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Fire safety of existing structures

Retrofit projects

Eoin O'Loughlin | Arup
Frederik Møller Poulsen | University College London

Structures in Fire Forum (StiFF) | Liverpool | 10 May 2024

Images credits Arup
unless noted otherwise

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Overview

Existing structures in fire

- Why are we here
- Challenges and opportunities
- A few examples
- Response
- Moving forward
- Questions & discussion

Why are we here

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We know we must do things differently

The Net Zero challenge – many solutions

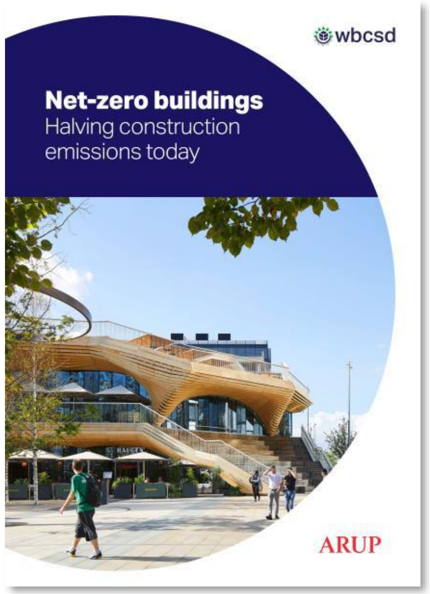
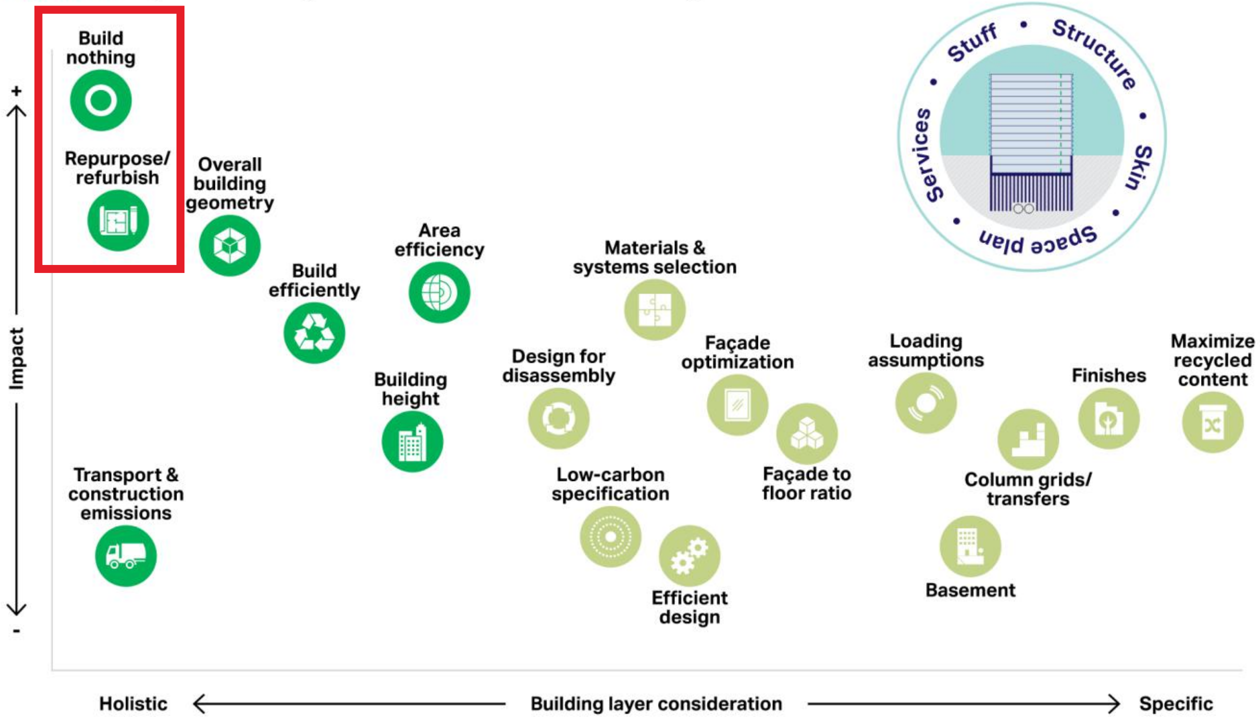


Figure 4: Key overarching considerations – whole-building decisions



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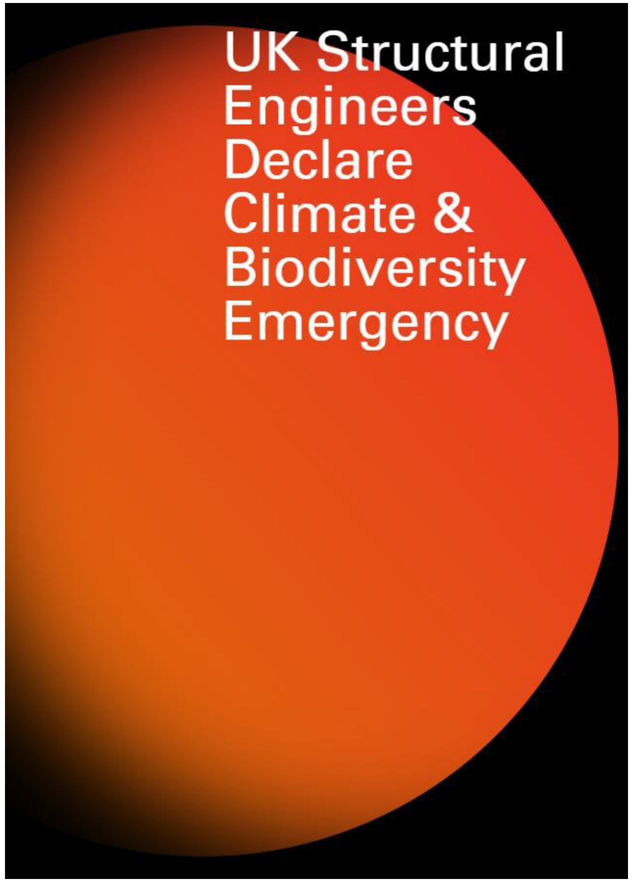
Existing structures are cool

Winds of change

'80% of existing buildings will still be in use in 2050'
COP26, Michelle Agha-Hossein



The Institution of StructuralEngineers
Structural Awards 2022

Winner 2022 | Award for showcasing the power of circular economy principles across all aspects of a project

The Institution of StructuralEngineers
Structural Awards 2023

2023 Shortlist
York Guildhall Refurbis

Structural Designer - Arup
Location - York, UK

2023 Shortlist
Bolands Quay Redevelopment

Structural Designer - Arup
Location - Dublin, Ireland

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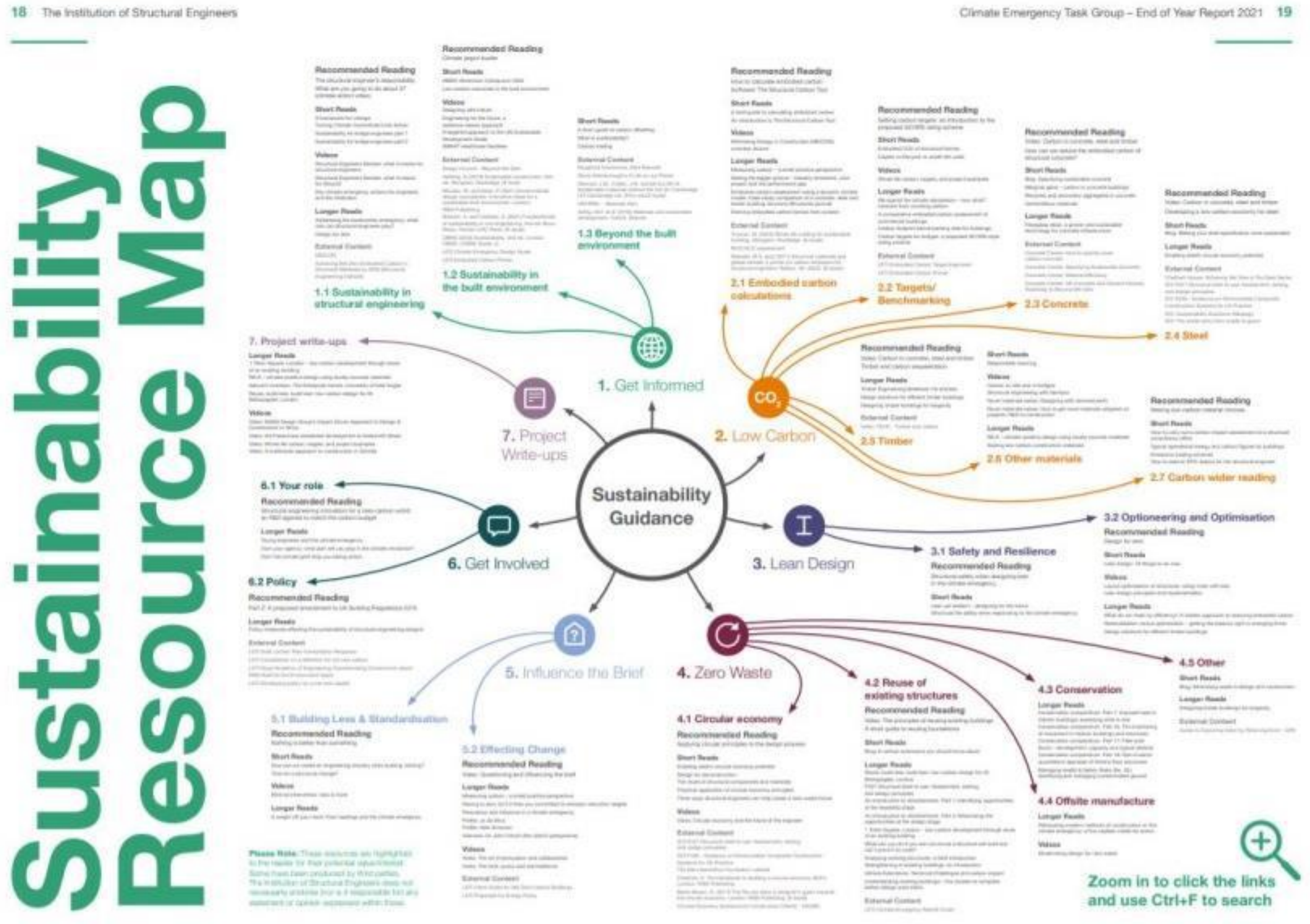
Moving the needle

Accelerating towards Net Zero



Will Arnold
Head of Climate Action at The Institution of Structural Engineers

Challenges and opportunities

Earning trust

Regulations
Competence
Quality
Perception

Image credit | Alamy | Shutterstock

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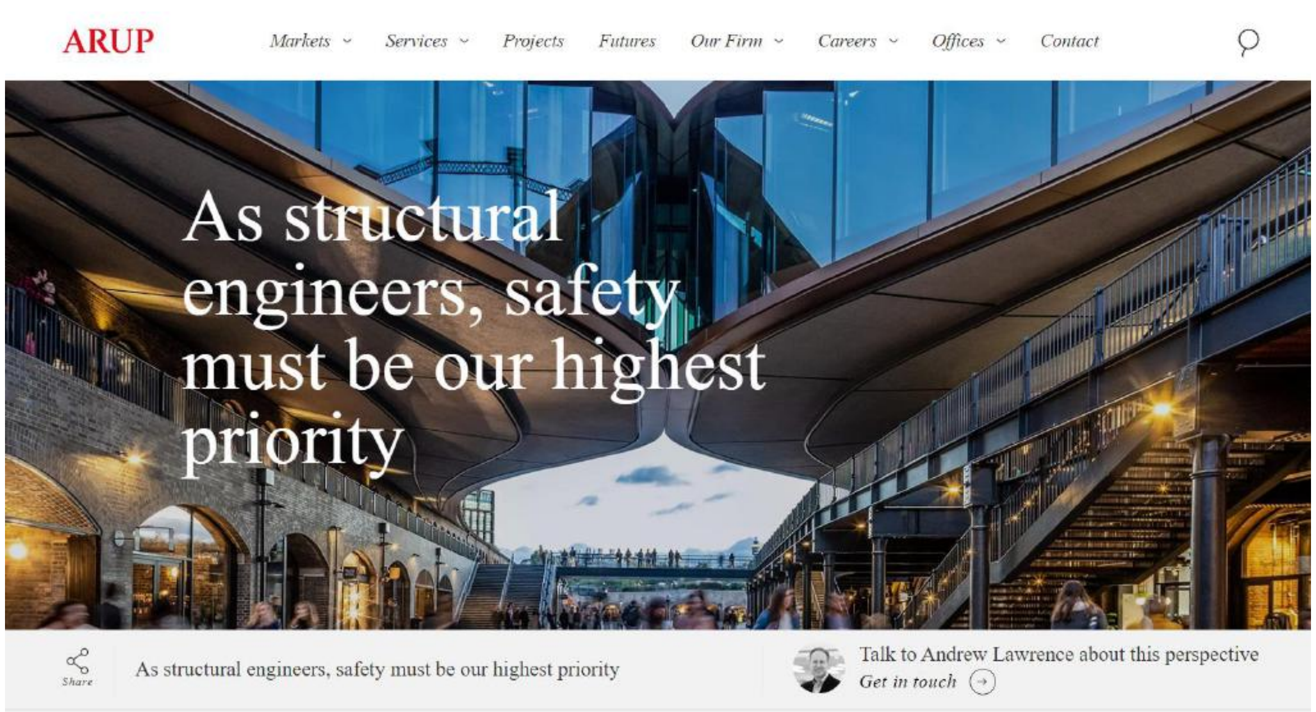
Safety first

Heeding lessons of the past



"Assessing an existing building is a very different skill from following codified rules to design a new building, and not all engineers currently have the experience, which can lead to safety issues being overlooked."

Climate emergency ☰ Structural fire safety

3.Lean design

Structural fire safety when responding to the climate emergency

Luke Bisby urges structural engineers to improve their understanding of 'fire resistance' as the profession looks to innovate rapidly in response to climate change.

As a member of the Standing Committee on Structural Safety (SCOSS) and Confidential Reporting on Structural Safety (CROSS), I was asked to offer some thoughts on possible fire safety pitfalls that might be relevant in the light of the IStructE's important work to address the climate emergency.

Given the enormous impact of structural engineering decisions on carbon emissions[1], it is clear that structural engineers have a moral obligation to urgently take action to address the climate emergency.

New design approaches and new technologies bring with them new hazards; they at least partially invalidate experience as a means of having confidence in our designs; they invariably introduce new and different, potentially unexpected, failure modes. Safety-critical disciplines are therefore wary of change. The history of engineering is littered with failures – some of them disastrous[2] – that have led to learning and to changes to our practice.

