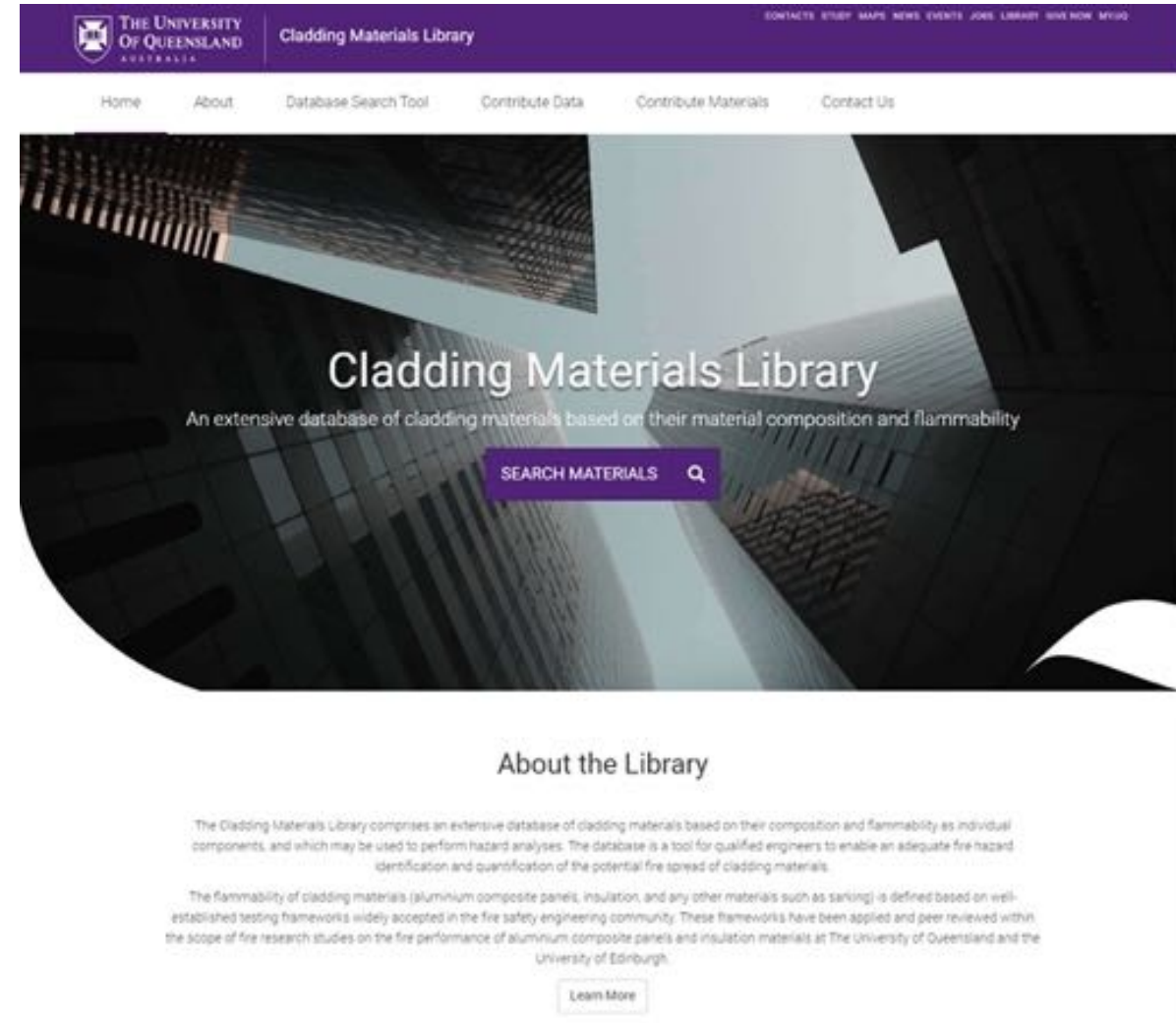


Façade fire performance of low carbon structures

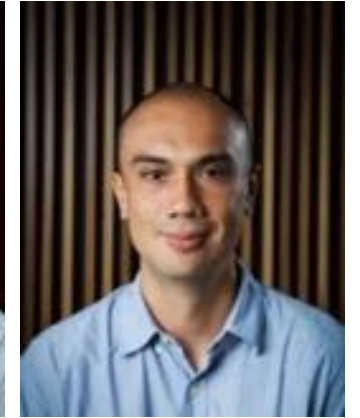
Martyn McLaggan
Lecturer in Low Carbon Design

12th May 2023

1. Background and context
2. Cladding Materials Library
 - Engineering framework
 - Data published in an open access library
 - Competency framework
3. Implications for structural fire engineering



Some of the team

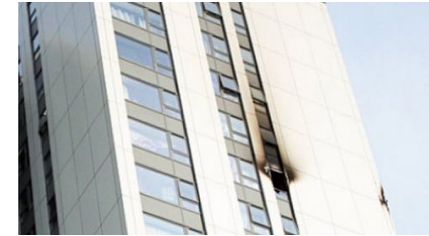
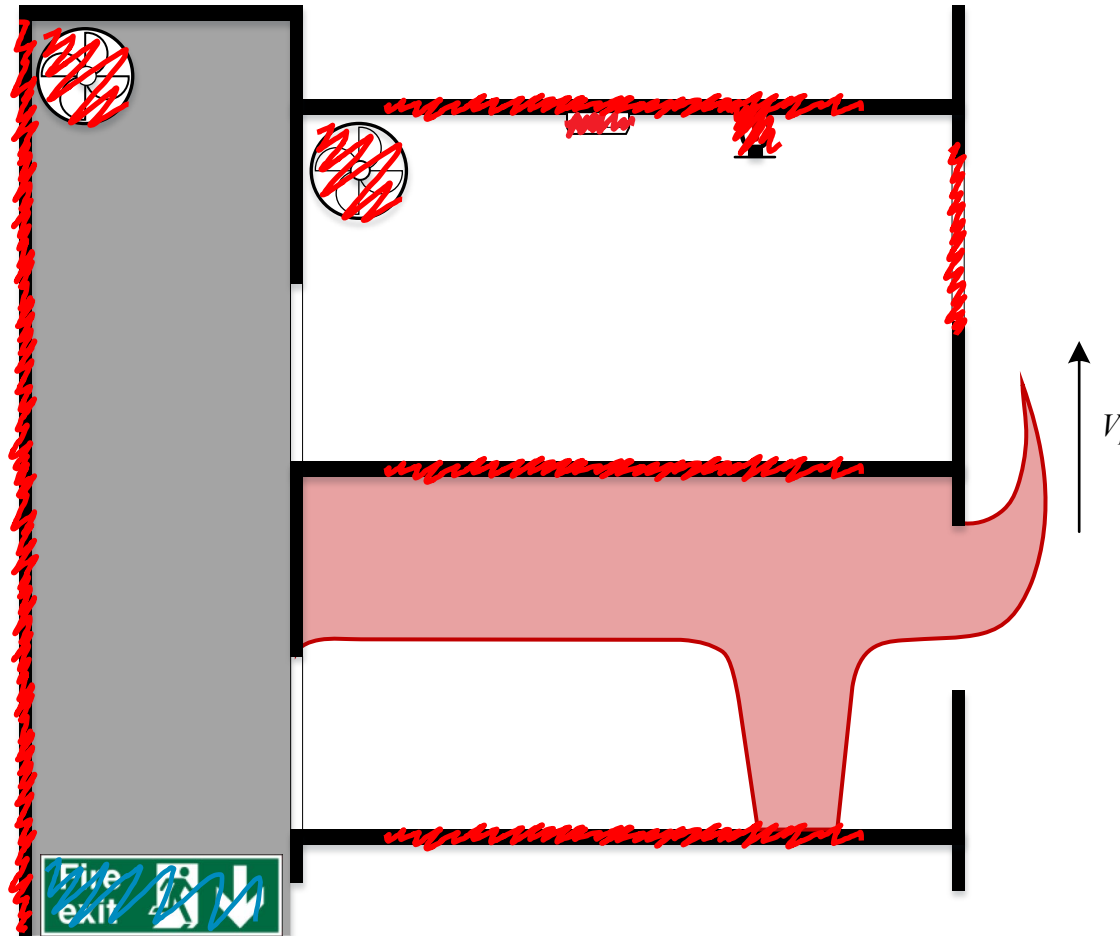


