

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

Overview

Existing structures in fire

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

Why are we here

We know we must do things differently

The Net Zero challenge – many solutions

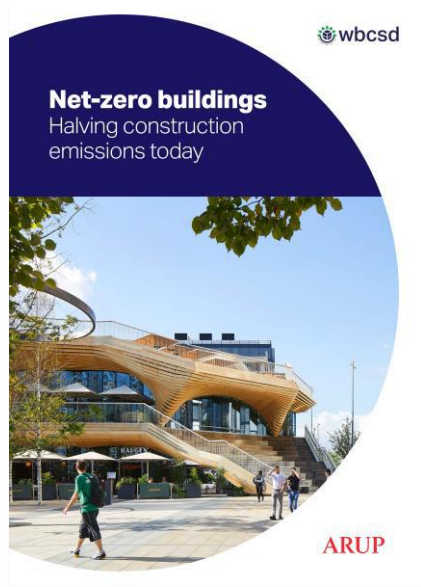
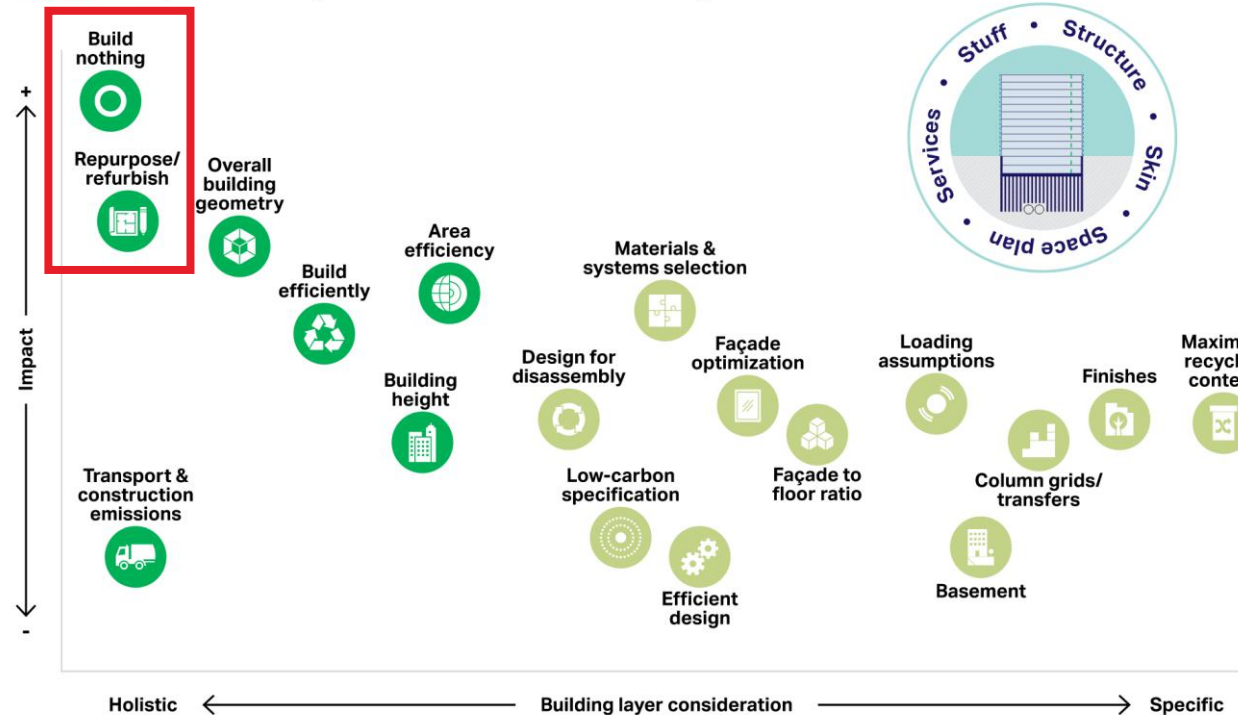


Figure 4: Key overarching considerations – whole-building decisions



The greenest building is the one that already exists

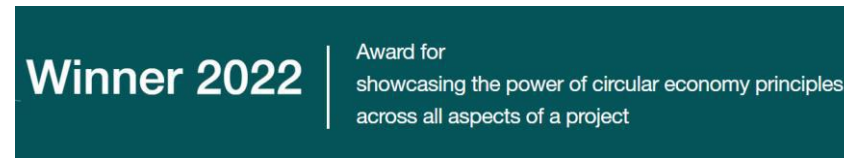
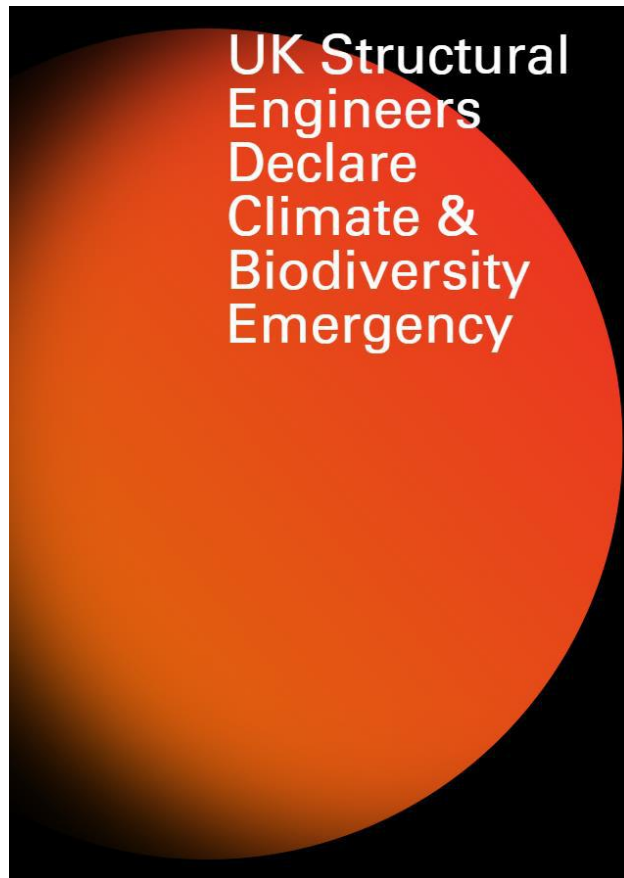
#RetroFirst

Existing structures are cool

Winds of change

'80% of existing buildings will still be in use in 2050'