Of course, new technologies and approaches themselves inevitably catalyse new learning and understanding; however, we must recognise that our powers of foresight are not complete. The collective experience of our profession has taught us there are some failure modes that we may not anticipate – where we will be forced to learn from our errors and mistakes, rather than our successes. Learning from failures is rarely a 'sustainable' approach.

We must therefore constantly scan the horizon for failure modes that may lurk just out of sight. And we must be ever more vigilant in this during times of rapid innovation. An alternative could be to walk blindly into the future, perhaps because the consequences of not acting are greater than the consequences of continuing on our current path. But surely such an approach must be taken only as a last resort.

At times of rapid innovation, it is crucial that members of the structural engineering community constantly reflect on safety, and thus on the structural fire safety assumptions and simplifications that are inherent in their designs. The increasing use of mass timber as primary structure for high-rise buildings has recently received considerable attention in this regard[3], but more conventional building materials such as reinforced concrete[4] and structural steel[5], particularly when applied in novel ways, including lean, modular and offsite construction, each present their own, admittedly very different, challenges in this context.

'Fire resistance' design – the conventional framework

For the vast majority of structures, adequate structural fire safety – adequate for the protection of life, that is – is *presumed* to be provided by ensuring that the individual structural elements (or partitions) from which a structure is constructed have appropriate 'fire resistance' ratings[6].

My own experience suggests that many structural engineers, both in the UK and elsewhere, have only a cursory understanding of the fundamental basis of 'fire resistance' design, or of the fire safety design framework that they themselves are routinely applying in projects.

For instance, it is my experience that few structural engineers understand what 'fire resistance' is, how (or *why*) 'fire resistance' tests are performed, or the extent to which such testing and assessment captures (or indeed fails to capture) either the thermal environments or the mechanical boundary conditions, loading or deformations of a structural element or a system of elements during a real building fire.

Many structural engineers (and other building designers) fail to understand that the prescribed periods of 'fire resistance' given, for instance, within Table B4 of Approved Document B in England and Wales[7] do not represent actual periods of time in a real fire.

These issues are worth careful consideration by structural engineers seeking to optimise building designs or introduce material or other innovations. For example, how can a multi-parameter optimisation of a structural design be confidently undertaken without deeply considering the consequences for structural fire safety?

'Fire resistance' design – uncertainty and conservatism

The evidence that the existing 'fire resistance' design framework is providing an adequate *level of safety* in buildings is largely historical. Notwithstanding the reality that fires that are sufficiently severe to seriously challenge loadbearing structures are comparatively unlikely, we only rarely observe significant structural failures in real fires. Applying the *argument from ignorance* could lead to a conclusion that this absence of evidence confirms that our coarse, conservative and unrealistic 'fire resistance' design framework – despite its many documented shortcomings[8] – is indeed delivering societally tolerable fire safety outcomes.

My own view is that, by and large, structural engineers don't actually *know* what level of safety is being provided by the existing 'fire resistance' design framework. We struggle to rigorously quantify the error bars that are inherent in most of our structural fire design decisions; or even to

"IT IS CRUCIAL THAT STRUCTURAL ENGINEERS CONSTANTLY REFLECT ON THE STRUCTURAL FIRE SAFETY ASSUMPTIONS AND SIMPLIFICATIONS THAT ARE INHERENT IN THEIR DESIGNS

Safety ☰ Climate emergency

HAVE YOUR SAY
tse@istructe.org
@IStructE
#TheStructuralEngineer

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What are we trying to achieve?

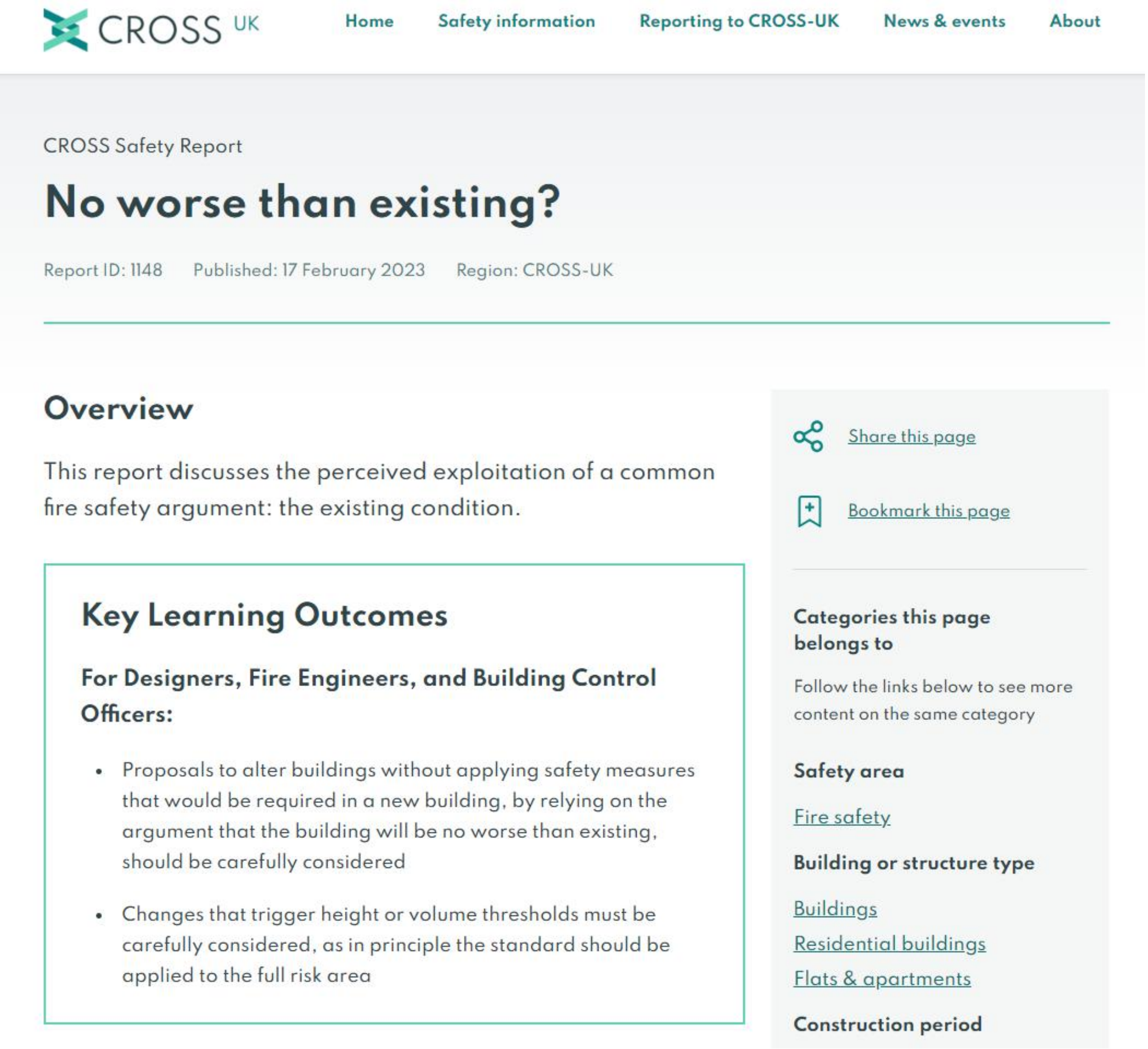
Regulatory requirements and applicable standards

legislation.gov.uk

Building work shall be carried out so that, after it has been completed—

[…] any building which is extended or to which a material alteration is made

*[…] **complies with the applicable requirements of Schedule 1** or, where it did not comply with any such requirement, **is no more unsatisfactory in relation to that requirement than before the work** was carried out.*



CROSS UK

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CROSS Safety Report

No worse than existing?

Report ID: 1148 Published: 17 February 2023 Region: CROSS-UK

Overview

This report discusses the perceived exploitation of a common fire safety argument: the existing condition.

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Key Learning Outcomes

For Designers, Fire Engineers, and Building Control Officers:

- Proposals to alter buildings without applying safety measures that would be required in a new building, by relying on the argument that the building will be no worse than existing, should be carefully considered
- Changes that trigger height or volume thresholds must be carefully considered, as in principle the standard should be applied to the full risk area