Background and context

Why vertical flame spread is unacceptable



NIST/Michael Chan



BBC/Camden New
Journal



REUTERS/Ahmed Jadallah

- Fire safety strategy and compartmentation reliance
- Robustness, inadequate property protection
- Classic means to ensure vertical compartmentation (spandrels etc.)
- Modern design and construction details
- Encapsulation and material compliance
- Proof of performance
- ‘Unanticipated’ failure mechanisms
- Initial investigations
- Remediation
- Inadequacy of previous methods
- Industry-wide problems and compliance



Construction and Building Materials 300 (2021) 124081

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Towards a better understanding of fire performance assessment of façade systems: Current situation and a proposed new assessment framework

M.S. McLaggan^{a,b}, J.P. Hidalgo^c, A.F. Osorio^c, M.T. Heitzmann^{b,c}, J. Carrascal^c, D. Lange^c, C. Malak^c, J.L. Tocco^d

^a School of Civil Engineering, The University of Queensland, Australia
^b Centre for Advanced Materials Processing and Manufacturing (CAMP), The University of Queensland, Australia
^c School of Mechanical and Mining Engineering, The University of Queensland, Australia
^d Department of Civil, Environmental and Geomatics Engineering, University College London, UK

ARTICLE INFO

Keywords:
Fire safety engineering
Façade
Cladding
Fire risk
Investigation
Simulation
Risk assessment
Cladding materials library
Structural analysis

ABSTRACT

This manuscript presents tools and data that serve to enable an evaluation of the risk associated with vertical fire spread on buildings. A highly detailed context to cladding fires is described to reveal the complexity and magnitude of the problem and to identify gaps of information. An engineering framework is then developed which delivers required information that fills some of these gaps and that needs to be used towards achieving quantified fire performance. The data used has been published as a publicly available database, entitled the Cladding Materials Library (www.claddingmaterialslibrary.com). This data can be used to support building fire risk assessment or as the basis for more in-depth research into façade fires. This paper presents the context of the data together with the complementary framework necessary for updating building professionals to have the capacity to implement the engineering framework.

1. Introduction

The manner in which high-rise building construction has evolved in the last two decades has resulted in the number of very large-scale building fires increasing in a dramatic way. Notable among these fires is the Shanghai fire with 51 victims and the Grenfell Tower fire with 72 victims. These fires have been documented extensively and in the majority of the cases the fast spread and ultimate magnitude of the fire is related to the manner in which the façade system was designed. Despite the numerous failures, it remains unclear how to address these complex systems to deliver a quantitative performance assessment that enables fire safety engineers to establish, in an explicit manner, an adequate fire safety strategy.

The façade system is an integral component of the fire safety strategy because the ultimate effectiveness of the strategy is strongly influenced by the need to contain the fire to a single floor. Or, in some cases, management, compartmentation, egress strategy (stay-put, phased, or simultaneous ‘all-out’), firefighting, and structural stability. For a building which has a stay-put evacuation strategy, the detection and alarm system are often limited to single units, and cannot alert occupants to the spread away from the compact of origin. Sprinklers, if included, act as a supplementary means to reduce the probability of fire growth but cannot be relied upon as a sole means of protection. Sprinklers, as well as smoke extraction and stair pressurization systems, will become overwhelmed once multiple floors are affected by fire. Vertical fire spread represents a failure in compartmentation, and switching to an ‘all-out’ evacuation strategy becomes necessary but may not be safe due to the spread of fire and smoke throughout the building. Finally, the structure will be exposed to a long duration, full building fire for which it is not designed and which threatens the life of remaining occupants and firefighters in the building. This is described in more detail by Tocco [1].

Queensland Government response

Queensland Non-Conforming Building Products Audit Taskforce

- Establishment of the Non-Conforming Building Products Audit Taskforce, making six recommendations, including:

Recommendation 4: That the government develop of education and guidance material for building stakeholders

Recommendation 5: Evaluate possible options for fire testing, and develop a materials library to enable the rapid assessment of claddings

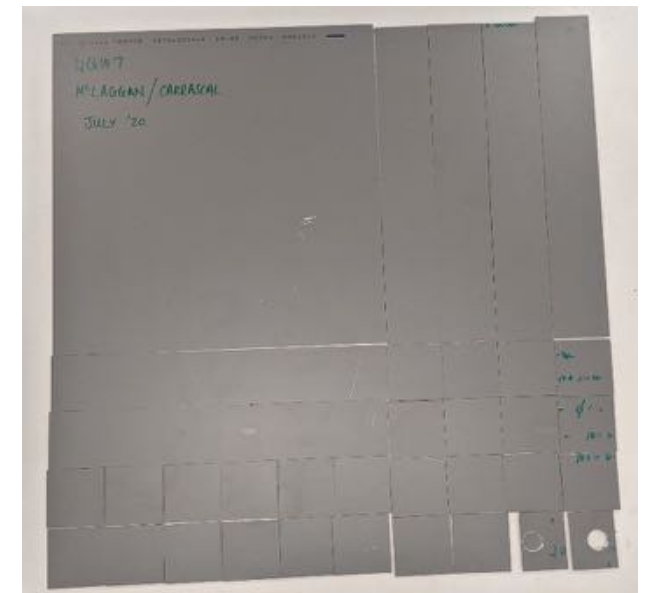
Recommendation 6: Development of a continuing professional development course to train and educate building professionals



Cladding Materials Library

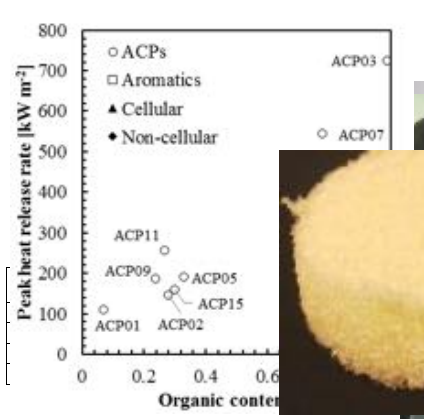
1. What are the materials?
2. What are their key properties?
3. How will they behave as part of the *system*?
4. Can the *building* respond to a façade system fire adequately?
5. What skills do building professionals require to assess this?

