous Safety Factors

Standardization of Response
Active
Passive
Fire Service

Waste
Unidentified Mistakes

Un Sustainable
Tomorrow: Design for Explicit Performance

- Architecture
- People
- Physiology
- Psychology
- Sociology

Factors: Sustainable

- Reactive Flow
- Burning
- Smoke/Heat
- Materials
- Solid Mechanics
- Fluid Mechanics
- Heat Transfer

- Structure
- Material Science
- Design Education
- Safety
- Sustainable Material Science
A viable technical proposition ...

an enormous philosophical departure

Thank you!