Categories this page belongs to

Follow the links below to see more content on the same category

Safety area

Fire safety

Building or structure type

Buildings

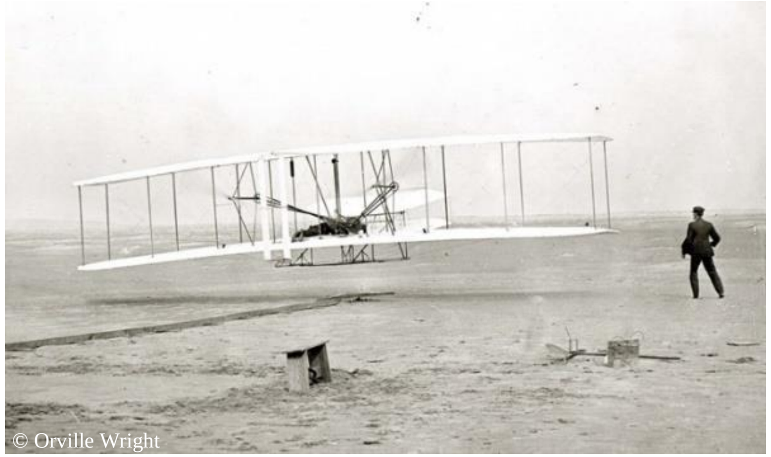
Residential buildings

Flats & apartments

Construction period

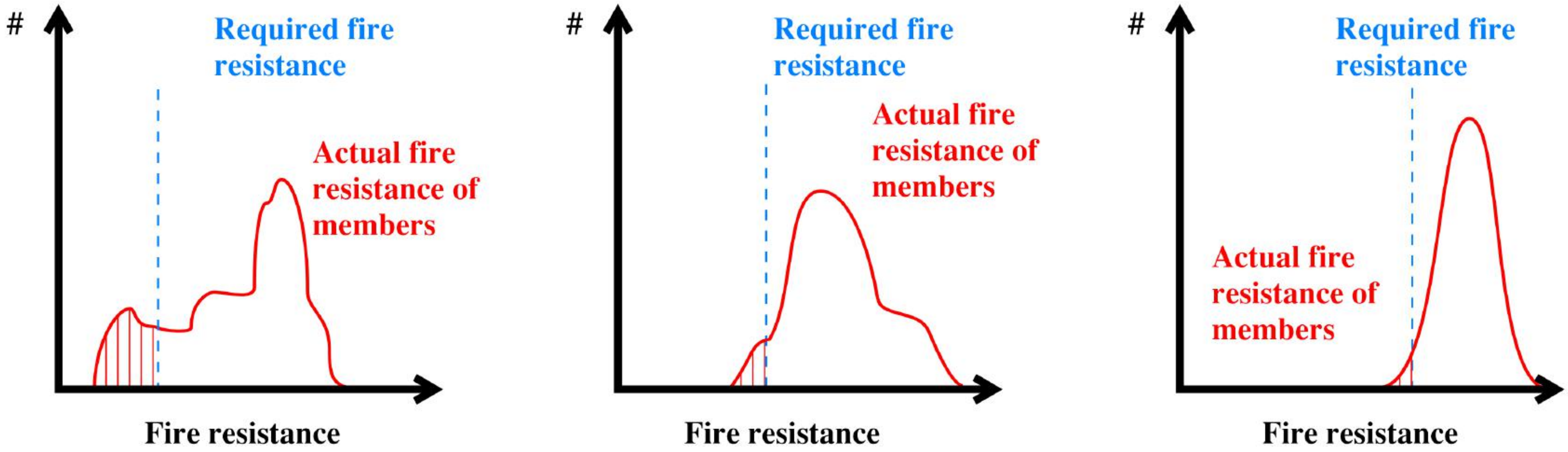
Evolving expectations

Fire safety in existing buildings



Evolving expectations

Structural fire performance



1900s → *Today*

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Range of guidance

SCI
Steel Knowledge

ASFP
www.asfp.org.uk


BRITISH STANDARD

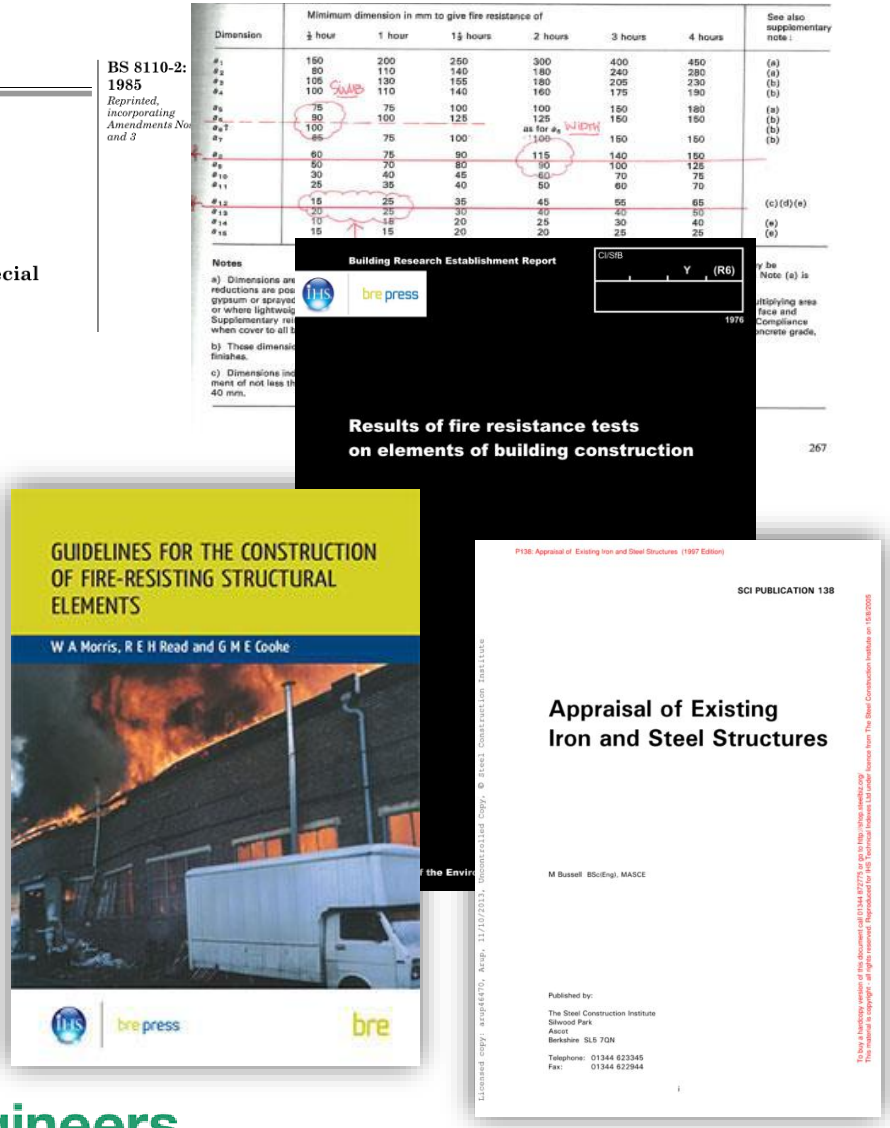
BS 8110-2: 1985

Reprinted, incorporating Amendments Nos 1, 2 and 3

Structural use of concrete —

Part 2: Code of practice for special circumstances

CP110:1972



THE INSTITUTION OF FIRE ENGINEERS
FOUNDED 1918 • INCORPORATED 1924

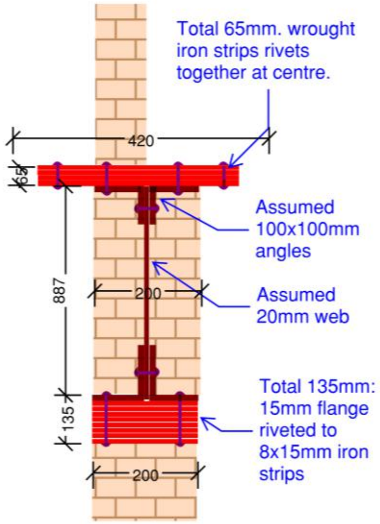
CROSS
COLLABORATIVE REPORTING FOR SAFER STRUCTURES

The Institution of StructuralEngineers

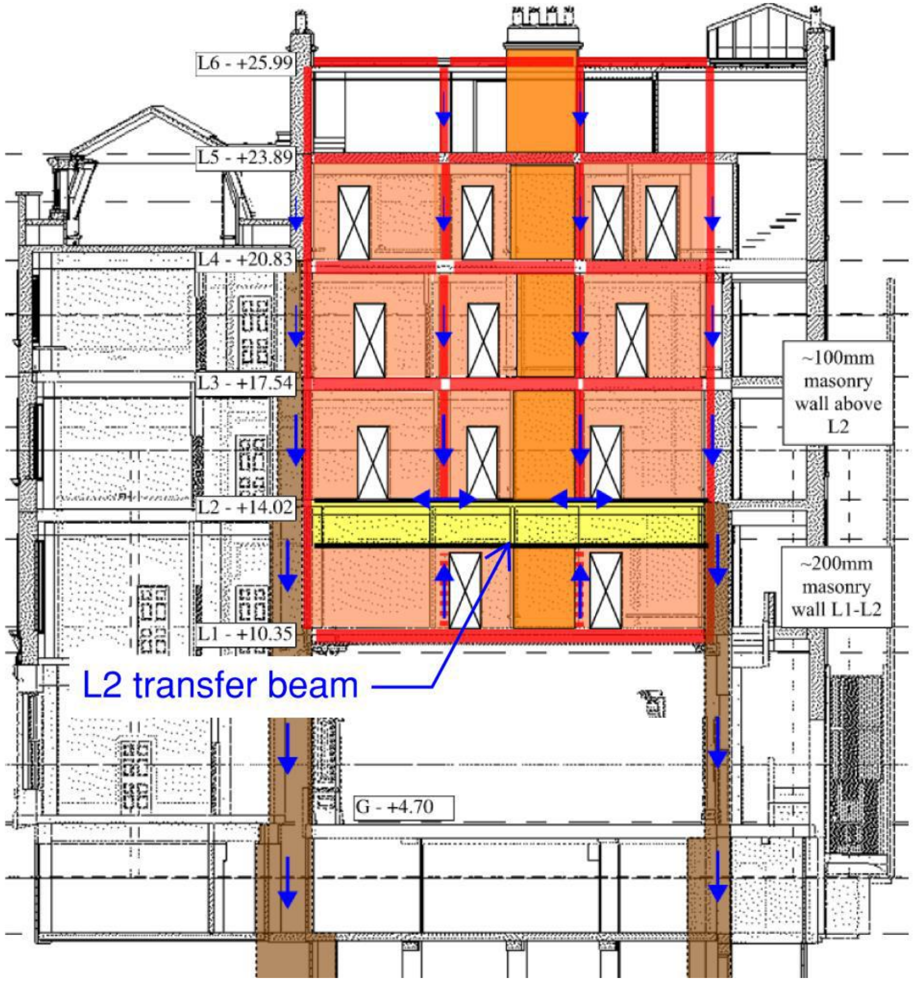
Ignorance is not bliss

Justifying "chronic unease"

- Often little to no useful information
- Accuracy / completeness questionable
- Even until very recently
- Observations from Safety Cases



Level 2 Transfer Beam (midspan)



Scope, judgement

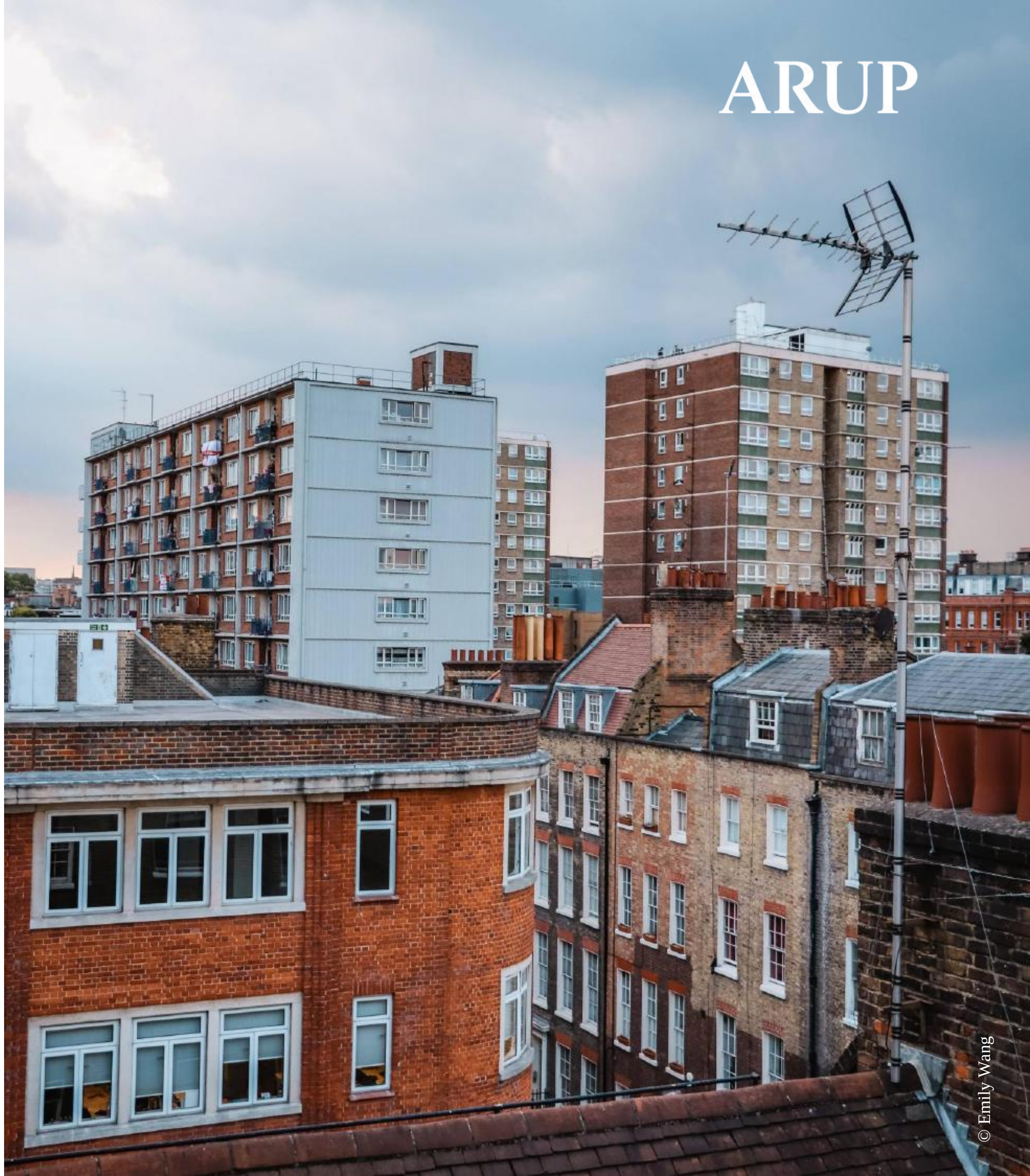
Reality, risk, liability

What is the problem?

Reusing existing buildings safely

- Objectives not clear
- Limited / disparate guidance and data
- Uncertainties carry risk
- Avoid making mistakes of the past…
- **Tension:** caution (risk) vs urgency (carbon)
- New skills and awareness needed
- Change in mindset too – persistence of the "non-worsening" approach
- Space for judgement
- Scope & liabilities

Opportunities??



A few examples

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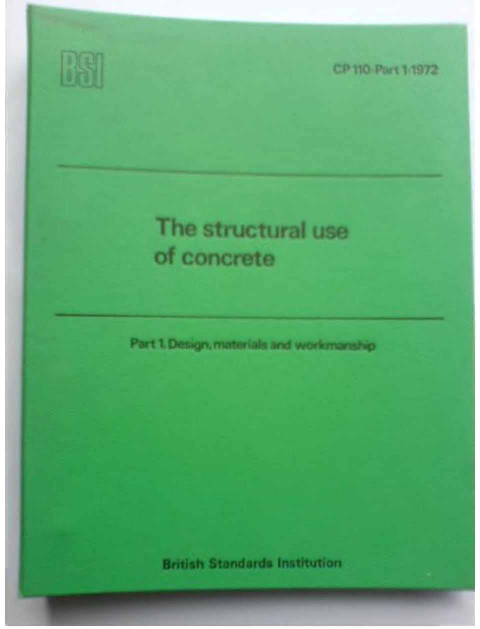
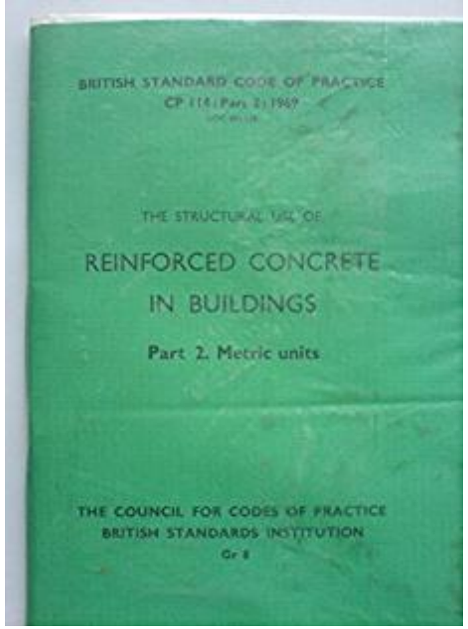
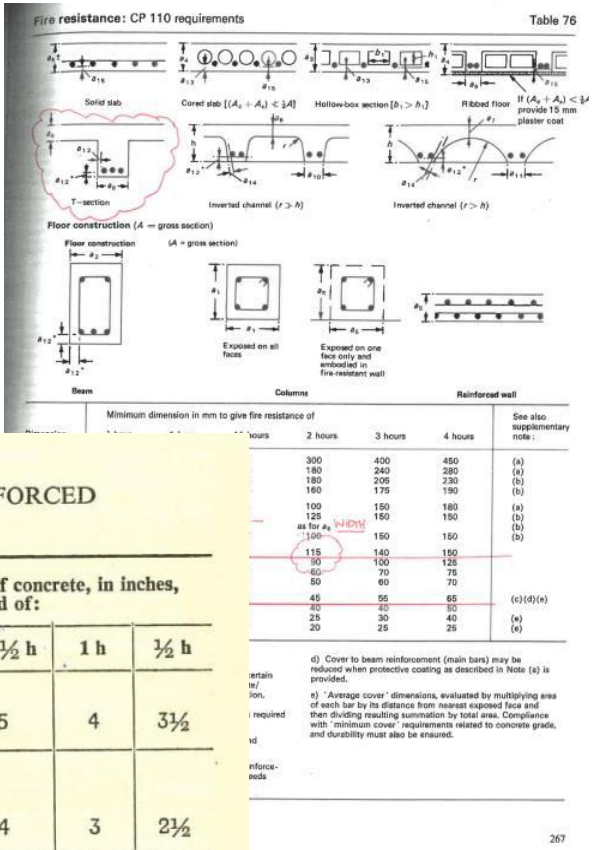
Existing structures in fire

Less cover used to be permitted in concrete (e.g. slabs)







A3. Floors of unprotected reinforced concrete.

TABLE 27. FIRE RESISTANCE OF REINFORCED CONCRETE FLOORS

Construction and materials	Minimum total thickness of concrete, in inches, for a period of:					
	4 h	3 h	2 h	1½ h	1 h	½ h
Solid slab construction and floors of precast channel or T-section	6	6	5	5	4	3½
Precast or in-situ inverted U-sections where the minimum thickness occurs only at the crowns	6	6	4	4	3	2½
Hollow-block construction and precast units of box or I-section	5	4	3½	3½	3	2½

NOTE 1. For all types of floor, the concrete cover to the main reinforcement should not be less than 1 in for the 4-hour grading nor less than ½ in for the lower gradings.
NOTE 2. The total thickness may include that of the screed and/or tile, where used.