- **Screening protocol** (run on all samples, in the region of 1,100)
 - Deliver a rapid initial assessment of each sample
 - Obtain unique fingerprint associated with each unique material
 - Quick and easy to run
- **Detailed testing protocol** (run on a select number of samples, currently 20+)
 - Determination of material properties
 - Detailed characterisation of flammability performance
 - Key metrics as used in the fire safety engineering community
 - The needed data for engineers to make an assessment

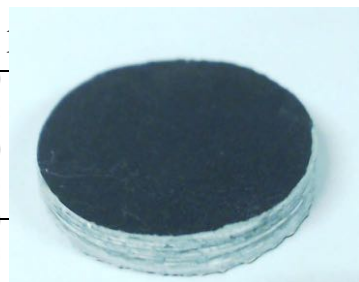


- **Screening protocol** (run on all samples, in the region of 1,100)
 - What are the constituent materials in a sample?
 - How much of each component is there?
 - What is the thermal degradation?
- **Detailed testing protocol** (run on a select number of samples, currently 20+)
 - How much energy does the material release?
 - What are the ignition characteristics?
 - What is the burning behaviour?
 - How much does the flame propagate in both opposed and concurrent conditions?

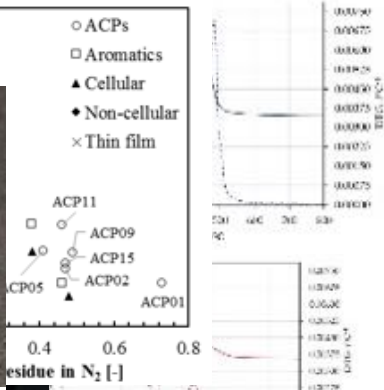
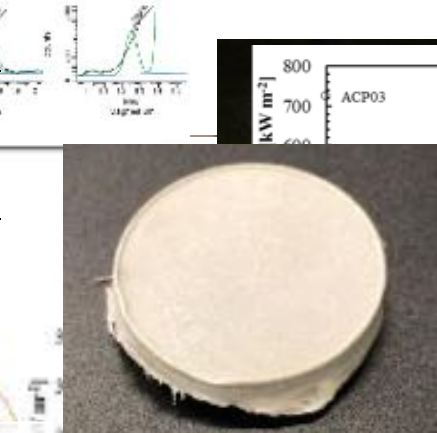
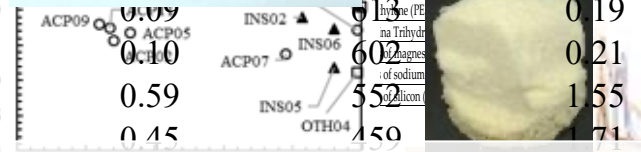
Table 2. Summary of computed critical flame spread.



ID	Category
INS02	Cellular
OTH01	Aromatic
ACP01	ACP
ACP15	ACP
ACP02	ACP

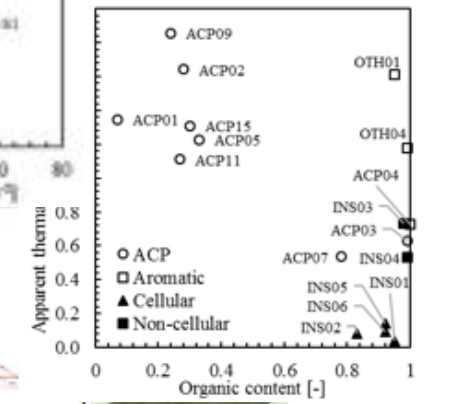
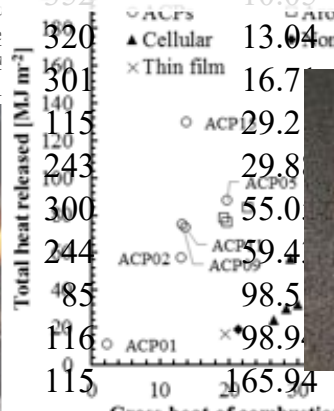
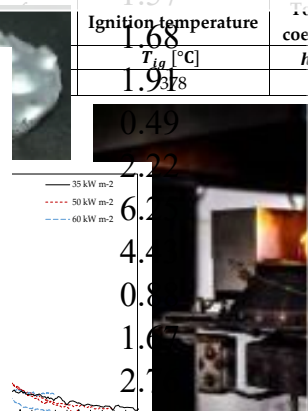
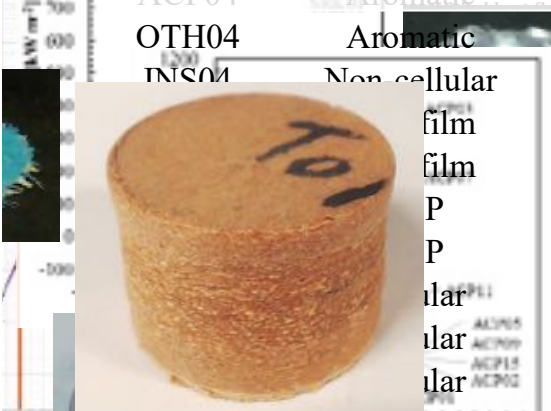
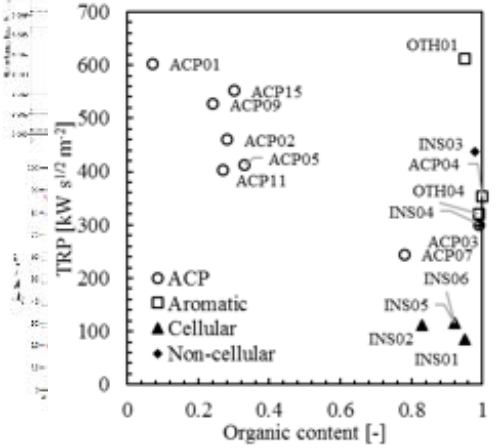
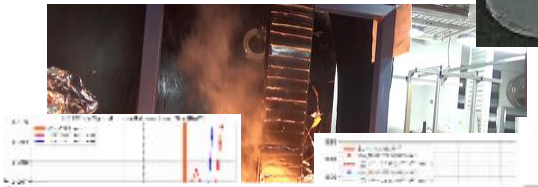