COP26, Michelle Agha-Hosseini



2023 Shortlist
York Guildhall Refurbishment

Structural Designer - Arup
Location - York, UK



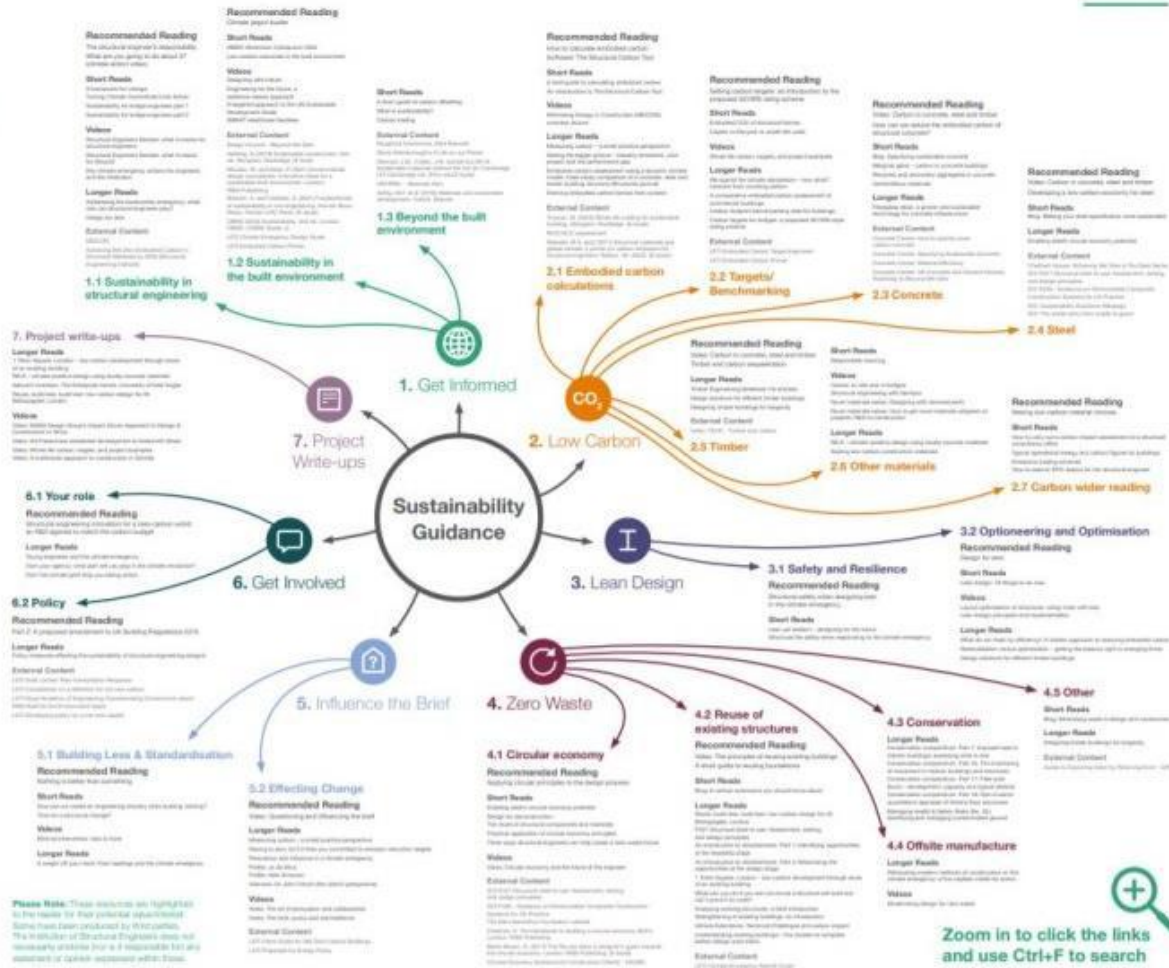
2023 Shortlist
Bolands Quay Redevelopment

Structural Designer - Arup
Location - Dublin, Ireland

Moving the needle

Accelerating towards Net Zero

Sustainability Resource Map



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

Challenges and opportunities

Earning trust

Regulations
Competence
Quality
Perception



What are we trying to achieve?

Regulatory requirements and applicable standards



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.


[Home](#)
[Safety information](#)
[Reporting to CROSS-UK](#)
[News & events](#)
[About](#)

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.

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

[Share this page](#)

[Bookmark this page](#)

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](#)

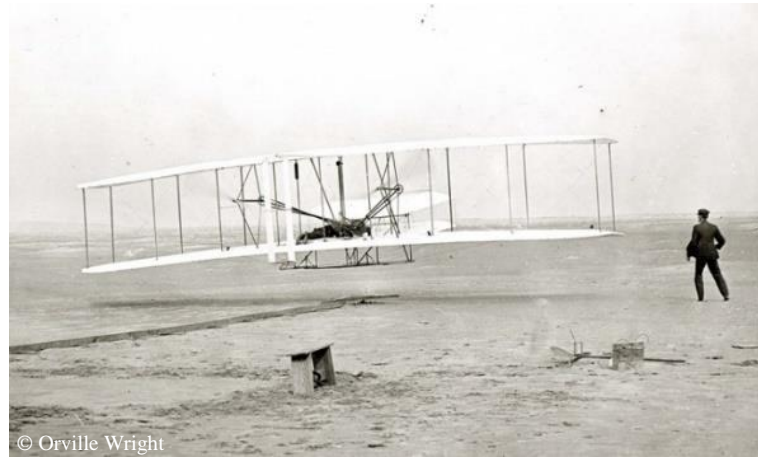
[Residential buildings](#)

[Flats & apartments](#)

Construction period

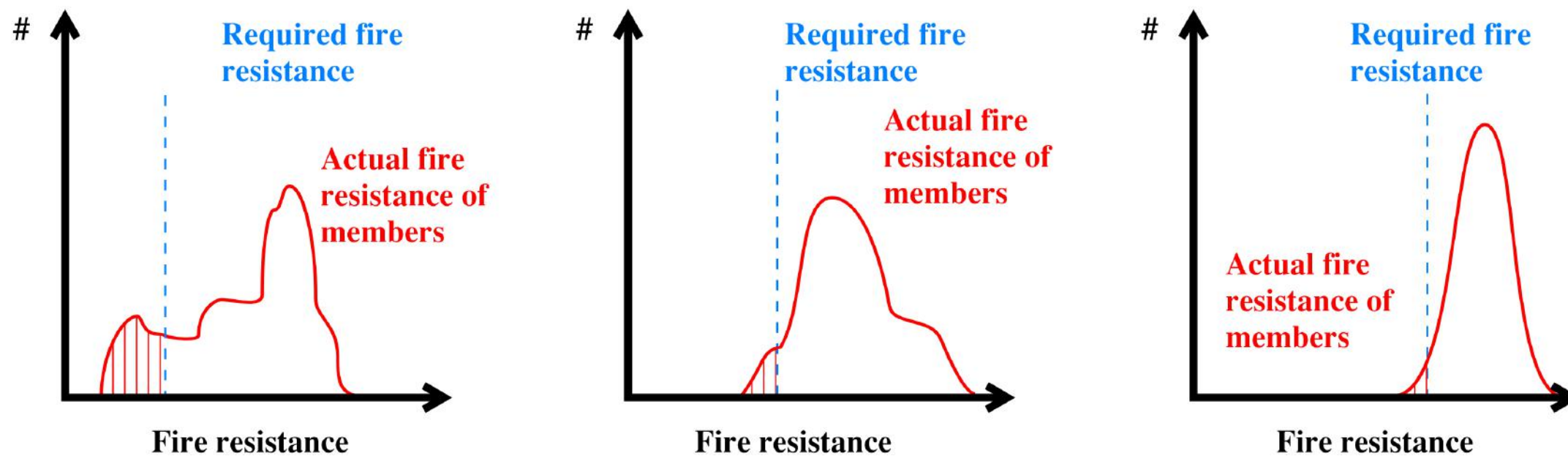
Evolving expectations

Fire safety in existing buildings



Evolving expectations

Structural fire performance



1900s



Today

Range of guidance

CP110:1972



BRITISH STANDARD

Structural use of concrete —

Part 2: Code of practice for special circumstances

BS 8110-2: 1985
Reprinted, incorporating Amendments Nos 1 and 3

Dimension	Minimum dimension in mm to give fire resistance of						See also supplementary note
	½ hour	1 hour	1½ hours	2 hours	3 hours	4 hours	
#1	180	200	250	300	400	450	(a)
#2	80	110	140	180	240	280	(a)
#3	105	130	155	180	205	230	(b)
#4	100	110	140	160	175	190	(b)
#5	75	75	100	100	150	180	(a)
#6	80	100	125	125	150	150	(b)
#7	100	75	100	as for #6	150	150	(b)
#8	85	75	100	115	140	150	
#9	50	70	80	90	100	125	
#10	30	40	45	60	70	75	
#11	25	35	40	50	60	70	
#12	15	25	35	45	55	65	(c)(d)(e)
#13	20	25	30	40	50	55	(e)
#14	10	15	20	25	30	40	(e)
#15	15	15	20	20	25	25	(e)