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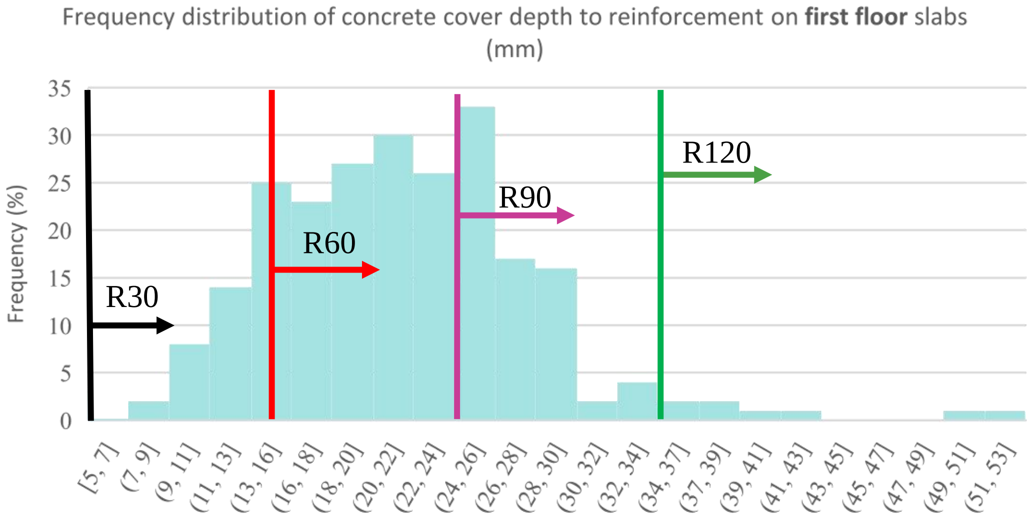
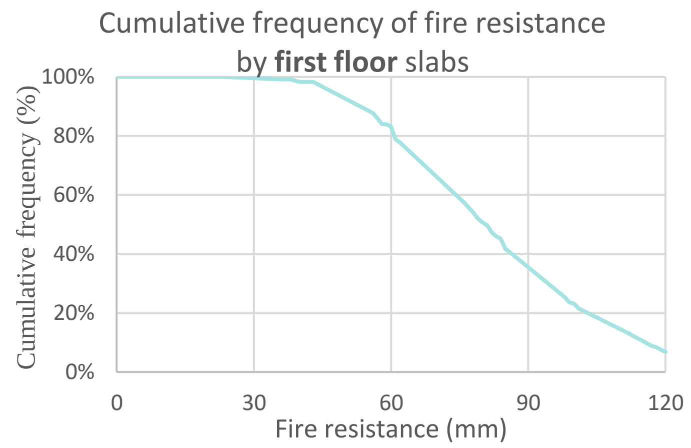
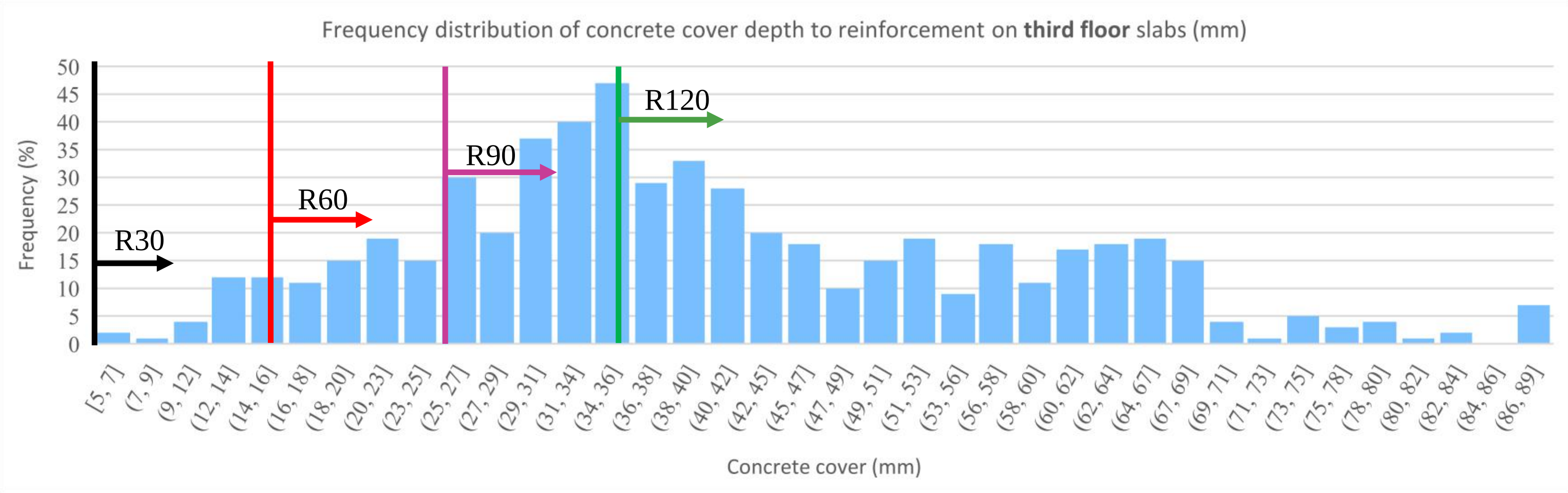
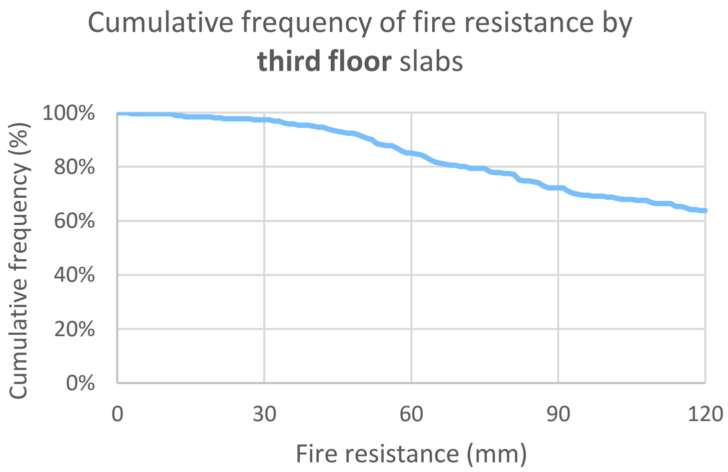
Existing structures in fire

Quality control and variability









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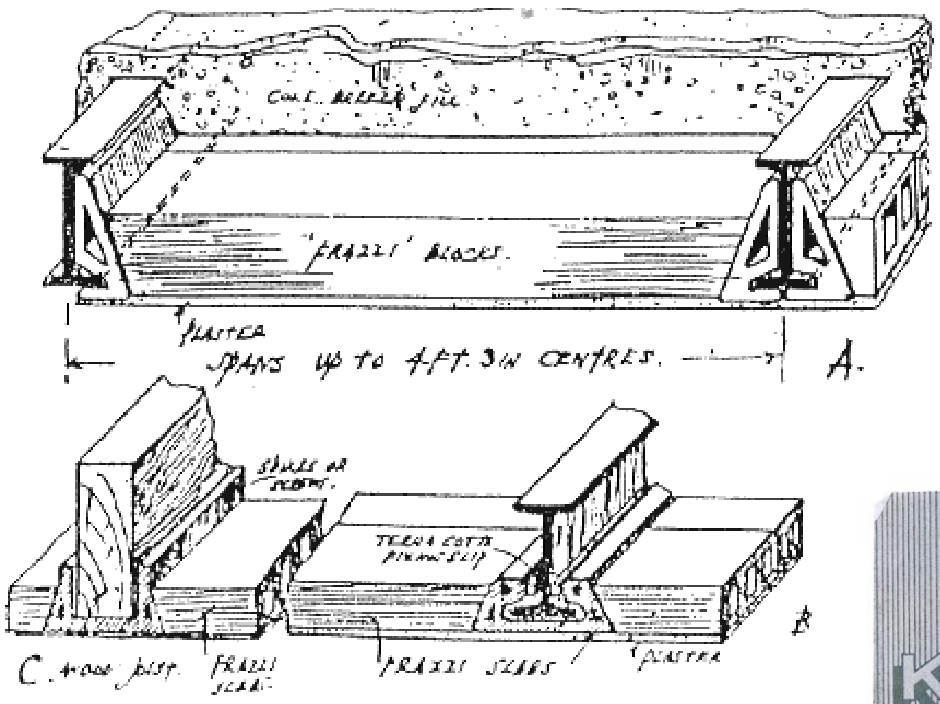
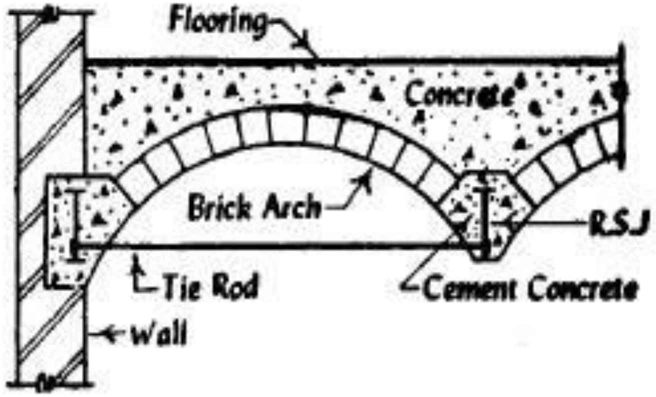
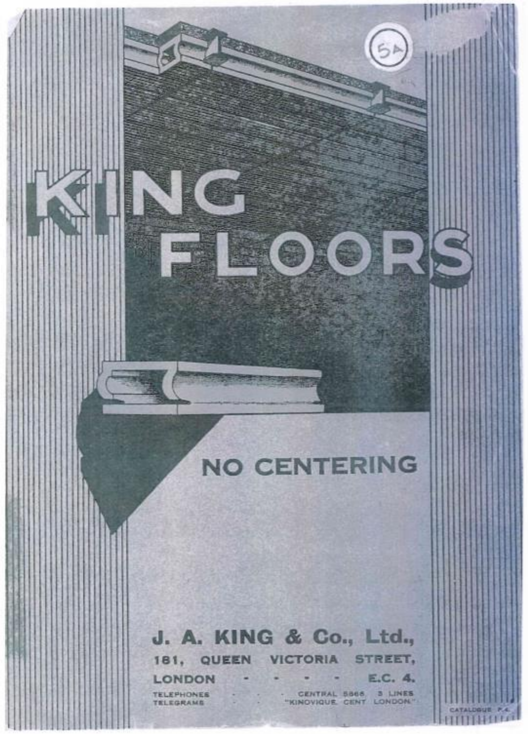
Existing structures in fire

Historic floor systems - good, bad & the ugly



Frazzi flat terracotta lintel system





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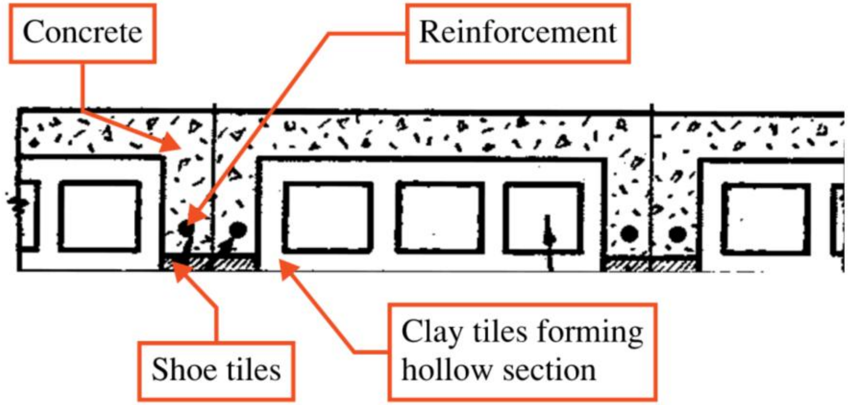
Existing structures in fire

Historic floor systems - good, bad & the ugly



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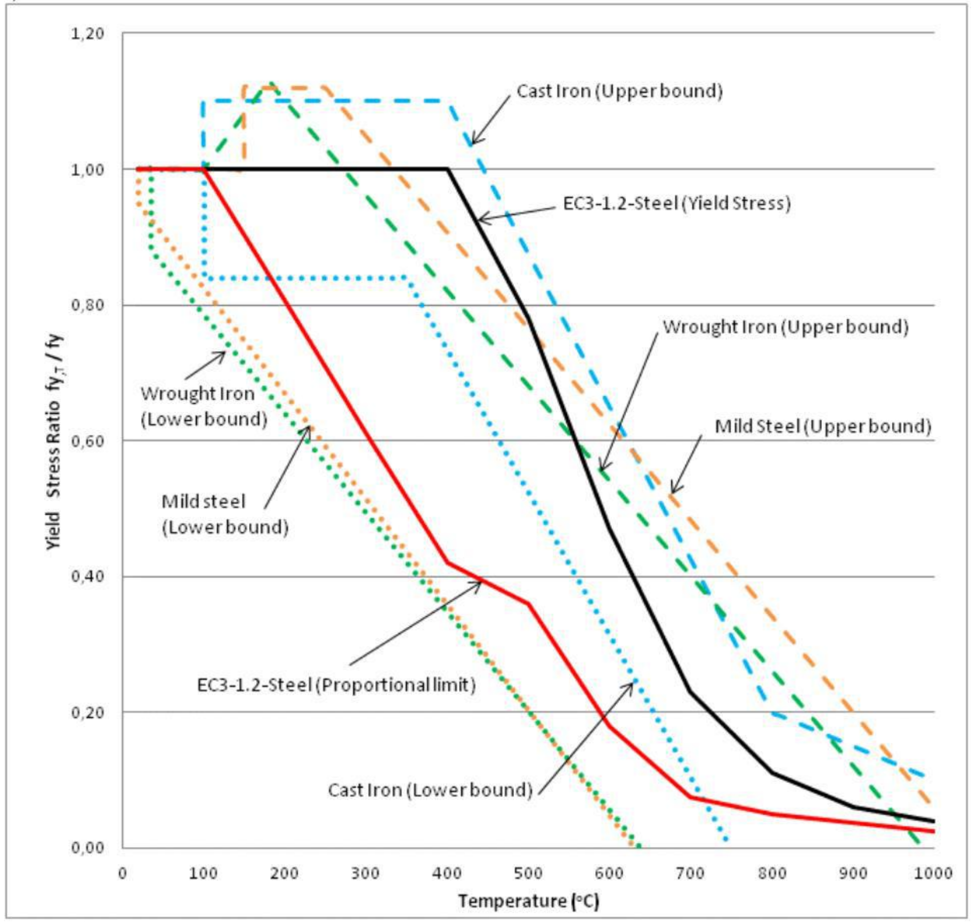
Unprotected iron and steel