$$p \frac{d}{dt} p = \text{Eq. (3)}$$



Cladding Materials Library

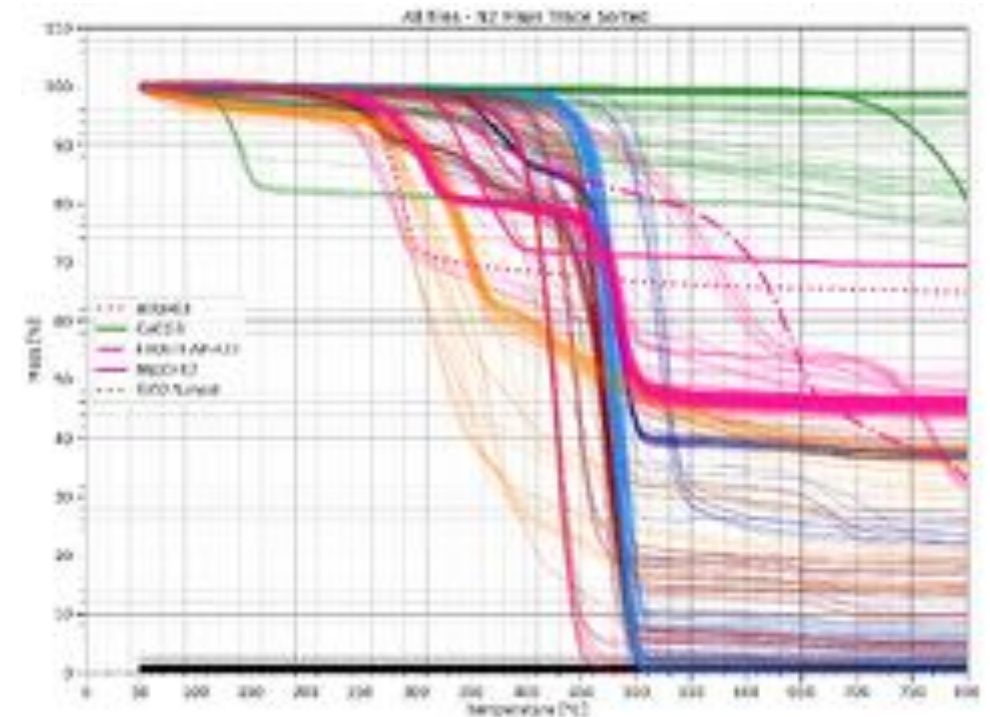
www.claddingmaterialslibrary.com



		ΔH_c [kJ g ⁻¹]
	0.9718	4.9
	1.1502	7.2
	0.6696	5.8
Average		13.08
St. Dev.		0.19

- 3,856 FTIR tests
- 2,379 EDXRF tests
- 2,485 TGA tests (at about 1.5 hours each)
- 67 bomb calorimeter tests
- 164 cone calorimeter tests
- 156 mass loss calorimeter tests
- 114 lateral flame spread and ignition tests

= 9,221 experiments/tests (thanks Tam *et al.*)



- Hazard classification according to material flammability
- Identify materials which have clearly unacceptable performance
- Identify materials which have the possibility of acceptable performance
- Estimates must be conservative
- Large-scale tests are not a panacea: if they are used, they must represent a *relevant* system and a competent engineer must *interpret* the results