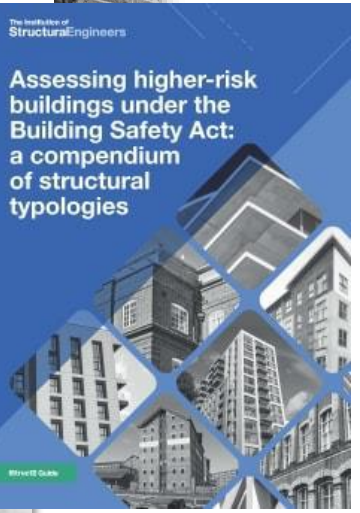
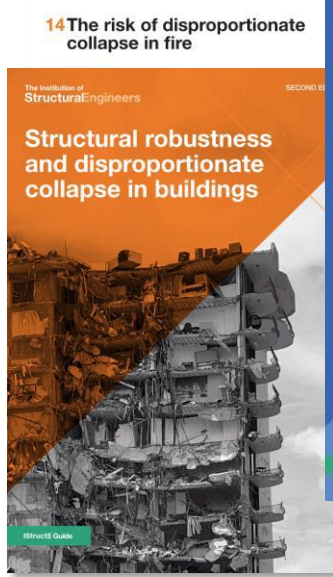
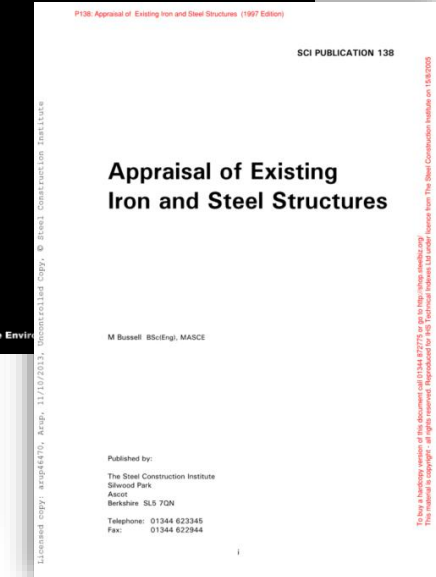
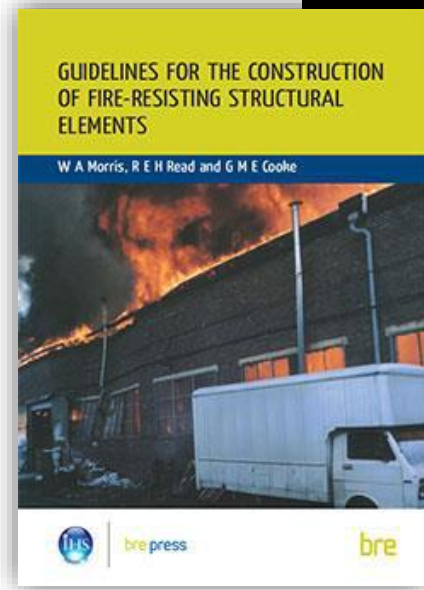
Building Research Establishment Report