© School of Architecture at McGill University

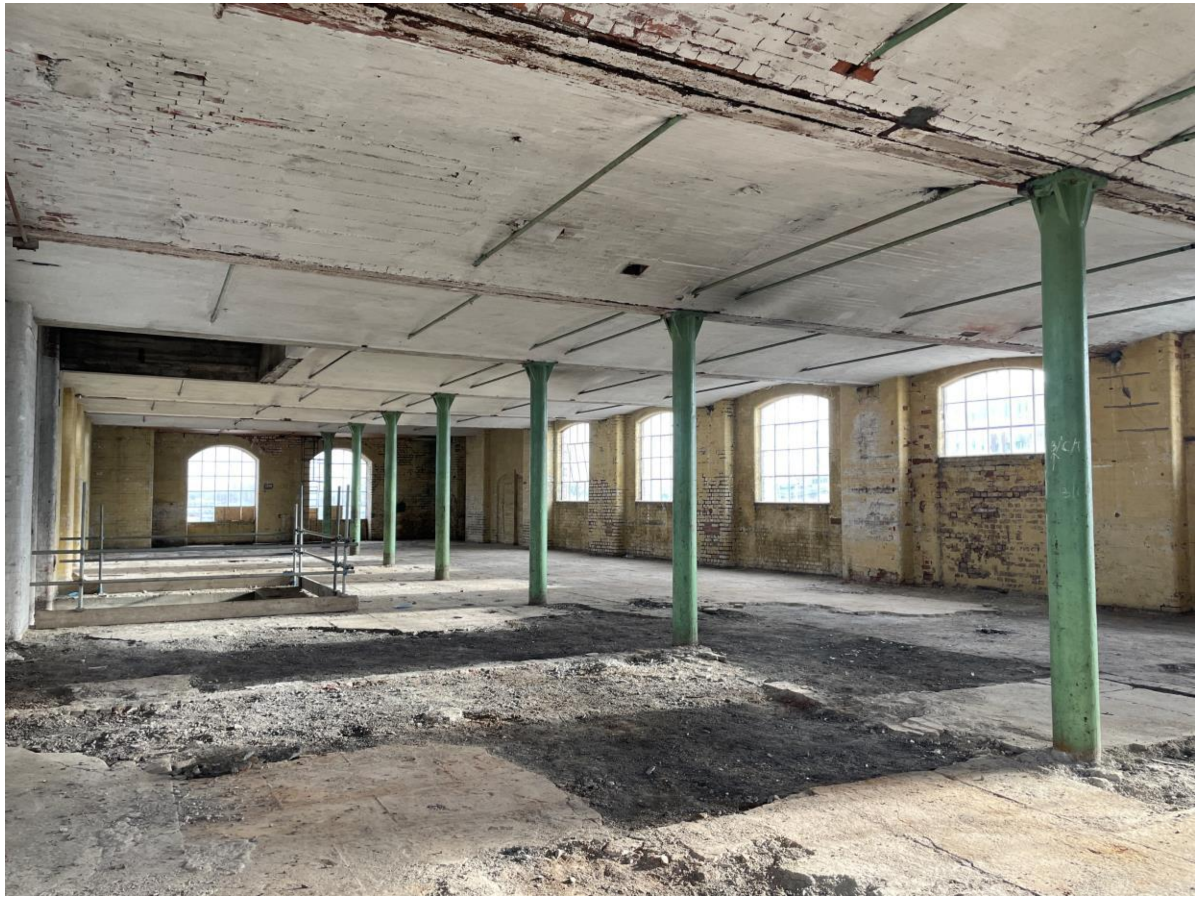
Steel Knowledge

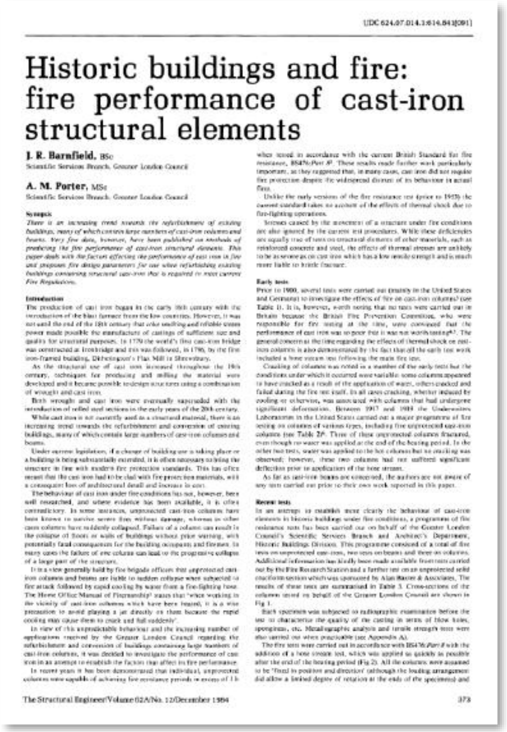


Maraveas (2015)

Existing structures in fire

Unprotected iron and steel





UDC 624.07.014.1:614.841[091]

Historic buildings and fire: fire performance of cast-iron structural elements

J. R. Barnfield, BSc
Scientific Services Branch, Greater London Council

A. M. Porter, MSc
Scientific Services Branch, Greater London Council

The Structural Engineer/Volume 62A/No. 12/December 1984 373

SCI
Steel Knowledge

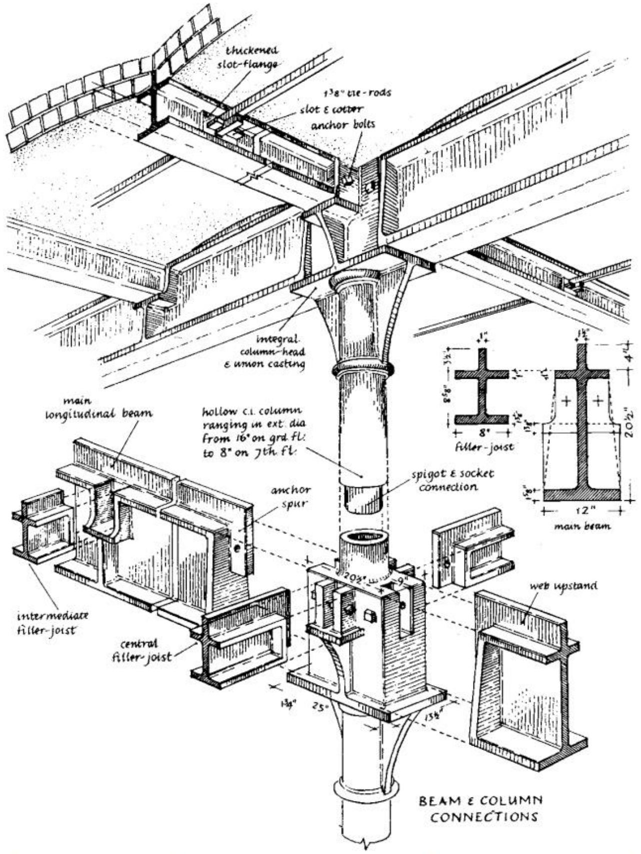


Figure 3.6 *Typical early 19th century cast iron frames (reproduced from M*

Existing structures in fire

Large Panel System “LPS” precast concrete

Image source: BBC

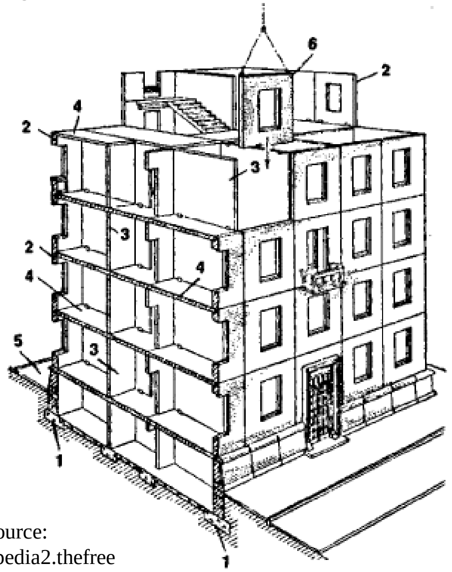
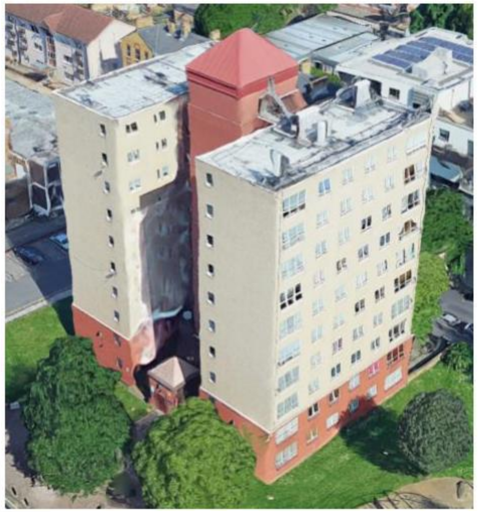
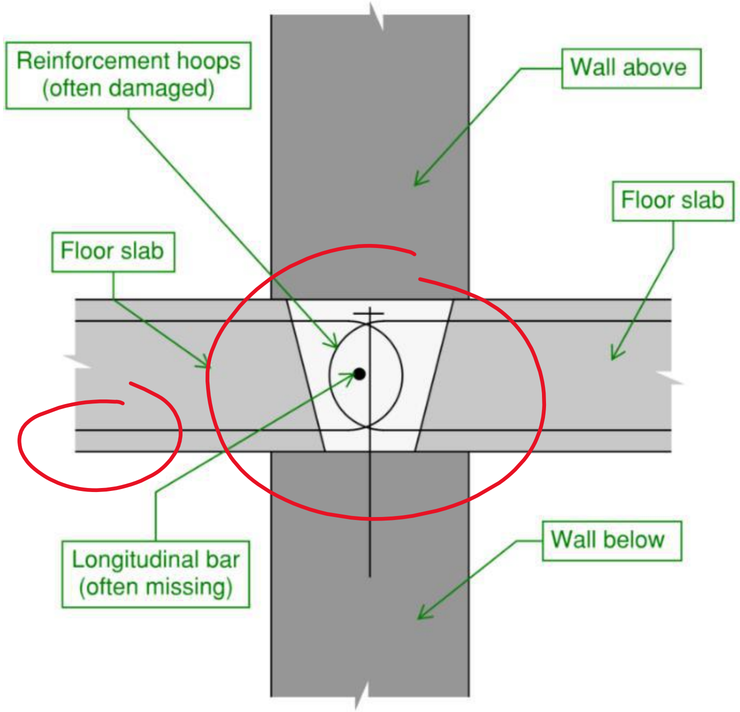


Image source: encyclopedia2.thefreedictionary.com

Image source: buildingfailures.wordpress.com



© OneHousing



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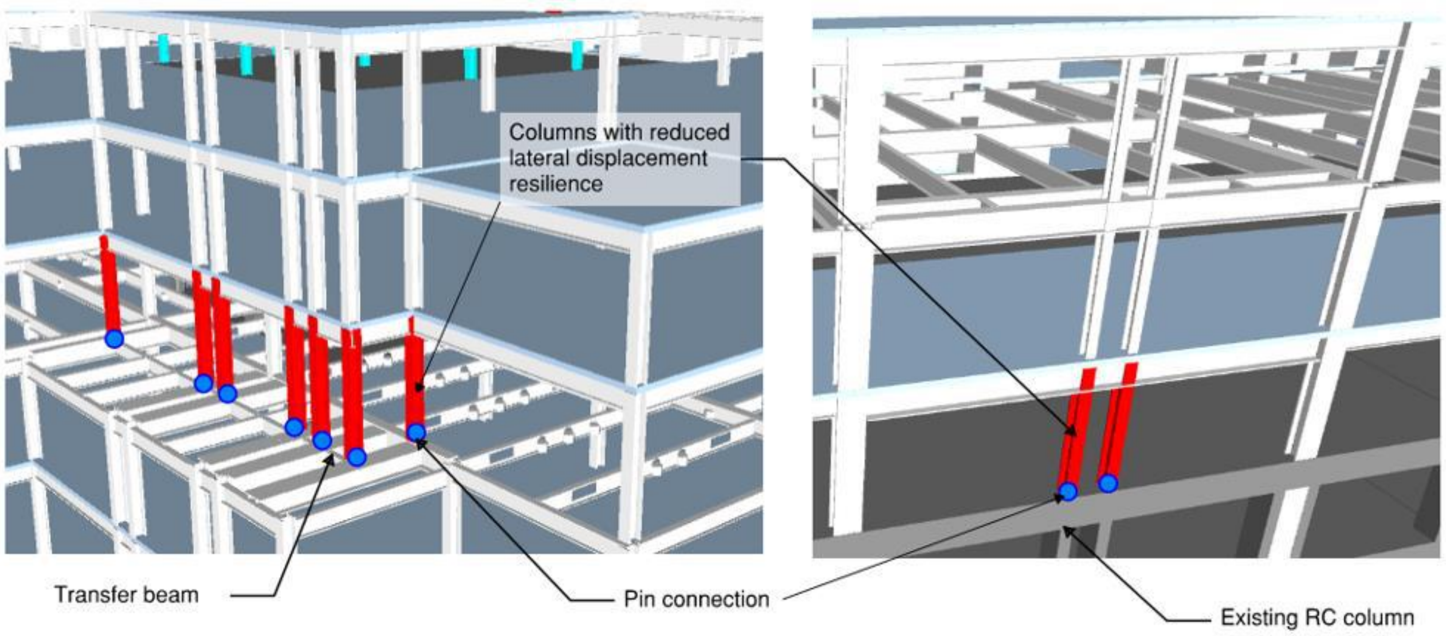
Existing structures in fire

Extensions



© KPF

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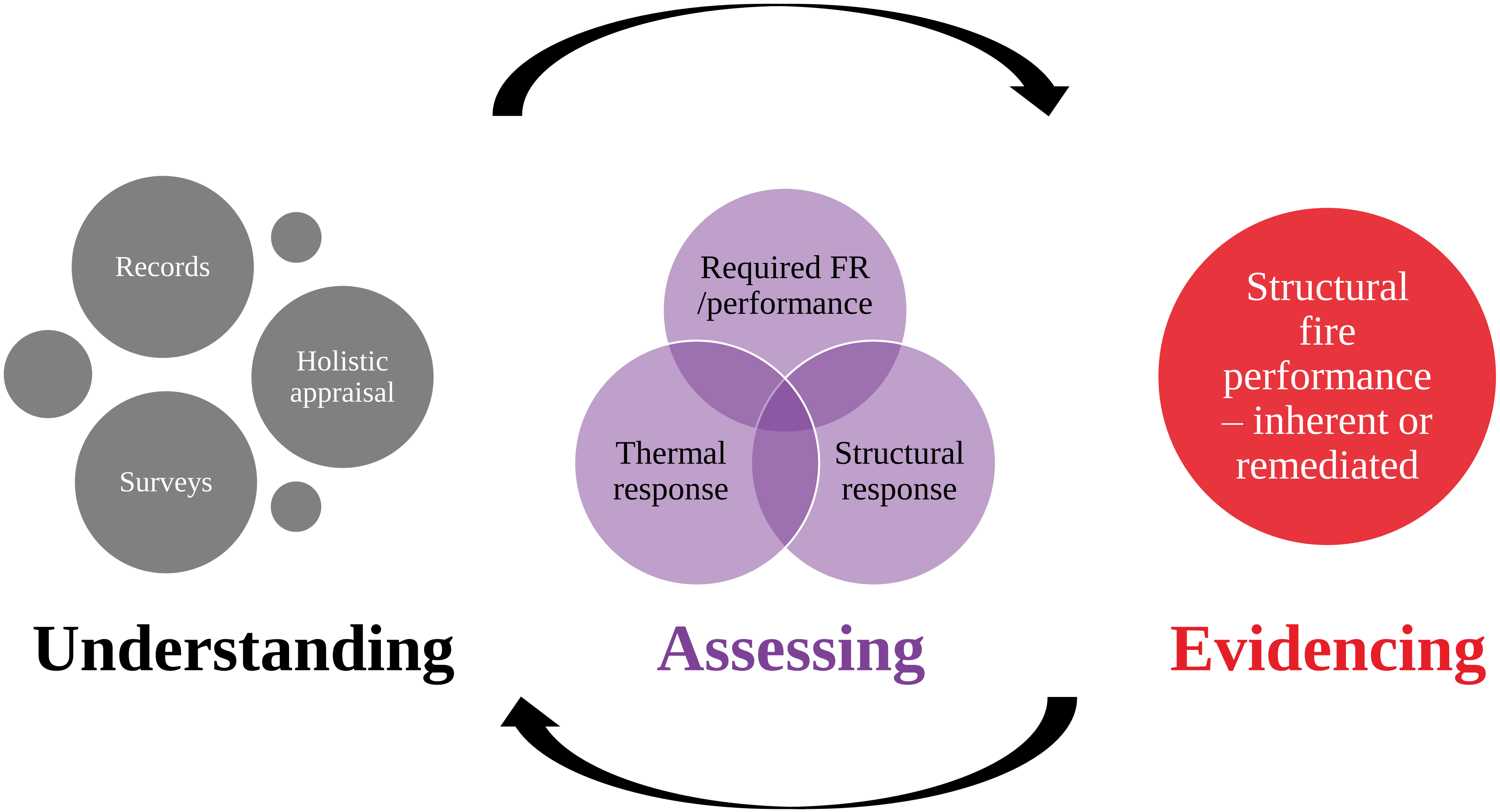
Existing structures in fire

Protection & remediation

Response

Mapping the approach

What do we do? In what order?