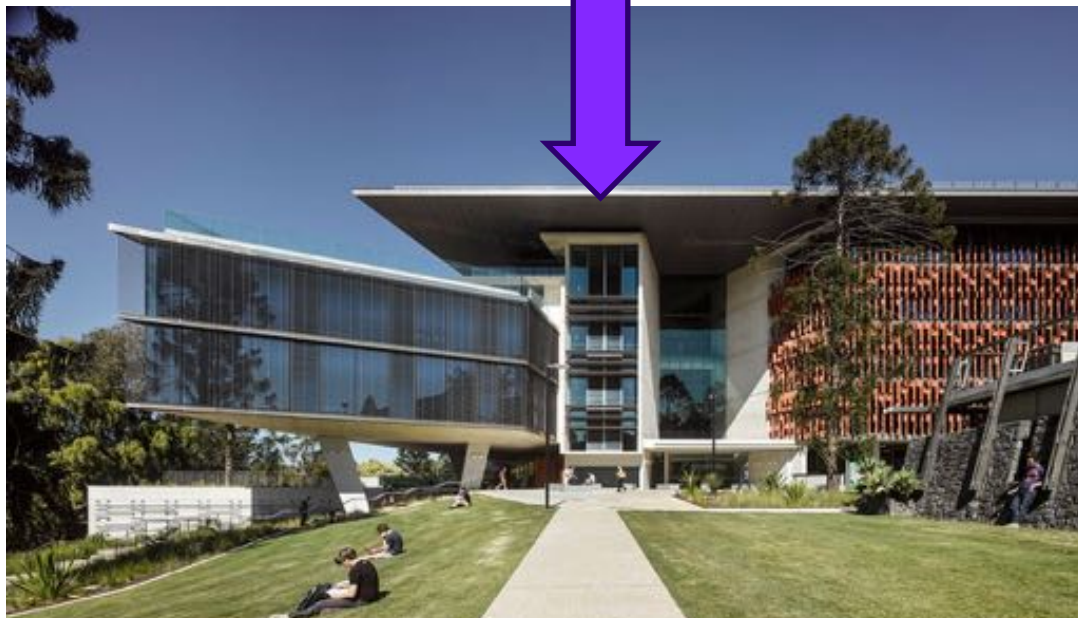


Material-scale

System-scale

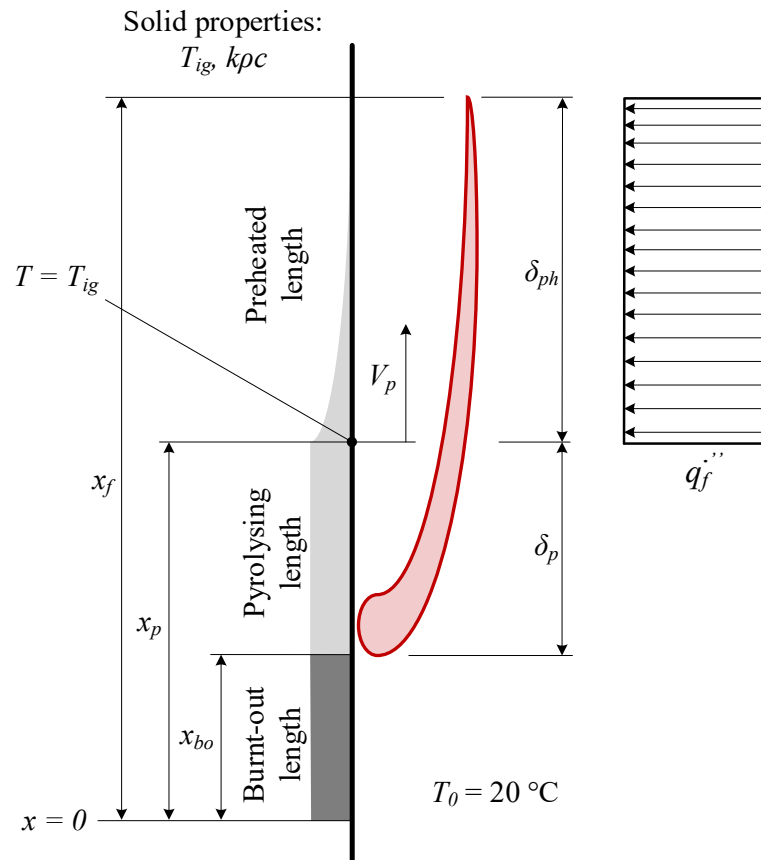
Large-scale

Building



Fundamental concept

Estimate flame spread velocity
vs.
Time to untenable conditions/structural collapse



Material-scale classification

Concurrent (upward) flame spread equation:

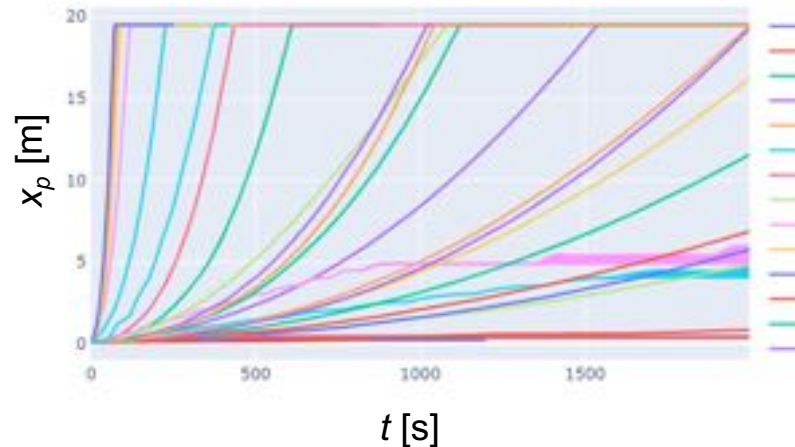
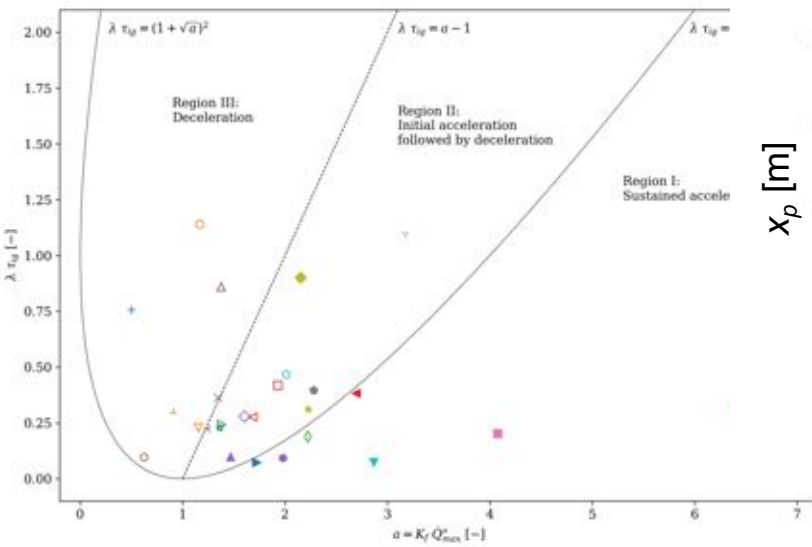
$$V_s = \frac{4 \dot{q}_f''^2 \delta_{ph}}{\pi k \rho c} \frac{1}{(T_{ig} - T_0)^2}$$

Volterra-type integral:

$$V(t) = \frac{1}{\tau_{ig}} \left[K \left(\dot{Q}'_b + x_{p,0} \dot{Q}''(t) + \int_0^t \dot{Q}''(t - t_p) V(t_p) dt_p \right)^n - \left(x_{p,0} + \int_0^t V(t_p) dt_p \right) \right]$$