Results of fire resistance tests on elements of building construction

267



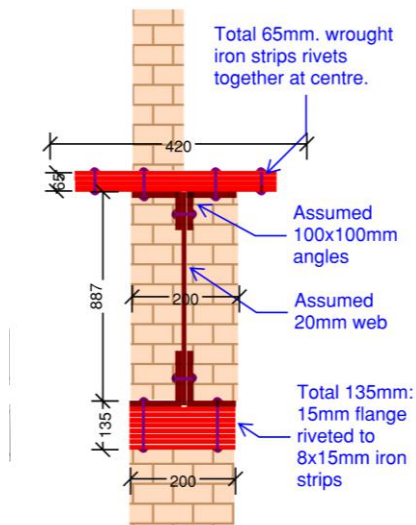
THE INSTITUTION OF FIRE ENGINEERS
FOUNDED 1918 • INCORPORATED 1924



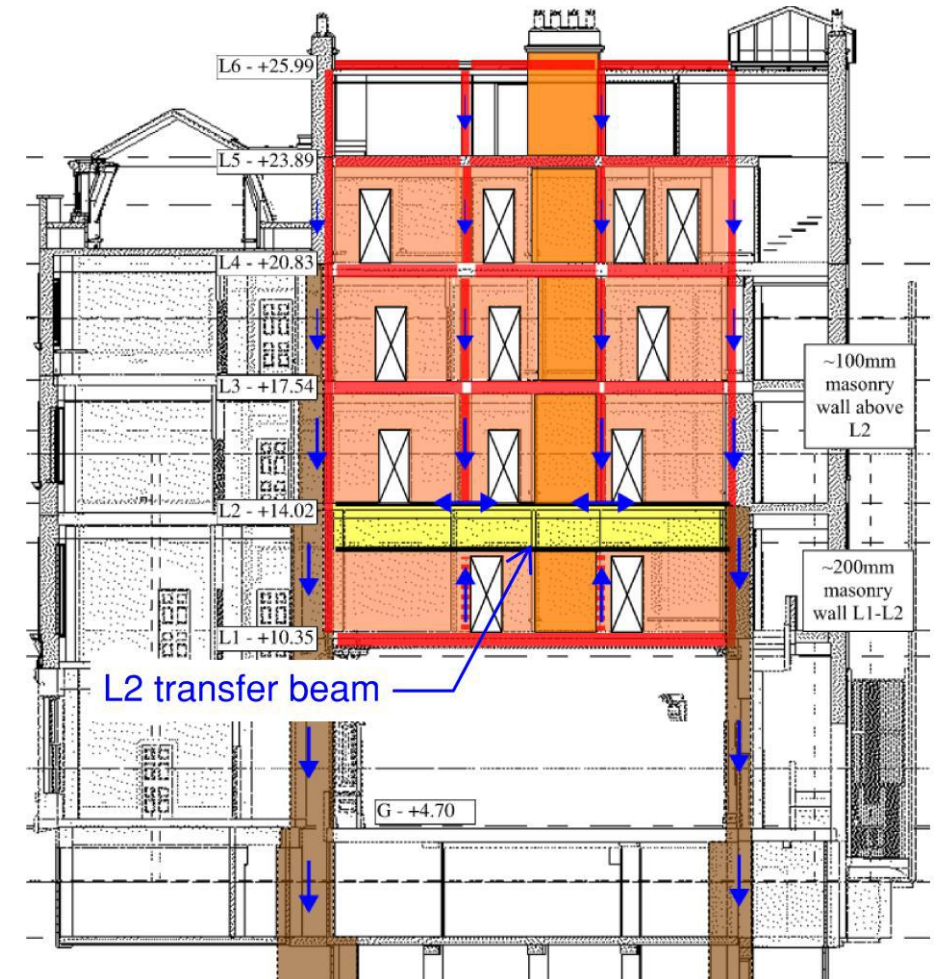
Ignorance is not bliss

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



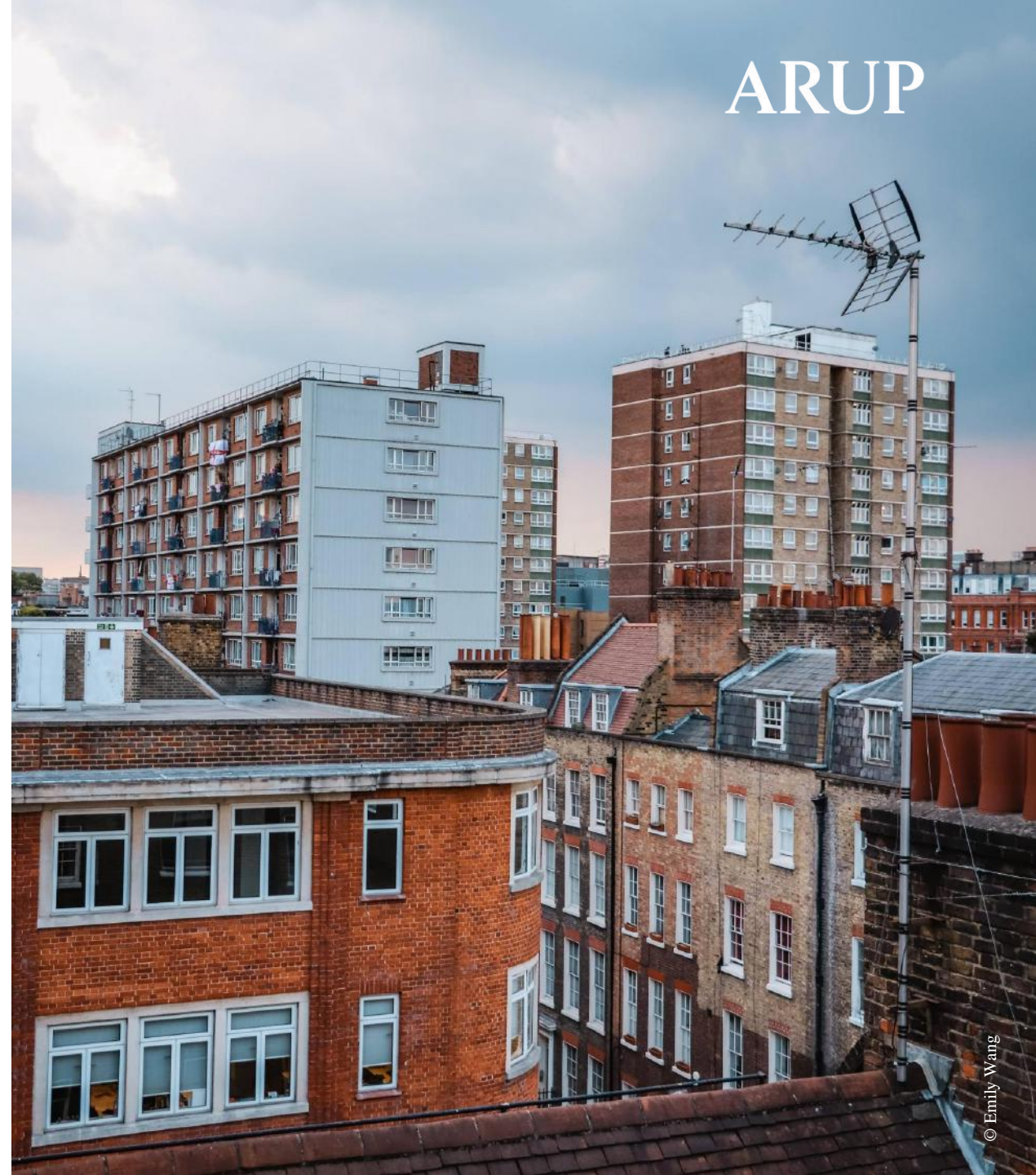
**“Perfect is the
enemy of good”**
-Voltaire

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

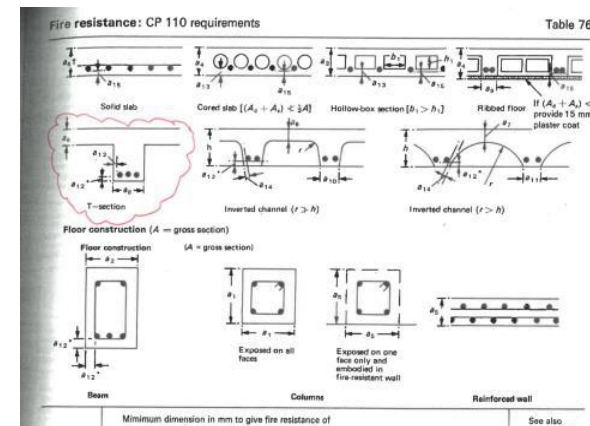
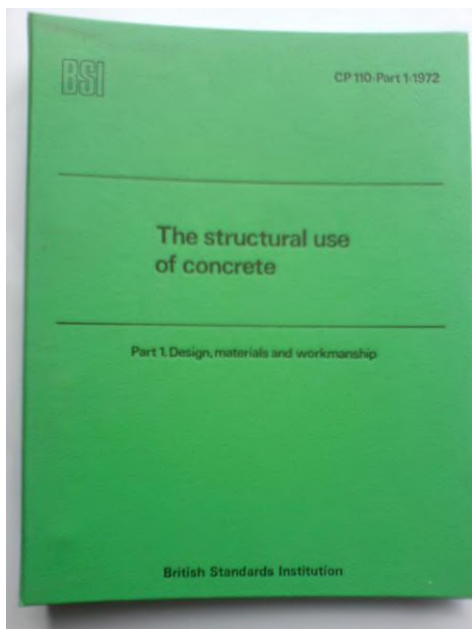
Opportunities??



A few examples

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 tie, where used.

Minimum dimension in mm to give fire resistance of	hours				See also supplementary note:
	2	3	4	5	
300	400	450	450	(a)	
180	240	280	280	(a)	
180	206	230	230	(b)	
160	175	190	190	(b)	
100	150	180	180	(a)	
125	150	150	150	(b)	
100	150	150	150	(b)	
115	140	150	150		
90	100	125	125		
80	70	70	70		
80	60	70	70		
45	55	65	65	(c) (d) (e)	
40	40	50	50		
25	30	40	40	(e)	
20	25	25	25	(e)	

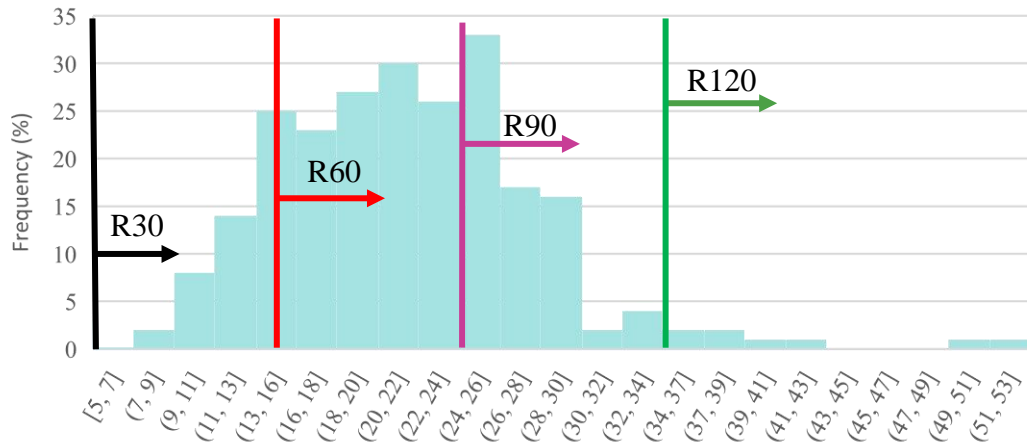
(c) Cover to beam reinforcement (main bars) may be reduced when protective coating as described in Note (e) is provided.

(d) "Average cover" dimensions, evaluated by multiplying area of each bar by its distance from nearest exposed face and then dividing resulting summation by total area. Compliance with "minimum cover" requirements related to concrete grade, and durability must also be ensured.