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What do we do? In what order?

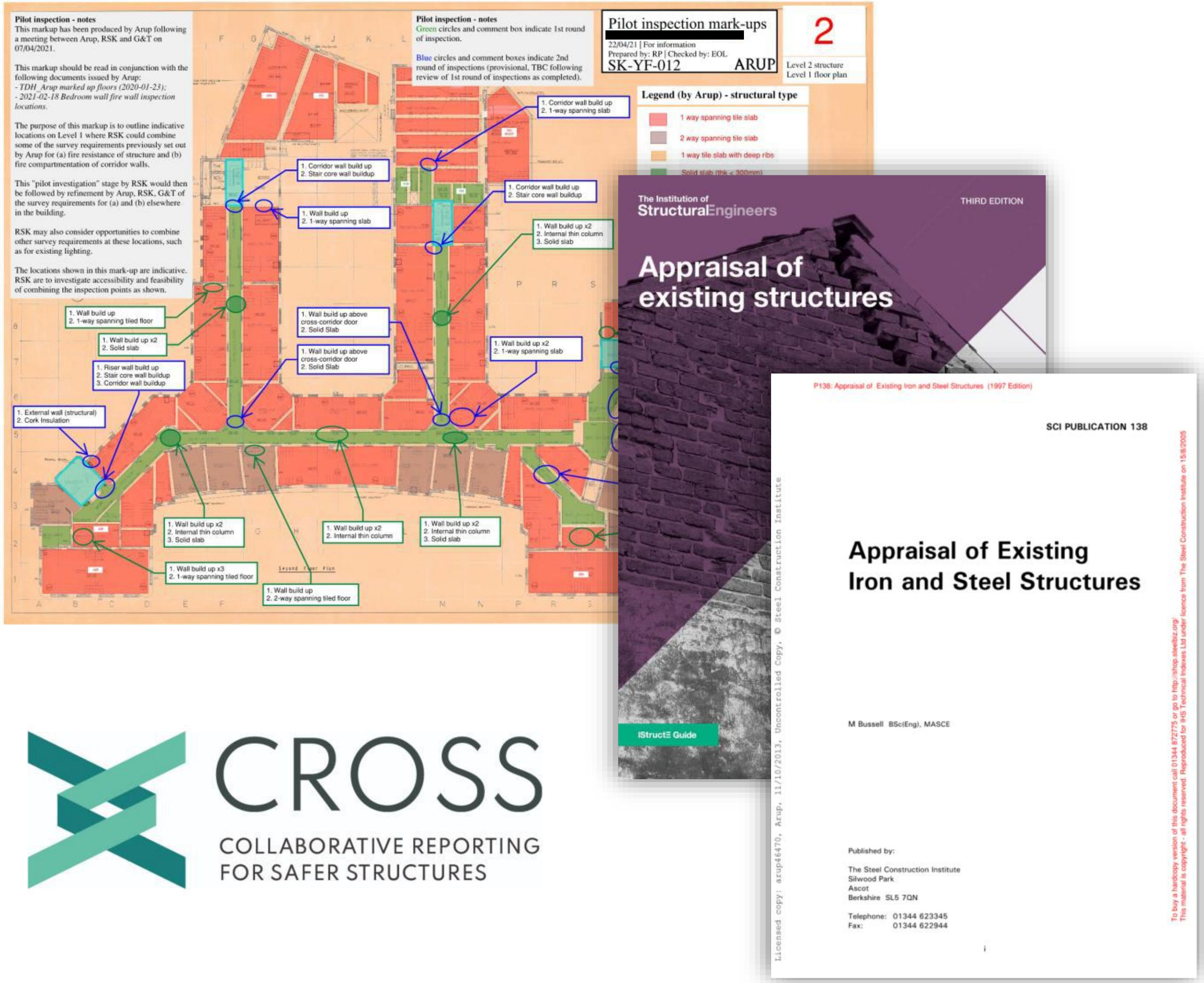
Addressing known unknowns, and unknown unknowns

Incrementally increase understanding

- Record drawings, reports, calculations
- Visual surveys (experienced eye)
- Intrusive/scanned survey data

Incrementally increase appraisal complexity

- Literature (+ awareness of typical deficiencies or weaknesses)
- Checks: original + current codes
- More advanced analysis (fire, heat transfer, thermo-mechanical)
- Bespoke testing



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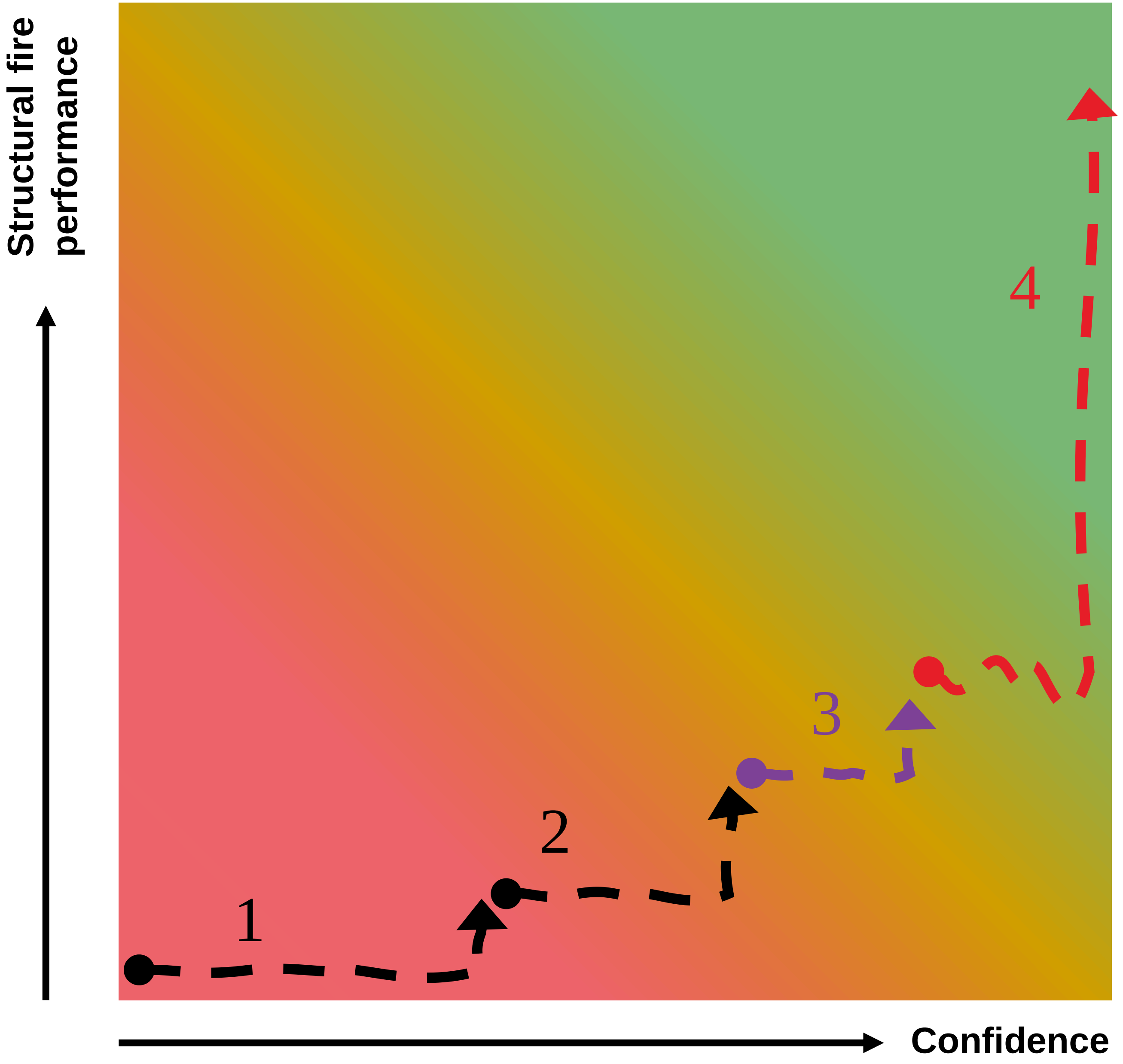
COLLABORATIVE REPORTING FOR SAFER STRUCTURES

A framework

Routemap towards confidently demonstrating adequate structural performance in fire

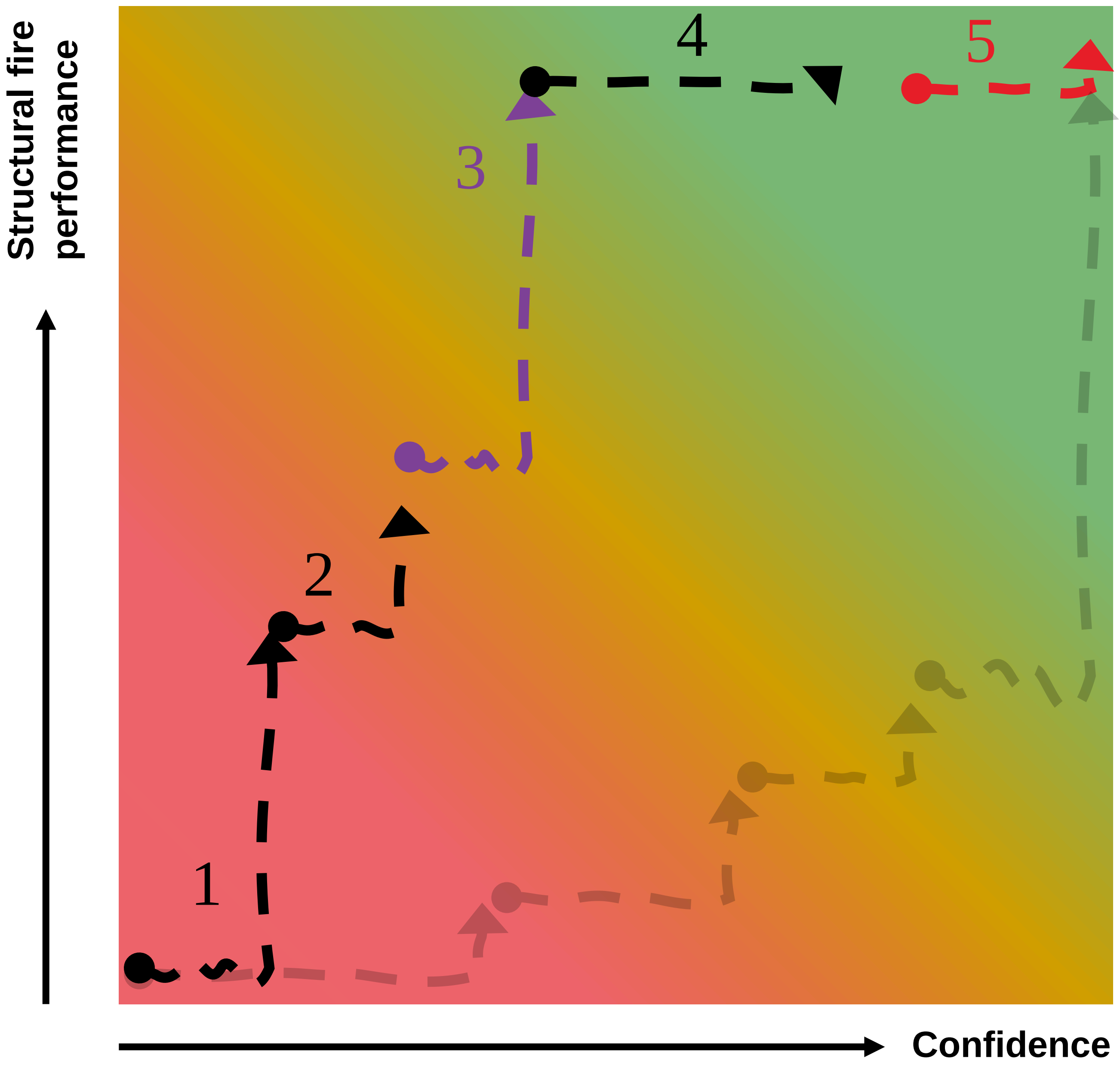
1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Evidencing – full remediation



A framework

Routemap towards confidently demonstrating adequate structural performance in fire

1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Understanding – full building survey
5. Evidencing – assessment shows adequate fire resistance