Analytical solution

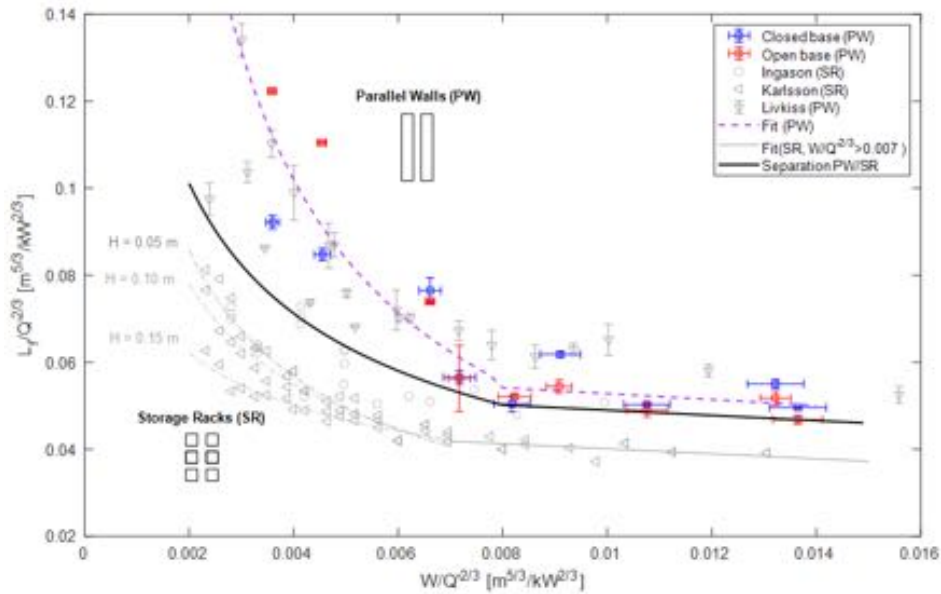
Numerical solution



Material ID	Type	$K_f \dot{Q}'_{max} - \frac{\tau_{ig}}{\tau_{ba}} - 1$ Eq (10)	$V(t)$ Eq (9)	$\frac{d\delta_{ph}}{dt}$ Exp
INS02	PHF	-0.34	Deceleration	-
ACP22	ACP FR	0.33	Deceleration	-
INS01	PIR	0.49	Finite acceleration	-
ACP15	ACP FR	0.51	Finite acceleration	-
ACP02	ACP FR	0.52	Deceleration	-
ACP34	ACP FR	0.52	Finite acceleration	0
ACP09	ACP FR	0.55	Deceleration	-
OTH01	Phenolic	0.61	Deceleration	-
ACP05	ACP FR	0.73	Finite acceleration	-
INS12	PUR	0.75	Sustained acceleration	-
ACP06-S1	ACP A2/thin film	0.77	Deceleration	-
ACP35	ACP FR	0.81	Finite acceleration	-
ACP04	Cellulose/phenolic	1.02	Finite acceleration	-
OTH24	WPC	1.03	Sustained acceleration	-
ACP11	ACP FR	1.12	Finite acceleration	-
INS05	PIR	1.27	Finite acceleration	> 0
SRK01-S1	Sarking	1.27	Finite acceleration	-
OTH04	Plywood	1.33	Sustained acceleration	< 0
INS04	EPS	1.58	Finite acceleration	-
ACP01	ACP A2	1.66	Deceleration	-
ACP10	ACP A2/thin film	1.74	Finite acceleration	-
INS06	PUR	1.89	Sustained acceleration	-
OTH23	GFRP	1.96	Sustained acceleration	-
ACP07	ACP PE	3.26	Sustained acceleration	> 0
INS03	Polyester wool	3.57	Finite acceleration	-
ACP03	ACP PE	5.67	Sustained acceleration	-

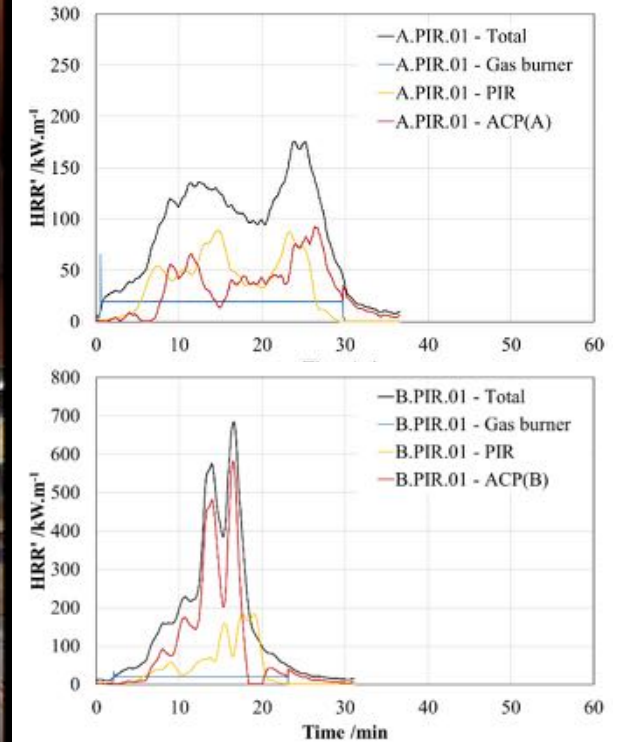
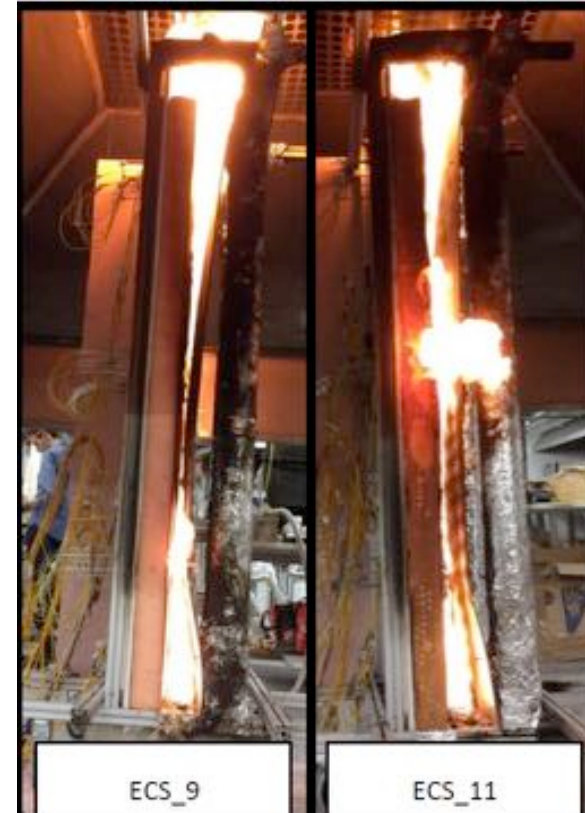
McLaggan, M. S., Gupta, V., Hidalgo, J. P., & Torero, J. L. (2021). Upward Flame Spread for Fire Risk Classification of High-Rise Buildings. *International Journal of High-Rise Buildings*, 1-20.

Potential flame elongation in inert systems



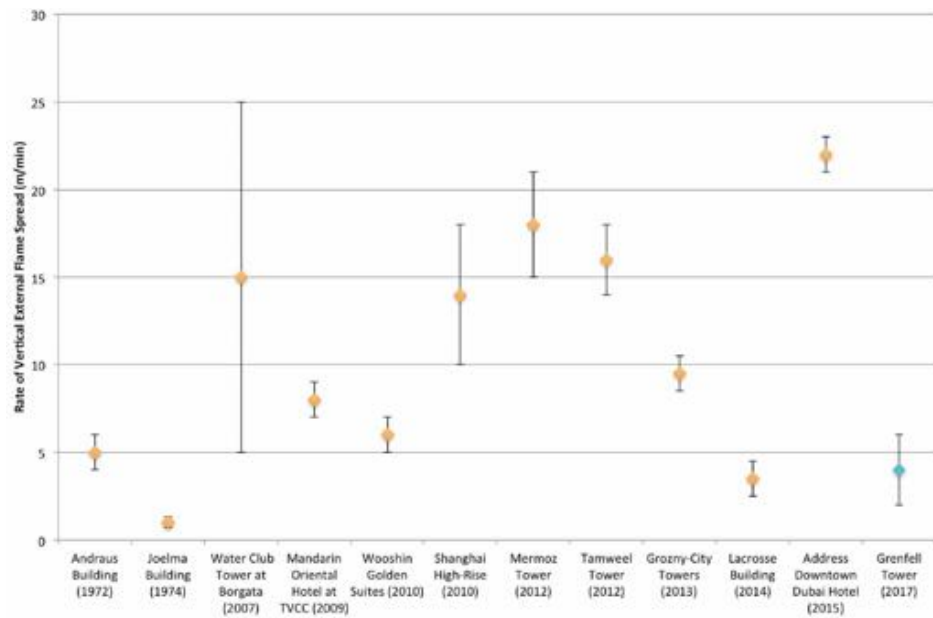
Mendez, Julian E., et al. "Effect of cavity parameters on the fire dynamics of ventilated façades." *Fire safety journal* 133 (2022): 103671.