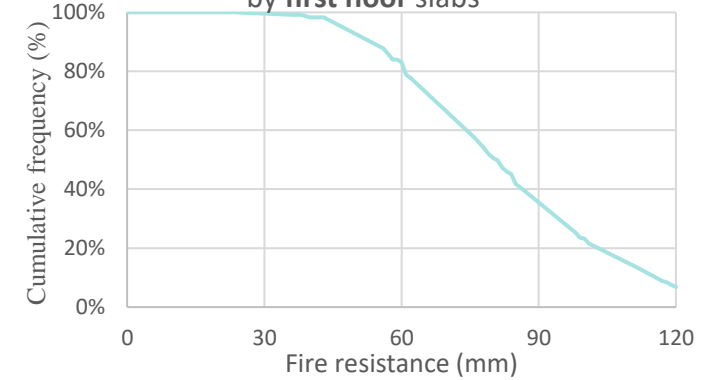
Existing structures in fire

Quality control and variability

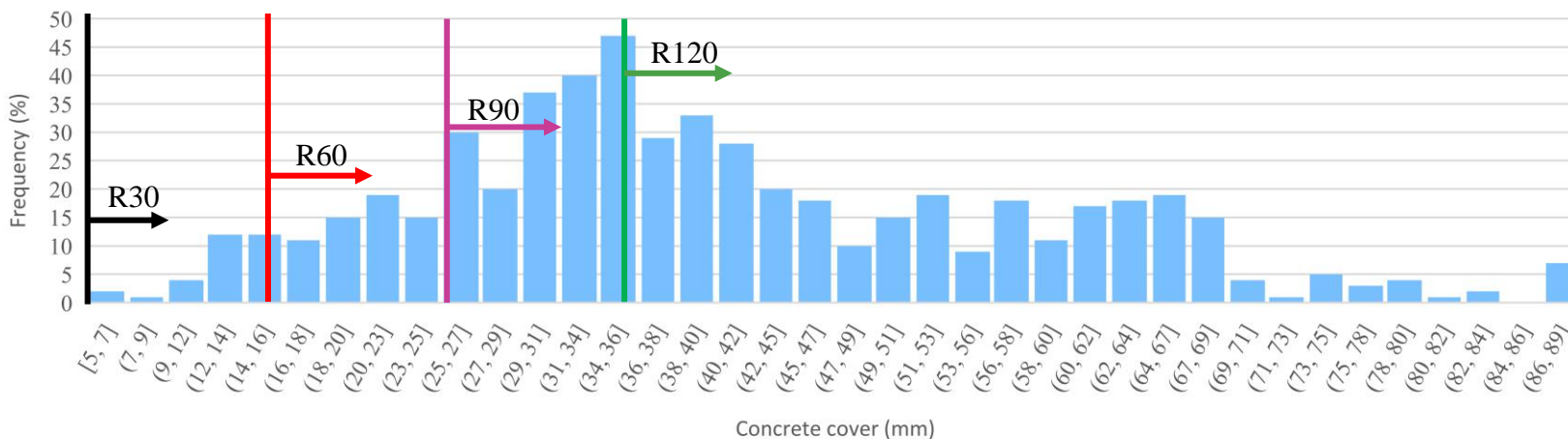
Frequency distribution of concrete cover depth to reinforcement on **first floor** slabs (mm)



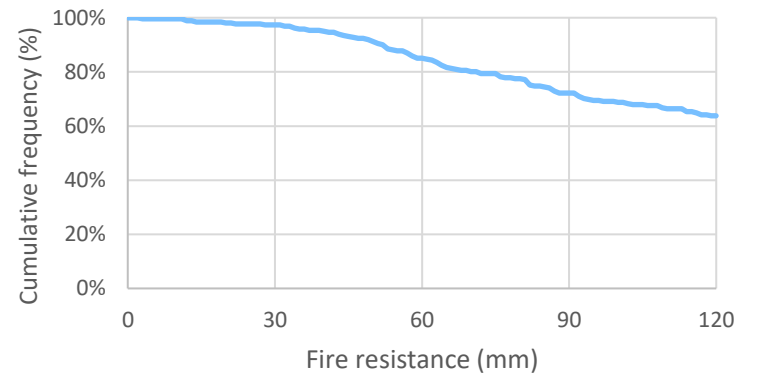
Cumulative frequency of fire resistance by **first floor** slabs



Frequency distribution of concrete cover depth to reinforcement on **third floor** slabs (mm)

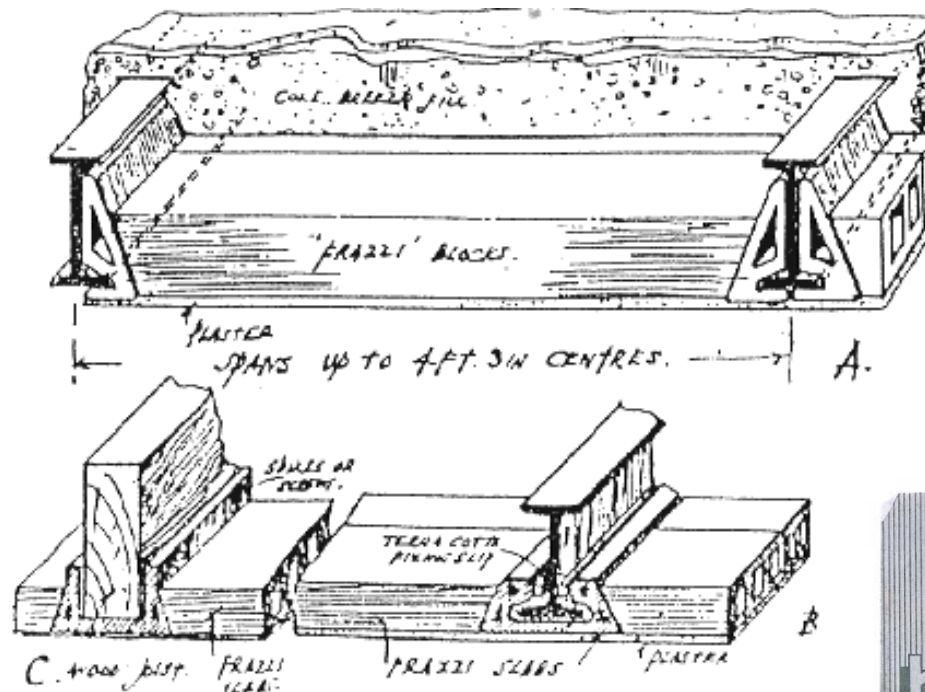


Cumulative frequency of fire resistance by **third floor** slabs

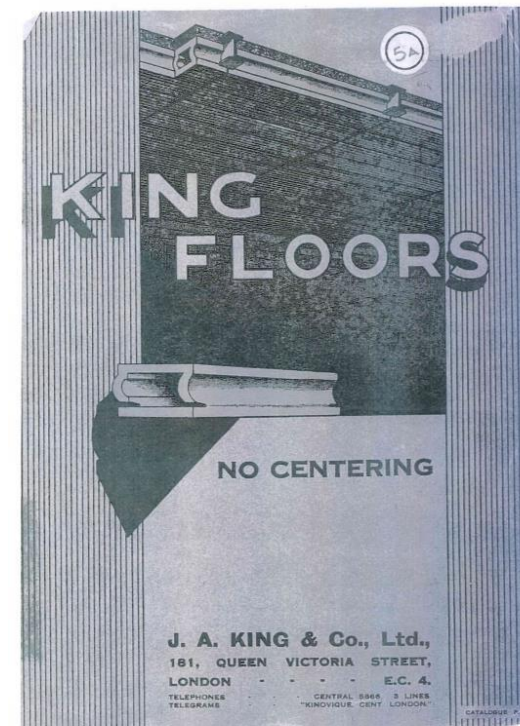
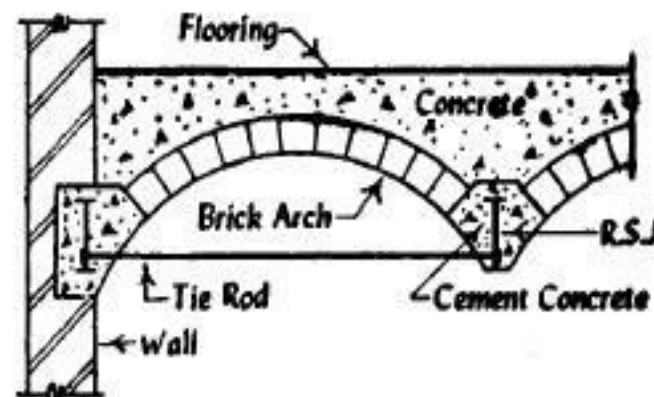