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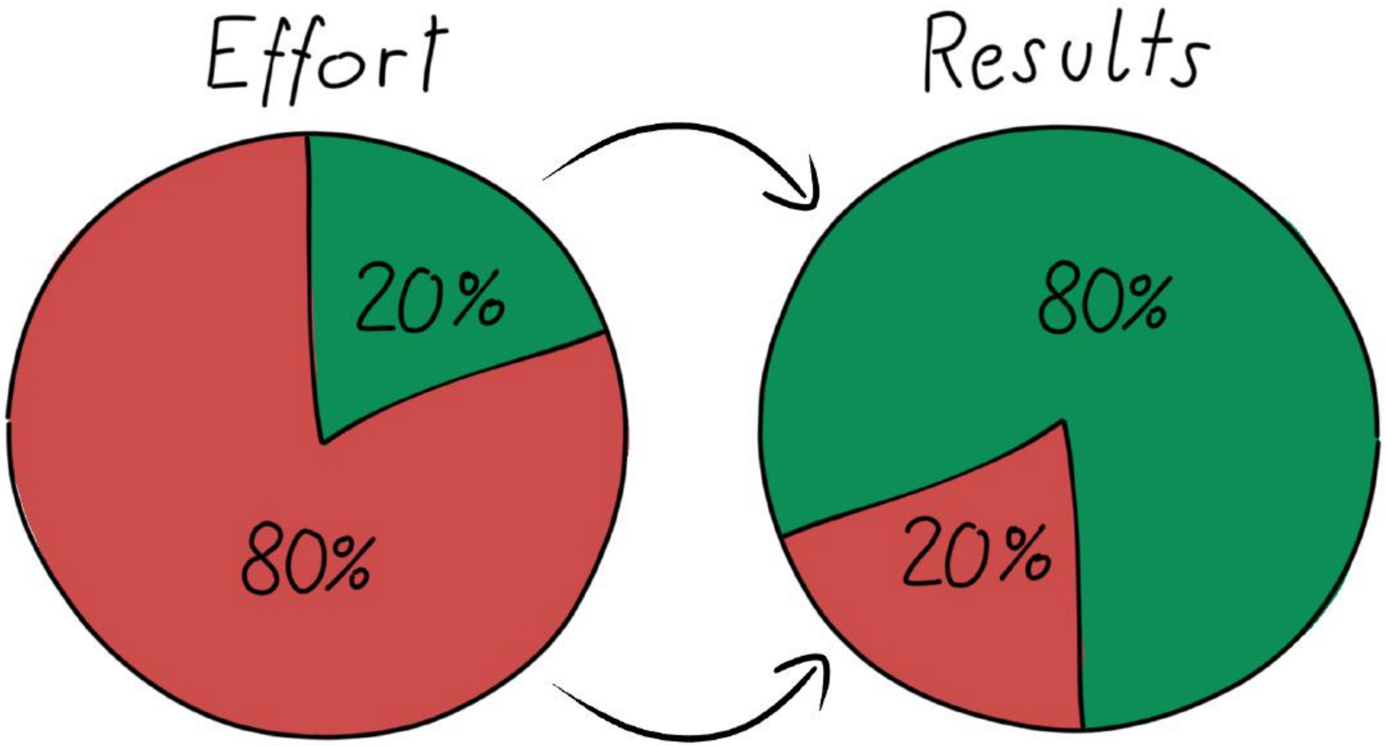
Proportionality

Dealing with ‘tensions’

- What are the consequences?
- Multi-dis input – fire, structures, SFE
- Who are the decision makers?
- What is needed to inform their decisions?



A framework

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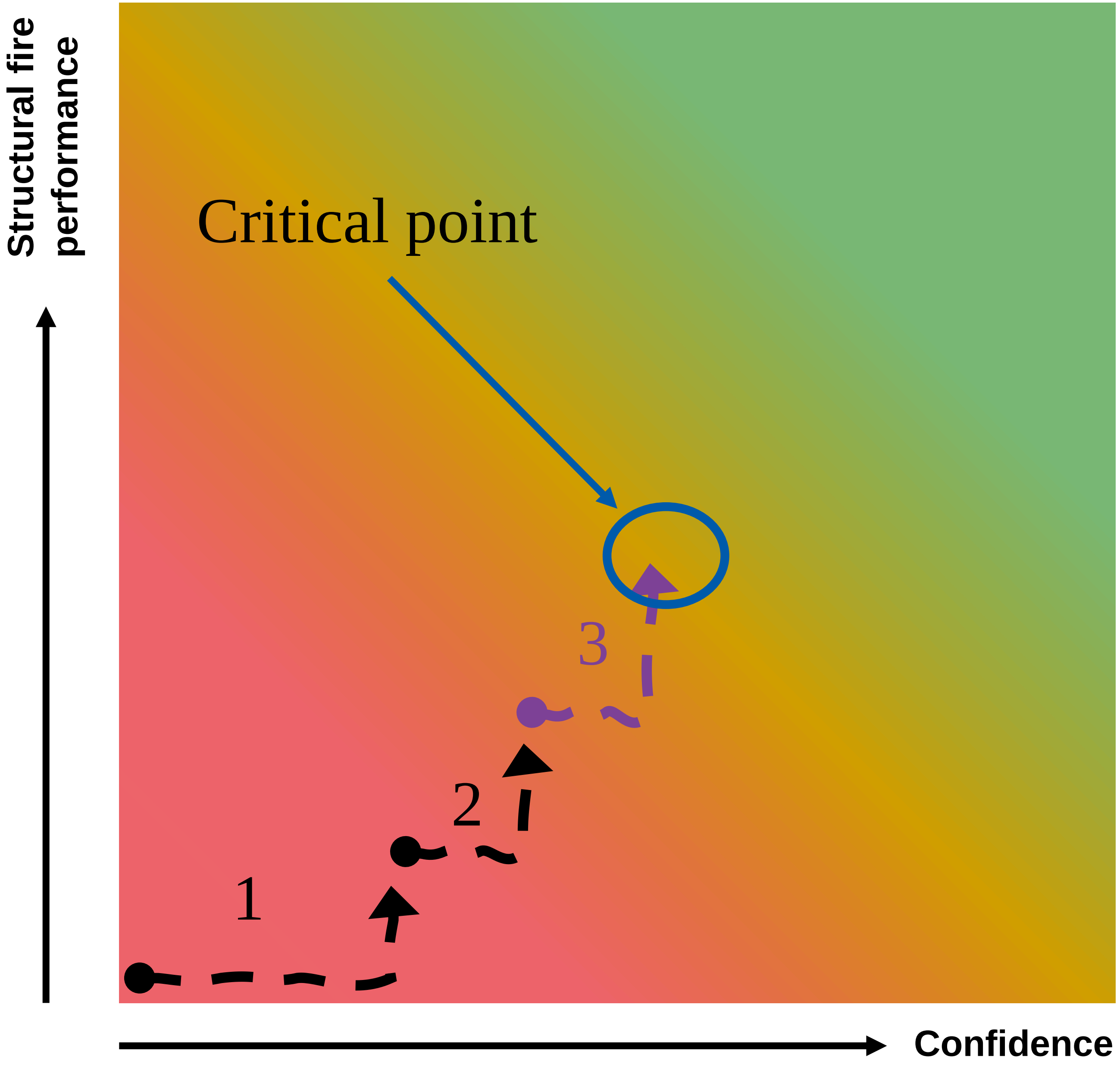

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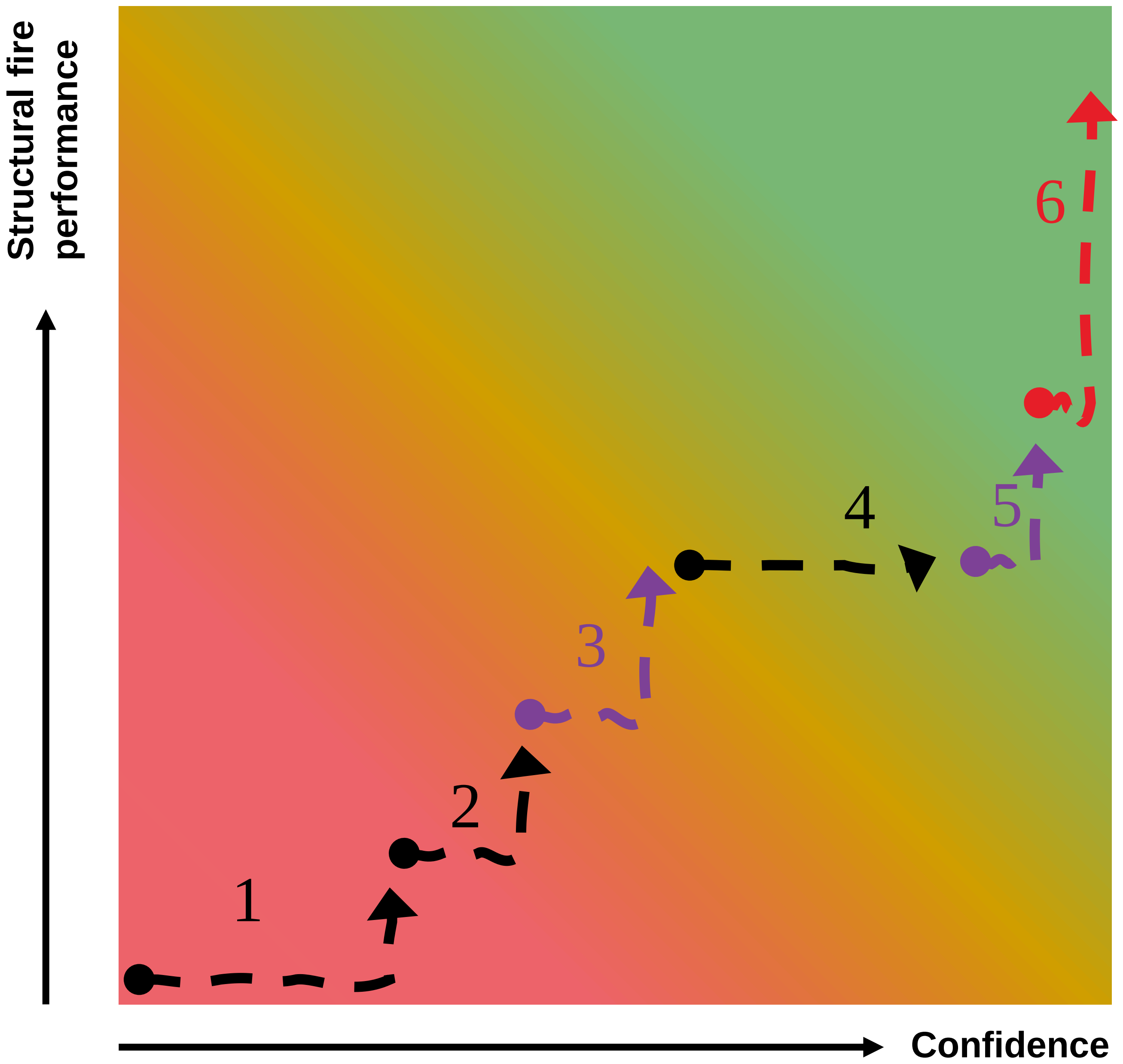
A framework

Routemap towards confidently demonstrating adequate structural performance in fire

1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Understanding – full building survey
5. Assessing – assessment of survey data
6. Evidencing – full remediation



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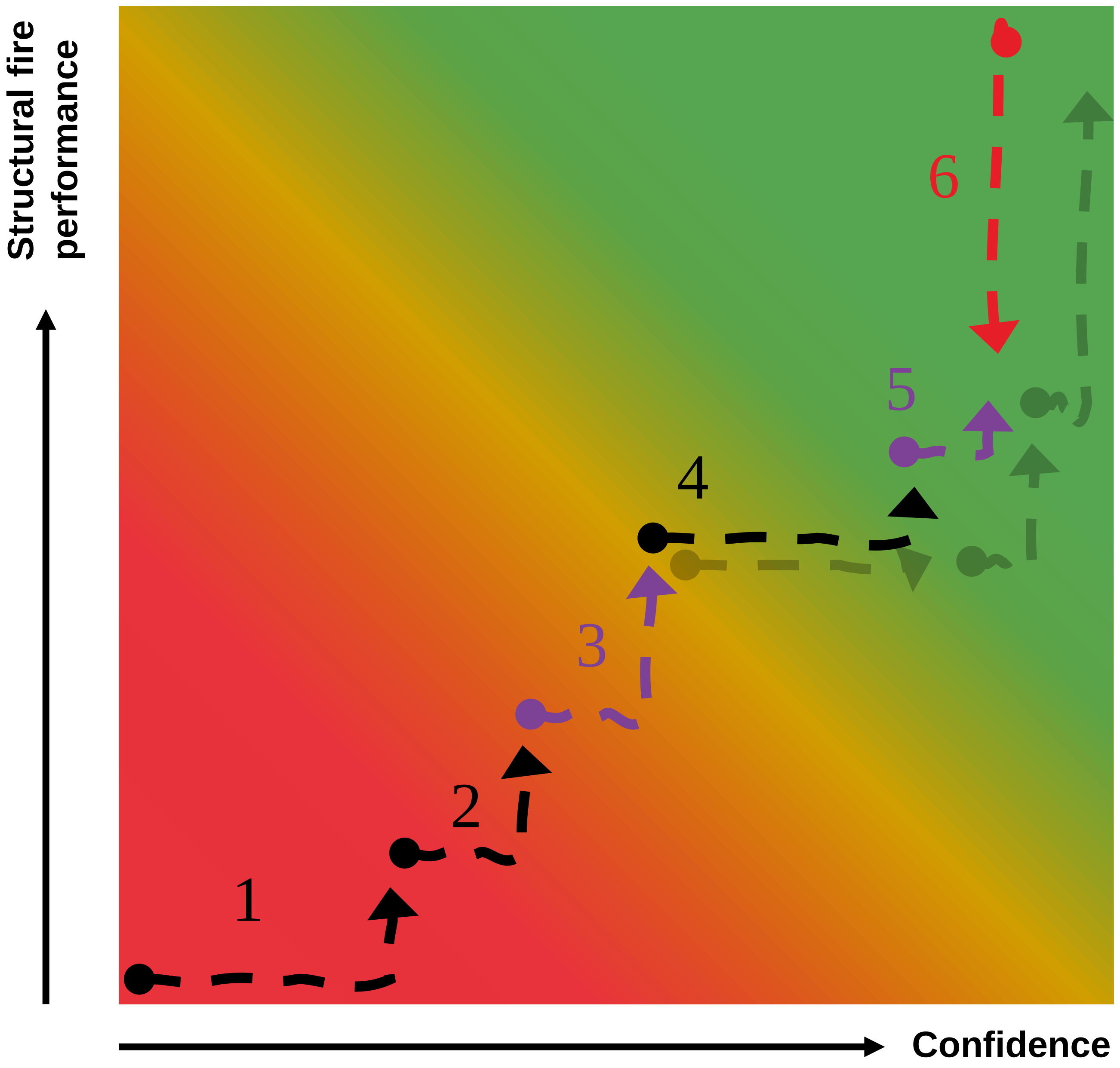
A framework

Routemap towards confidently demonstrating adequate structural performance in fire