Simplified systems containing combustibles



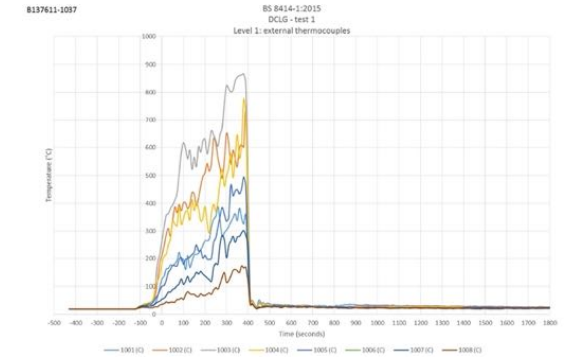
Garvey, B. *et al.* (2019). Experimental methodology to study the fire contribution of cladding materials. *Proceedings of Interflam* (pp. 2079–2090).

Real building fires

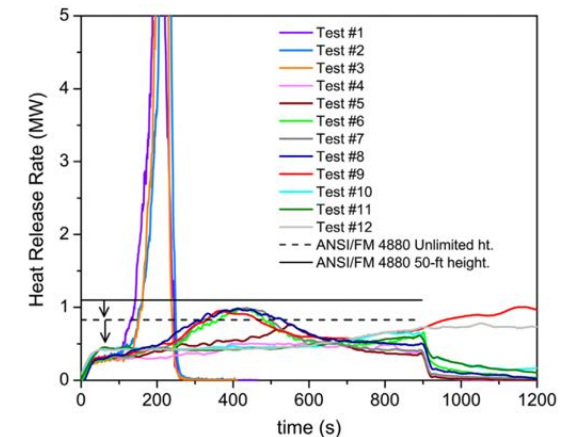


Torero, J. L. (2018). Grenfell Tower Inquiry: Professor Jose Torero expert report (Phase 1 - supplemental), JTOS000001.

Large-scale test data



BRE Global. (2017). BRE Global Client Report – BS8414-1:2015+A1:2017 test, DCLG test 1.



Agarwal, G., Wang, Y., & Dorofeev, S. (2020). Fire performance evaluation of cladding wall assemblies using the 16-ft high parallel panel test method of ANSI/FM 4880. *Fire and Materials*, April, 1–15.

Competency framework

CPD for fire safety engineers

A joint CPD programme delivered by...



<https://www.civil.uq.edu.au/fire-externalspreadcpd>



Course structure (35 h)

Module 1 – Analysis of the fire strategy of a building (4 h).

Module 2 – Fundamentals of vertical fire spread (7 h).

Module 3 – Review of professionalism and the design process (2 h).

Module 4 – Mechanics of the coupled structure-façade system (1 h).

Module 5 – Cladding Materials Library and Laboratory sessions (7 h).

Module 6 – Reformulation of the fire safety strategy. (11 h).

Module 7 – Examination (3 h).

CPD Day		Day 1	Day 2	Day 3	Day 4	Day 5
8:00	8:15	Registration + Coffee	Morning coffee	Morning coffee	Morning coffee	Morning coffee
8:15	8:30					
8:30	8:45	Explicit fire safety strategy	Introduction	Responding to the 'Shergold & Weir Inquiry'	The Material Library framework	Laboratory session
8:45	9:00		Material composition (polymers)			
9:00	9:15		Thermal decomposition reactions			
9:15	9:30					
9:30	9:45					
9:45	10:00					
10:00	10:15		Coffee break			Coffee break
10:15	10:30	Coffee break		Coffee break	Coffee break	
10:30	10:45	Explicit fire safety strategy	Flaming ignition	Curtain walling systems	The Material Library framework	Laboratory session
10:45	11:00		Heat release rate and burning rate			
11:00	11:15					
11:15	11:30					
11:30	11:45					
11:45	12:00					
12:00	12:15					
12:15	12:30					
12:30	12:45		Lunch			Lunch
12:45	13:00	Lunch	Lunch	Lunch	Lunch	Lunch
13:00	13:15					
13:15	13:30	Implicit fire safety strategy	Flame spread (concurrent and opposed)	Case study 1	Case study 2	Exam
13:30	13:45					
13:45	14:00		Fire retardants			
14:00	14:15					
14:15	14:30					
14:30	14:45					
14:45	15:00					
15:00	15:15	Coffee break	Coffee break	Coffee break	Coffee break	
15:15	15:30	Implicit fire safety strategy and vertical fire spread	External fire plumes	Case study 1	Case study 2	
15:30	15:45					
15:45	16:00		System vs material behaviour			
16:00	16:15					
16:15	16:30					
16:30	16:45					
16:45	17:00					

- 2 day CPD
- For other building professionals, e.g.:
 - Certifiers
 - Manufacturers
 - Building owners
 - Architects
- Professionals need to be able to identify complex problems, know the limit of their abilities, and how to highlight issues
- 75% run by government



CPD Certifiers and Building Industry Professionals

This two-day CPD course has been developed to provide building certifiers and other industry professionals with the specialist knowledge required to understand the key principles regarding building fire safety strategy, facade design and the interactions between a facade and the building in the event of a fire involving the external wall of a building.

In addition, the course will give practitioners a full understanding of the application of the National Construction Code (NCC) and Queensland Building Regulation 2006 cladding requirements. This will facilitate the correct interpretation of requirements and support consistent certification outcomes that meet the intent of the National Construction Code (NCC) and satisfy relevant Queensland legislative requirements in relation to external fire spread in buildings.