Existing structures in fire

Historic floor systems - good, bad & the ugly

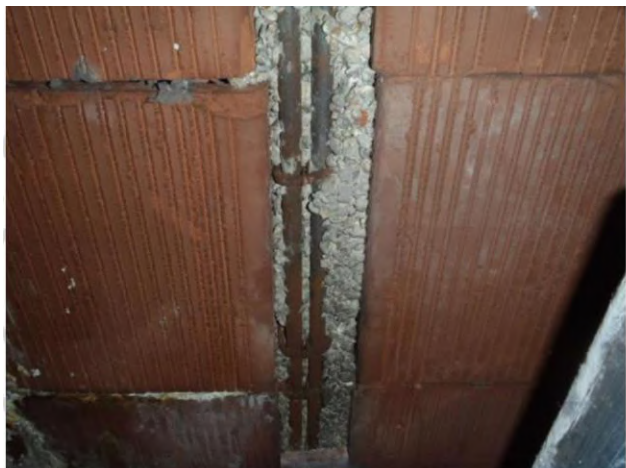
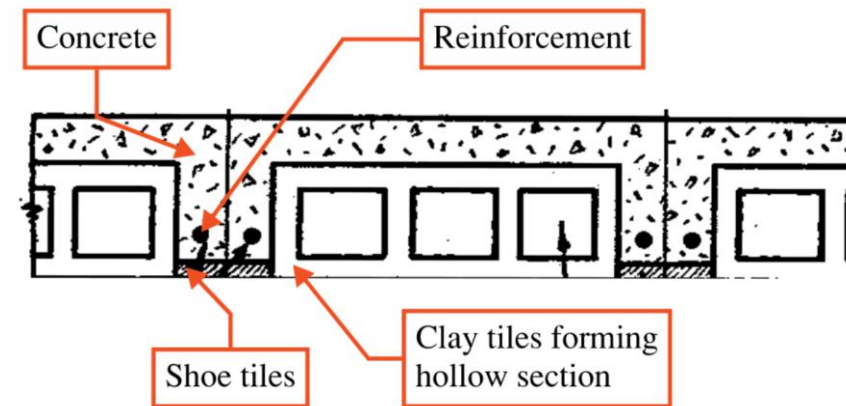


Frazzi flat terracotta lintel system



Existing structures in fire

Historic floor systems - good, bad & the ugly

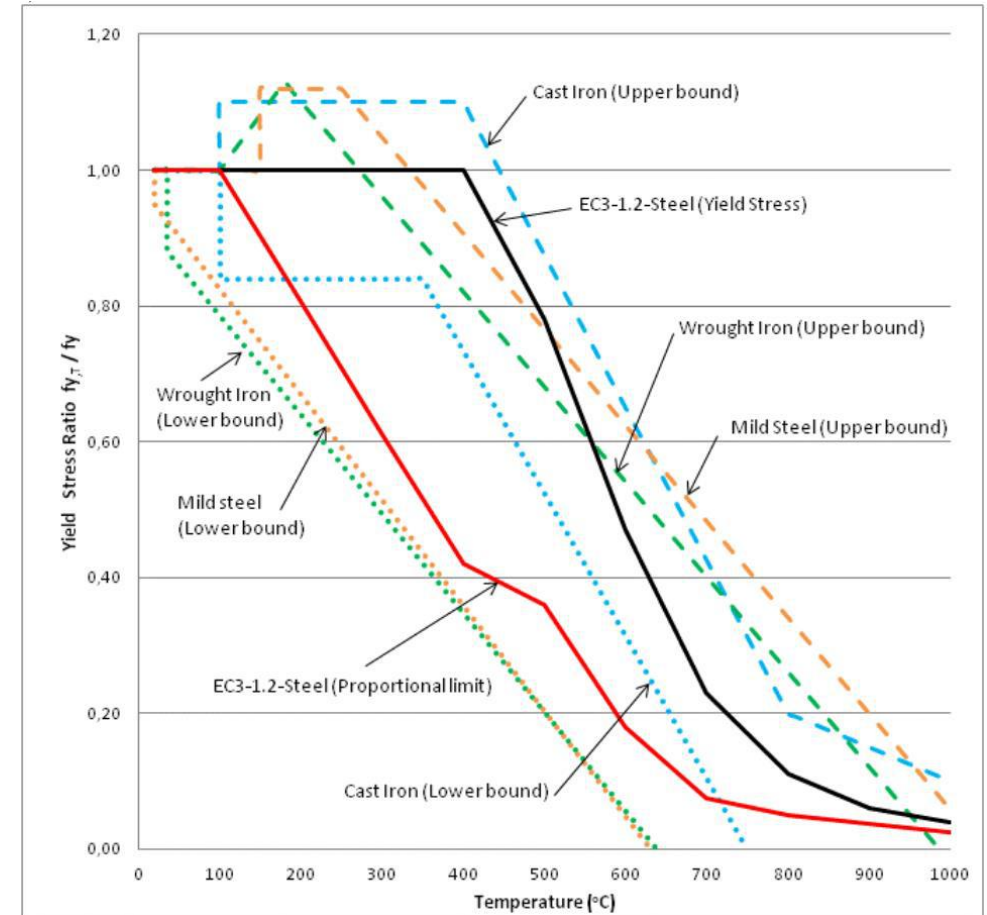


Existing structures in fire

Unprotected iron and steel



© School of Architecture at McGill University



Maraveas (2015)

Existing structures in fire

Unprotected iron and steel



LDC 02407 (01.10.16) (ARUP)

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

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

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

Summary
There is an increasing need towards the refurbishment of existing buildings, many of which contain large quantities of unprotected structural steel. Very few data, however, have been published on methods of protecting the fire performance of cast-iron structural elements. This paper deals with the factors affecting the performance of cast iron in fire and proposes fire design parameters for use when refurbishing existing buildings containing structural cast-iron that is exposed to open air.

Introduction
The production of cast iron began in the early 18th century with the introduction of the blast furnace from the low countries. However, it was not until the end of the 18th century that the availability of reliable power made possible the manufacture of castings of sufficient size and quality to attract attention. In 1780 the world's first cast-iron bridge was constructed at Frodingham and in 1789, by the first iron foundry building, 216 Strand in St. Martin's Street.

As the structural use of cast iron increased throughout the 19th century, techniques for producing and refining the material were developed and it became possible to design structures using a combination of wrought and cast iron.

Both wrought and cast iron were generally accompanied with the introduction of rolled steel sections in the early years of the 20th century. While cast iron is not generally used as a structural material, there has been increasing interest towards the refurbishment and conversion of existing buildings, many of which contain large quantities of cast-iron columns and beams.

Under various legislation, if a change of building use is taking place or a building is being substantially renovated, it is often necessary to bring the structure in line with modern fire protection concepts. This has often meant that the cast iron had to be clad with fire-protective materials, with a consequent loss of architectural detail and interest in cast iron.

The behaviour of cast iron under fire conditions has, however, been well researched, and some evidence has been available, in a form contrary to the common assumption, that cast iron columns have been known to survive severe fire without damage, whereas other cast-iron columns have actually collapsed. Failure of a column can result in the collapse of floors or walls, depending on their location, with potentially fatal consequences for the building occupants and firemen, in many cases the failure of one column can lead to the progressive collapse of a large part of the structure.

In a new pamphlet published by the Institute of Fire Engineers, the unprotected cast-iron column and beam are likely to suffer collapse when subjected to fire, followed by total collapse by the water from a fire fighting team. The Home Office Manual of Fire Precautions states that 'where existing in the vicinity of cast-iron columns which have been treated, it is a wise precaution to avoid placing a fire directly in front because the heat radiating into the open fire will melt and fall rapidly'.

In view of this responsibility towards the safety of the building number of approaches, reviewed by the Greater London Council regarding the refurbishment and conversion of buildings containing large quantities of cast-iron columns, it was decided to investigate the performance of cast iron in fire in order to establish the fire protection measures required to be taken in order to ensure that the performance of cast iron in fire is not impaired.

In recent years it has been demonstrated that individual unprotected columns were capable of withstanding fire resistance periods in excess of 1 h

which varied in accordance with the current British Standard for fire resistance, BS476 Part 4. These results made further work particularly important, as they suggested that, in many cases, cast iron did not require the protection demands for reinforced concrete of its behaviour in actual fire.

Under the early versions of the fire resistance test (prior to 1973) the current standard failed to account for the effects of thermal shock due to fire-fighting operations.

Incidents caused by the structure of a structure under fire conditions are also ignored by the current test procedure. In the three publications an equally important issue on the use of alternative materials, such as reinforced concrete and steel, the effects of thermal shock are unlikely to be a serious problem since they have a low thermal conductivity and are much more liable to brittle fracture.

Recent tests
Prior to 1980, several tests were carried out in Britain in the United States and Germany to investigate the effects of fire on cast-iron columns (see Table 1). In the Americas, with testing that no tests were carried out in Britain because the British Fire Protection Committee, who were responsible for fire testing at the time, were concerned that the performance of cast iron was superior to that of wrought steel. The general consensus on the fire resistance of the effects of thermal shock on cast-iron columns is also demonstrated by the fact that off the earth test work included a test on a cast-iron column following the main fire test.