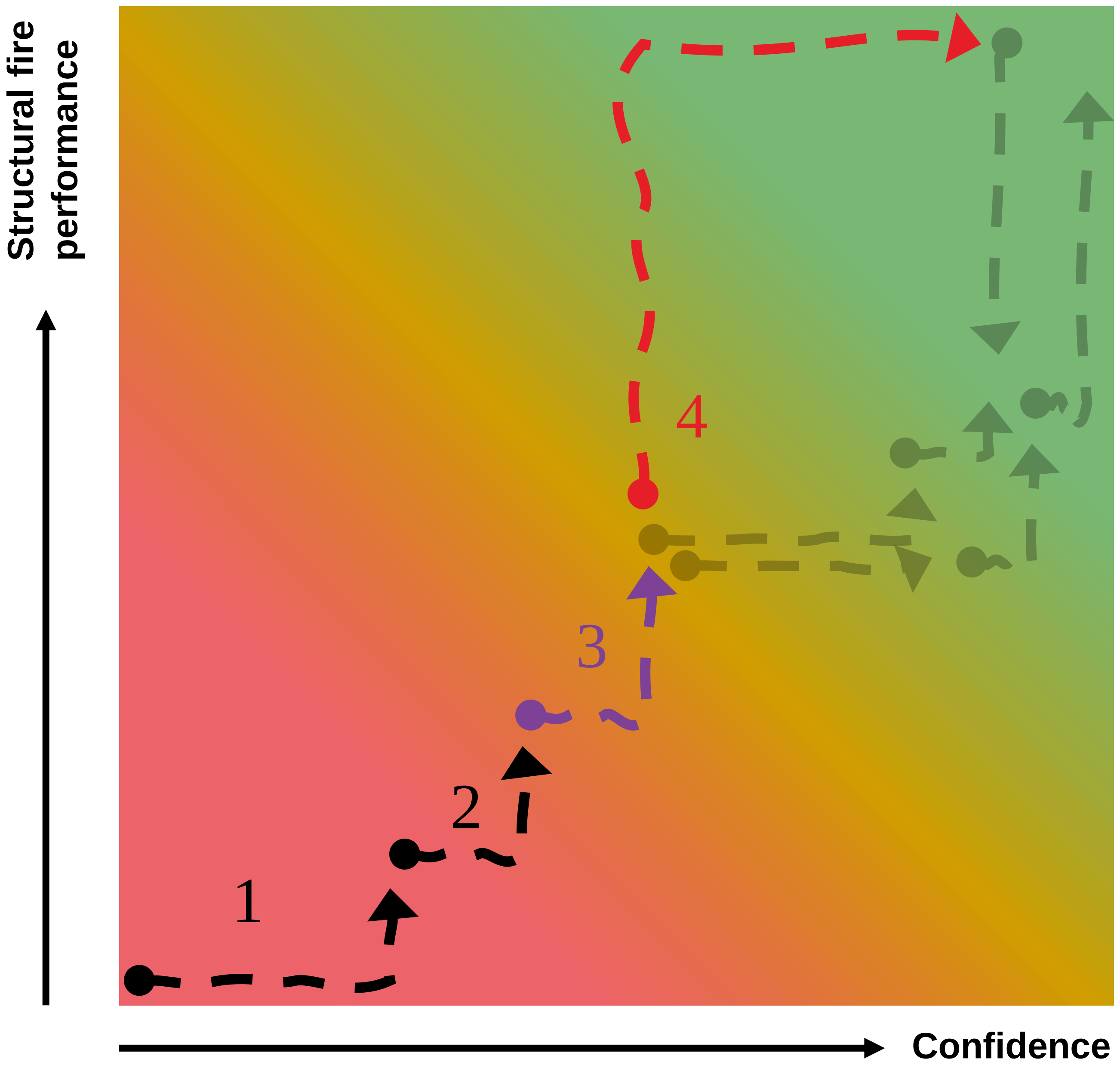
1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Understanding – full building survey
5. Assessing – assessment of survey data
6. Evidencing – adjustment to fire strategy lowering the required fire resistance



A framework

Routemap towards confidently demonstrating adequate structural performance in fire

1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Evidencing – performance based fire & structural analysis



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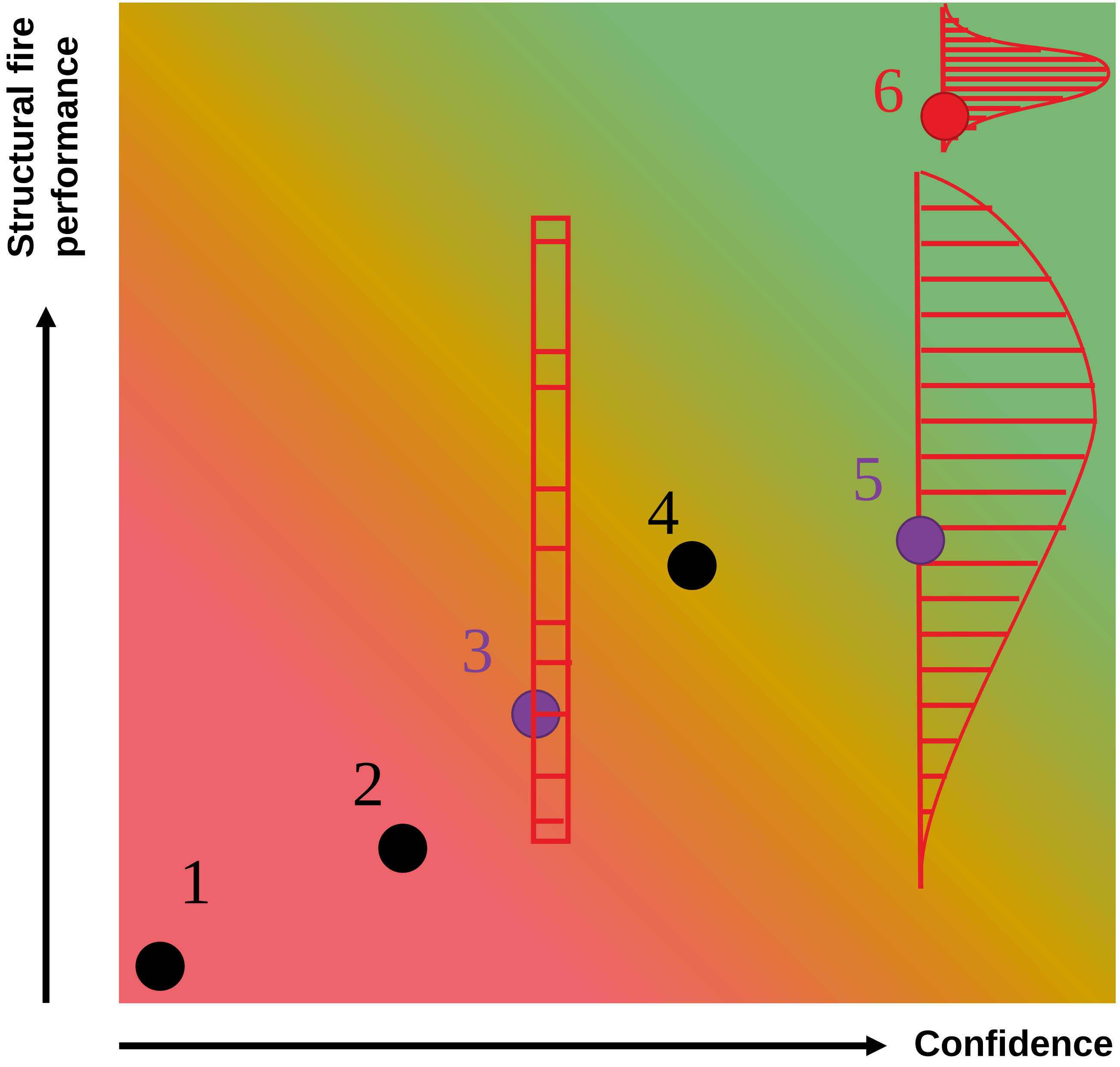
A framework

Routemap towards confidently demonstrating adequate structural performance in fire

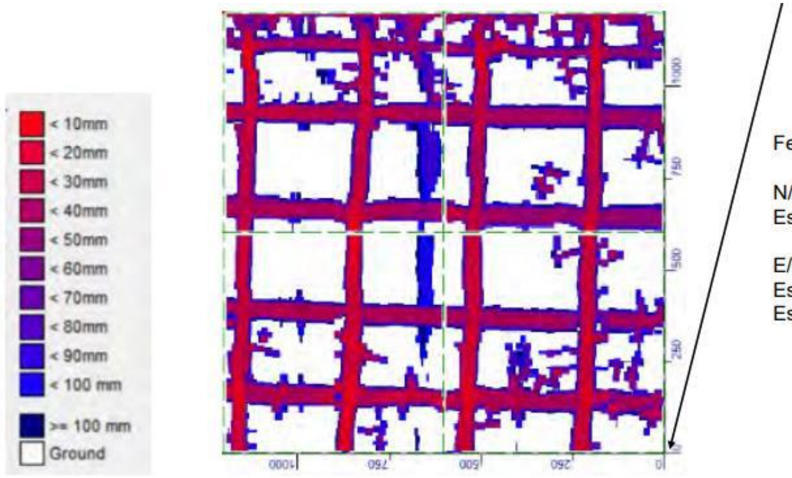
1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Understanding – full building survey
5. Assessing – assessment of survey data
6. Evidencing – full remediation



Undrerstanding existing structures

Building a picture

- Incremental scope – early bang for buck
- Outcome-focused – what are the exam questions
- Clearly communicated – scoping, briefing, check-ins
- Data – quality and format
- Integrate with wider (non-fire) surveys
- Collaboration
- **Get the data needed to inform a decision**



Ferroscan image showing slab soffit reinforcement arrangement.

N/S bars with spacing 200-300
Estimated minimum cover – 24mm (including finishes)

E/W bars spacing 300
Estimated minimum cover – 15mm (including finishes)
Estimated bar size – 12-14mm

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Understanding existing structures

Building a picture

Table 5: Summary of covermeter data – number of samples and proportion of total in building

Element type	Approx total number in building (36 storeys)	Number surveyed	% of total surveyed
Columns	864 (24 per floor)	75	8.7%
Walls	1,116 (31 per floor)	60	5.4%
Lintels (core walls) *	479 (14 per floor typically)	51	10.6%
Beams (beam-slabs) **	864 (24 per floor)	60	6.9%
Ribbed slab (bays) **	648 (18 per floor)	*** 87	13.4%

* Only limited survey of lintels was possible due to access restrictions. No bottom bars could be exposed. Detailed review of lintels is not necessary for Arup study.

** Number of different locations data collected from, which is typically only partial data for each element.

*** Single rib or location per bay.

Figure 2: Arup Revit model showing which structural elements were measured by Sandberg's covermeter (**RED** = elements with survey data (scanned or measured), typically one reading per member)

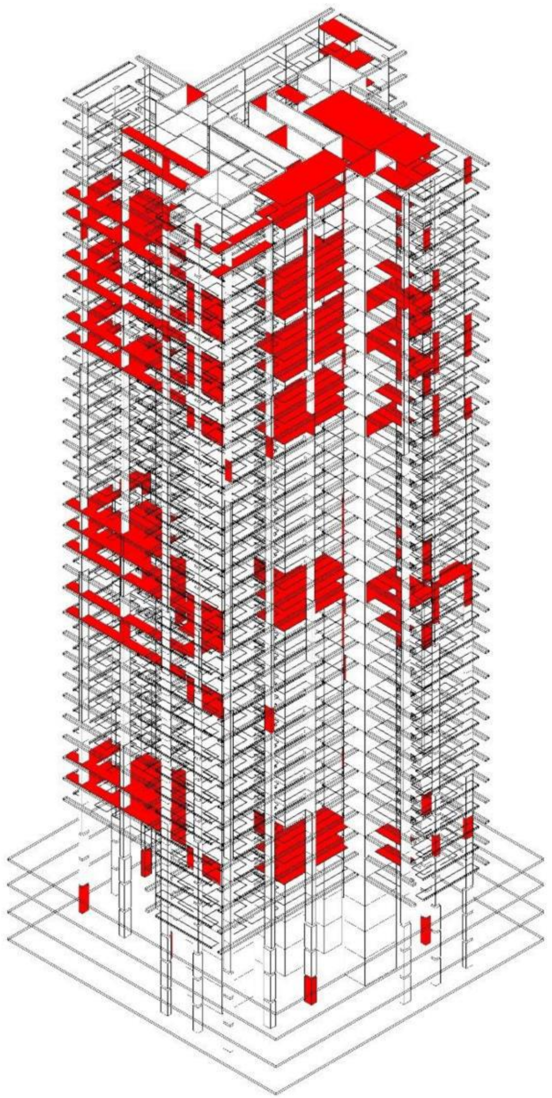
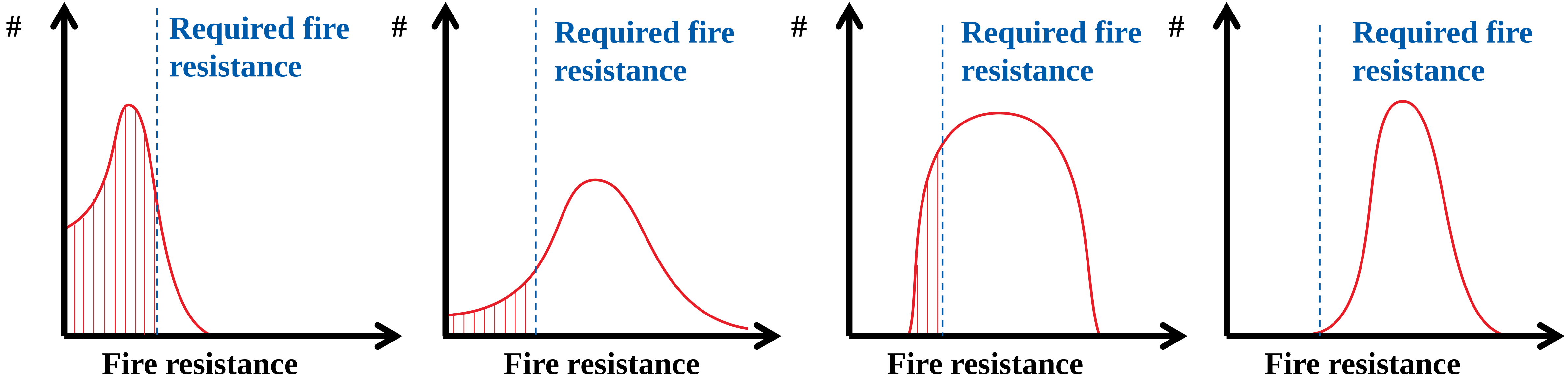


Table 6: Summary of covermeter data – number and floor of Sandberg's survey locations

Floor	Elements surveyed			
	Columns	Walls	Beams	Ribbed slabs
Roof			4	6
35	6	5	4	1
34				
33				
32			4	6
31	6	5	4	6
30	6	5		
29			4	6
28	6	5	4	6
27	6	5		
26			4	6
25	6	5	4	6
24	6	5		
23				
22				
21				
20				
19				
18				
17			6	6
16	6	5	4	6
15	6	5	4	6
14				
13			3	1
12	6	5	3	2
11				
10				
9				
8				
7				
6				
5			4	6
4	6	5	4	6
3				
2				
1		5		3
G		3		2
B	8	2		2

Assessing existing structures

How much confidence is required?



Moving forward

What's to be done?

What's missing?

What's needed most?

ARUP

Thank you

Questions and discussion