About the proposed course

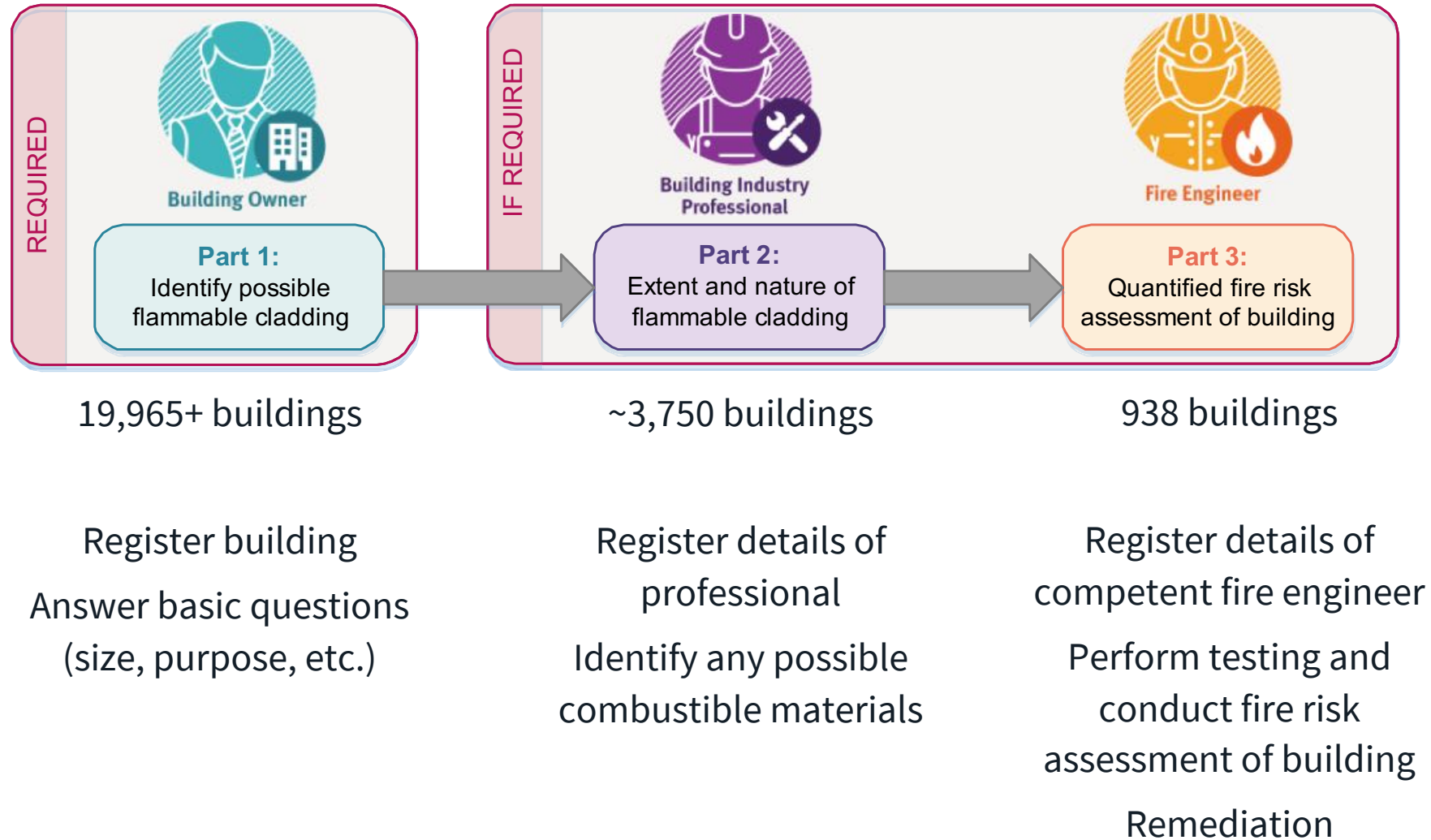
The course was first presented in October 2018. Based on enquiries received, a second course is now being considered for either 21 and 22 March 2019.

Please send your expressions of interest (by 22 February) to Gary Saunders from Audit Technique at Gary.Saunders@pwc.com.au

DAY 1 – LEGISLATIVE REQUIREMENTS

- General Background
- Queensland's New Legislative Provisions
- The Building Fire Safety Risk Assessment (BFRSA)

Implementation in Queensland

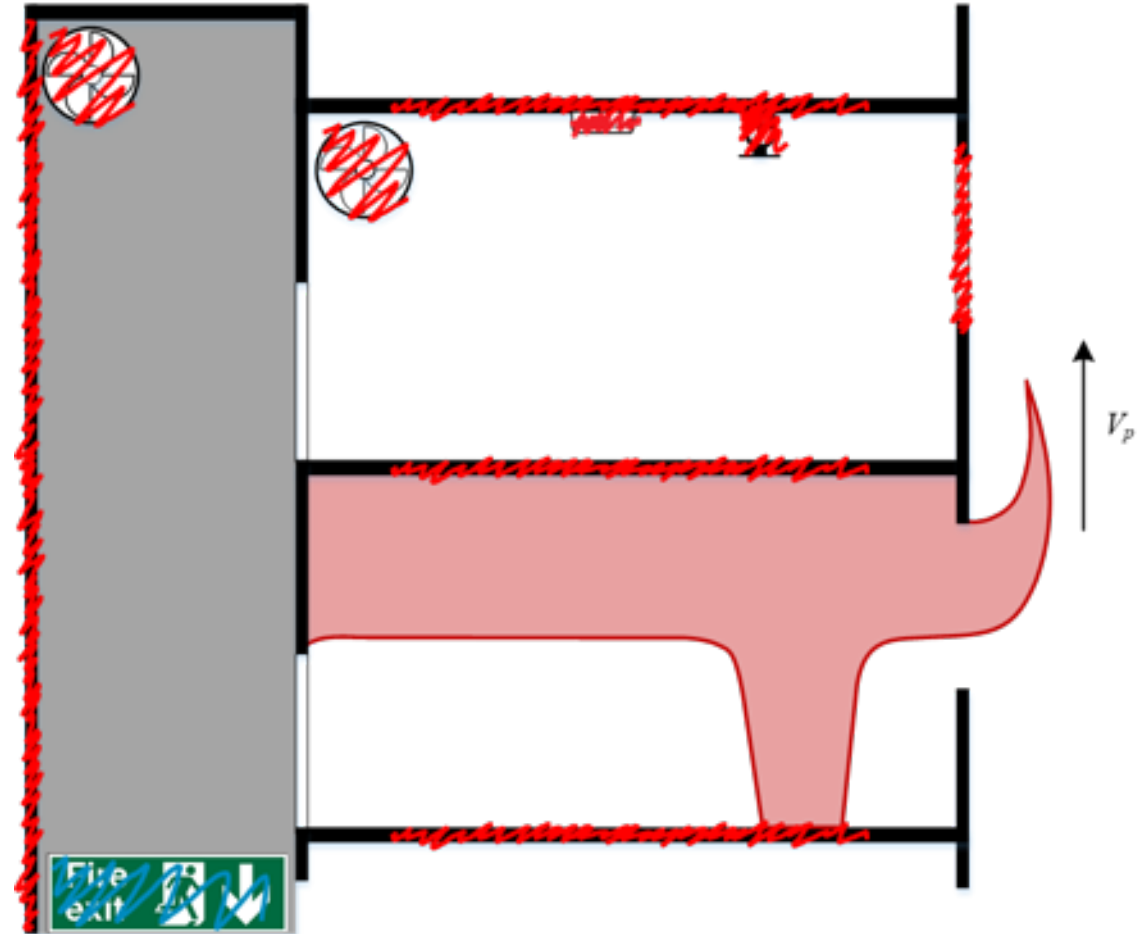


Implications for structural fire engineering

Façade fires and external fire spread introduce changes to the structural design

Structure must resist:

- Multi-storey or full building fires of a long duration
- Externally spreading fire with a specified velocity, duration and exposure





Impact of mass timber on the façade:

- Increased heat exposure due to greater energy released outside the compartment



Thanks for listening

Martyn McLaggan
Lecturer in Low Carbon Design

12th May 2023

Possible holistic risk assessment method

- Create a conservative but representative assessment of the building
- Fire is assumed to occur
- Acts as a framework, where more complicated components can be implemented as they are developed
- Identify possible weak areas