Cracking of columns was noted on a number of the early tests but the main reason under which columns were cracked was the application of water, which cracked and fell during the test. It is still recommended, however, that the cooling of columns, was associated with columns that had undergone significant deformation. Between 1981 and 1983 the Underwriters' Laboratories in the United States conducted a major programme of fire testing on columns of various types, including fire-protected cast-iron columns (see Table 2). Three of these unprotected columns showed, on average, no water was applied to the hot column but no cracking was observed. However, these two columns had no surface significant deflection prior to application of the test water.

As far as cast-iron beams are concerned, the authors are not aware of any tests carried out prior to their own work reported in this paper.

Recent tests
In an attempt to establish more clearly the behaviour of cast-iron columns in historic buildings under fire conditions, a programme of fire resistance tests has been carried out on behalf of the Greater London Council's Science, Service, Branch and Architects' Department, Historic Buildings Division. This programme consisted of a total of five tests on unprotected cast-iron, two steel columns and three cast-iron columns. Detailed information has already been made available from tests carried out by the Fire Research Station and a further set of cast-iron unprotected steel columns tests which were sponsored by Alan Moore & Associates. The results of these tests are summarised in Table 3. Cross-sections of the columns tested in height of the Greater London Council are shown in Fig. 1.

Each specimen was subjected to radiographic examination before the test to characterise the quality of the casting in terms of blow holes, porosity, etc. Metallurgical analysis and tensile strength tests were also carried out when practicable (see Appendix A).

The fire tests were carried out in accordance with BS476 Part 4 with the addition of a 'low' temperature test, which was applied to quickly to establish the effect of the heating period (Fig. 2). All the columns were subjected to a 'first' in position and direction (although the heating arrangement did allow a limited degree of rotation in the ends of the specimen and

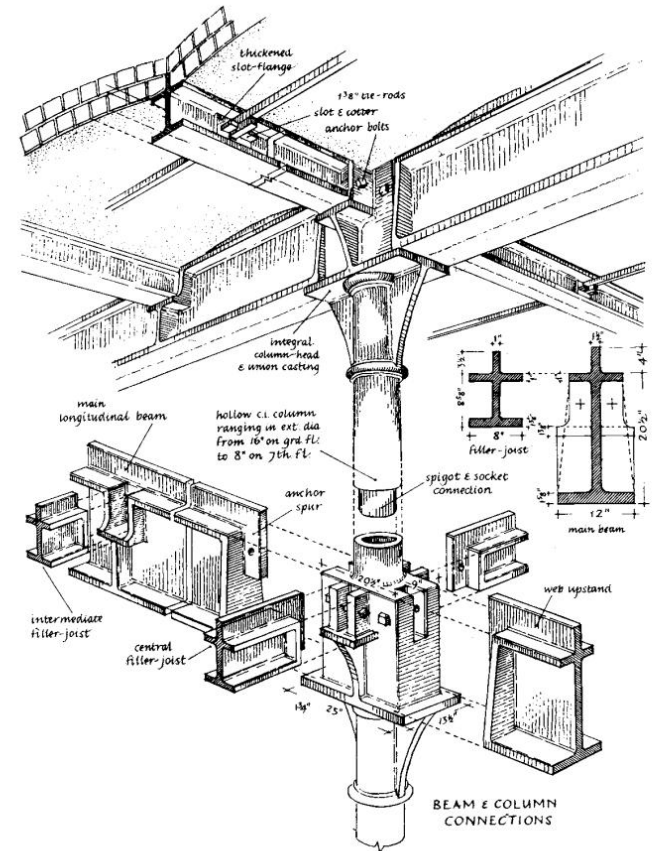


Figure 3.6 Typical early 19th century cast iron frames (reproduced from M...)

Existing structures in fire

Large Panel System “LPS” precast concrete



Image source: BBC

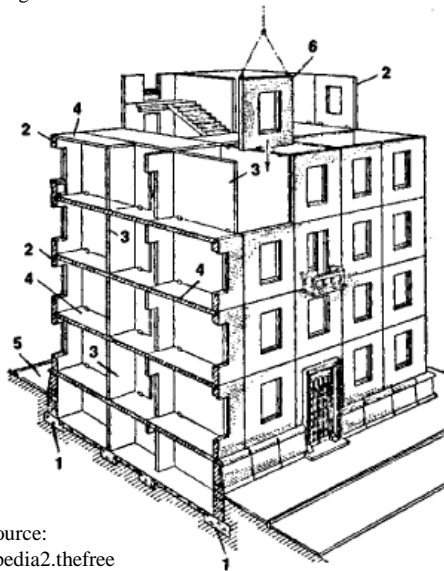
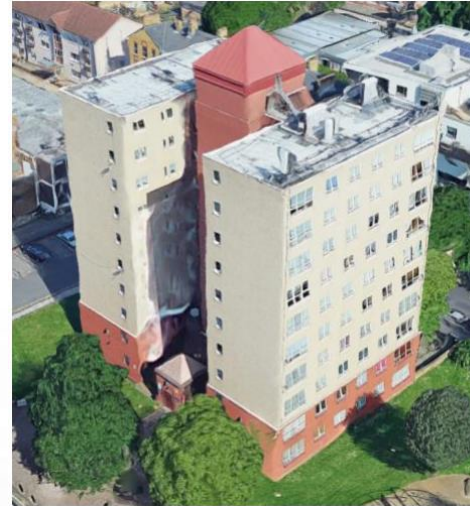


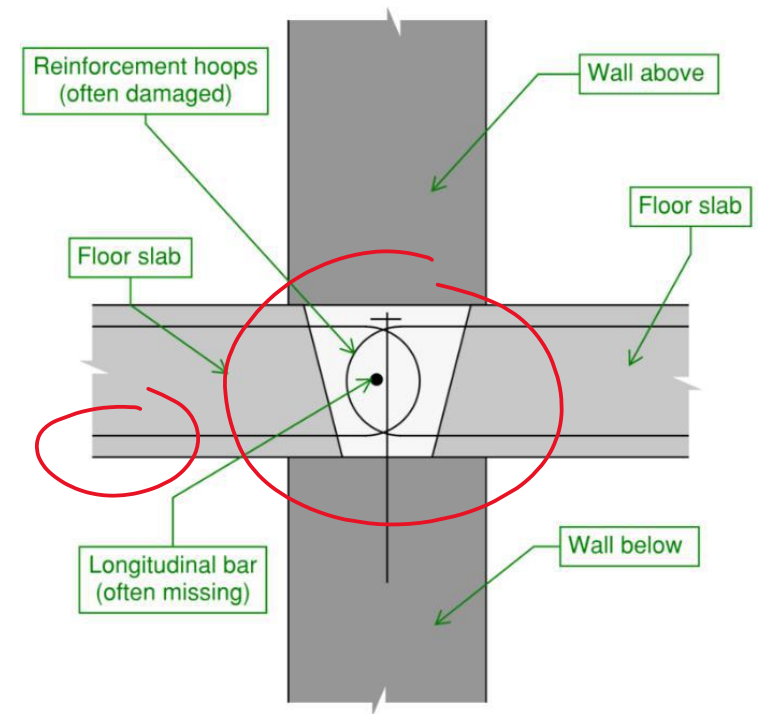
Image source: encyclopedia2.thefreedictionary.com



Image source: buildingfailures.wordpress.com

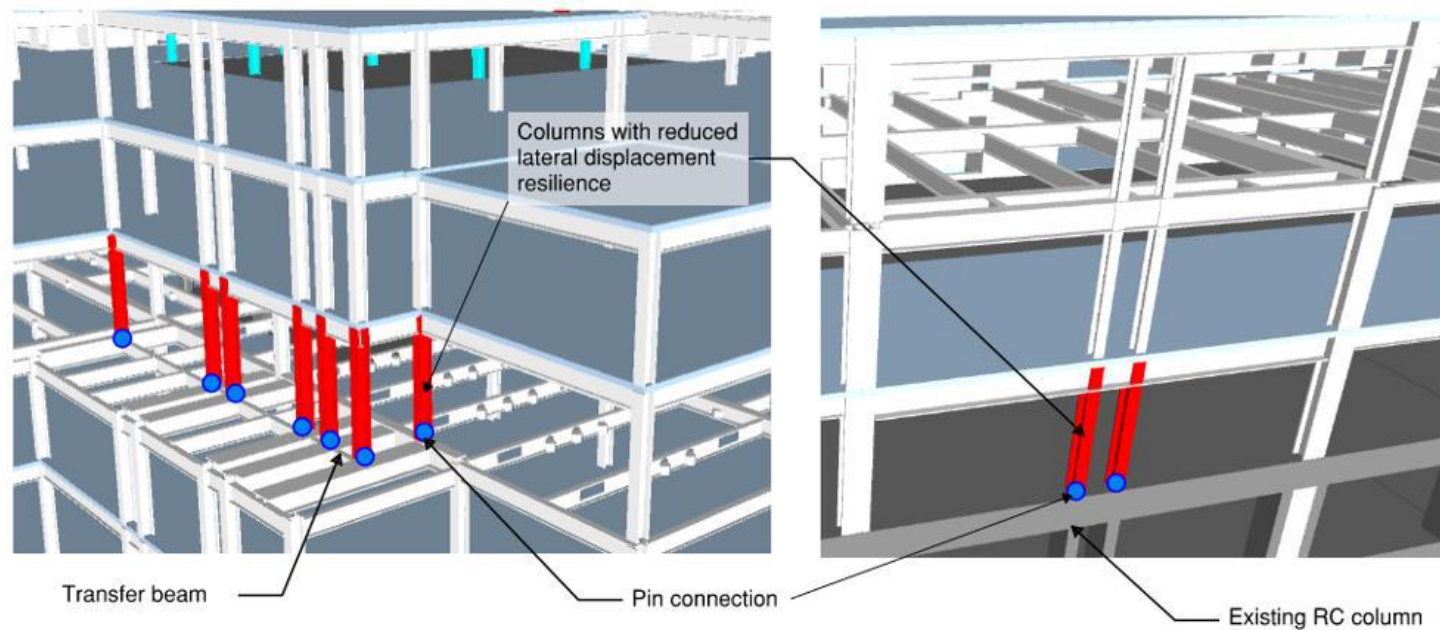


© OneHousing



Existing structures in fire

Extensions



© KPF



© KPF

Existing structures in fire

Protection & remediation

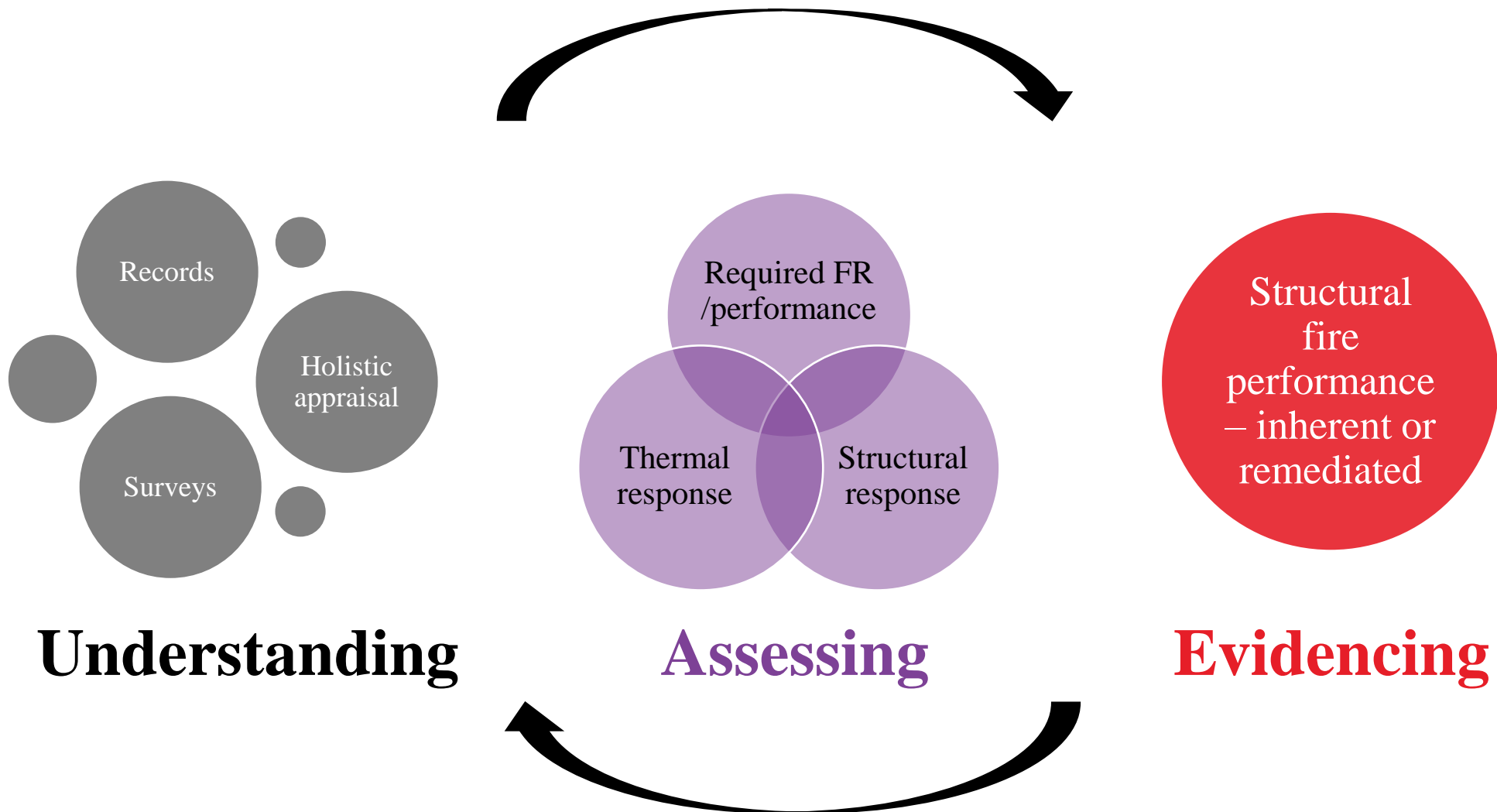


Response

ARUP

Mapping the approach

What do we do? In what order?



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

Pilot inspection - notes
This markup has been produced by Arup following a meeting between Arup, RSK and G&T on 07/04/2021.
This markup should be read in conjunction with the following documents issued by Arup:
- TDF, Arup marked up floors (2020-01-21);
- 2021-02-18 Bedroom wall fire wall inspection locations.
The purpose of this markup is to outline indicative locations on Level 1 where RSK could combine some of the survey requirements previously set out by Arup for (a) fire resistance of structure and (b) fire compartmentation of corridor walls.
This "pilot investigation" stage by RSK would then be followed by refinement by Arup, RSK, G&T of the survey requirements for (a) and (b) elsewhere in the building.
RSK may also consider opportunities to combine other survey requirements at these locations, such as for existing lighting.
The locations shown in this mark-up are indicative. RSK are to investigate accessibility and feasibility of combining the inspection points as shown.

Pilot inspection - notes
Green circles and comment boxes indicate 1st round of inspection.
Blue circles and comment boxes indicate 2nd round of inspections (provisional, TBC following review of 1st round of inspections as completed).

Pilot inspection mark-ups
22/04/21 | For information
Prepared by: RP | Checked by: EOL
SK-YF-012 | ARUP

Legend (by Arup) - structural type
1 way spanning tile slab
2 way spanning tile slab
1 way tile slab with deep ribs
Solid slab, 20k x 200mm

The Institution of Structural Engineers
THIRD EDITION
Appraisal of existing structures

P138: Appraisal of Existing Iron and Steel Structures (1997 Edition)
SCI PUBLICATION 138
M Bussett BSc(Eng), MASCE

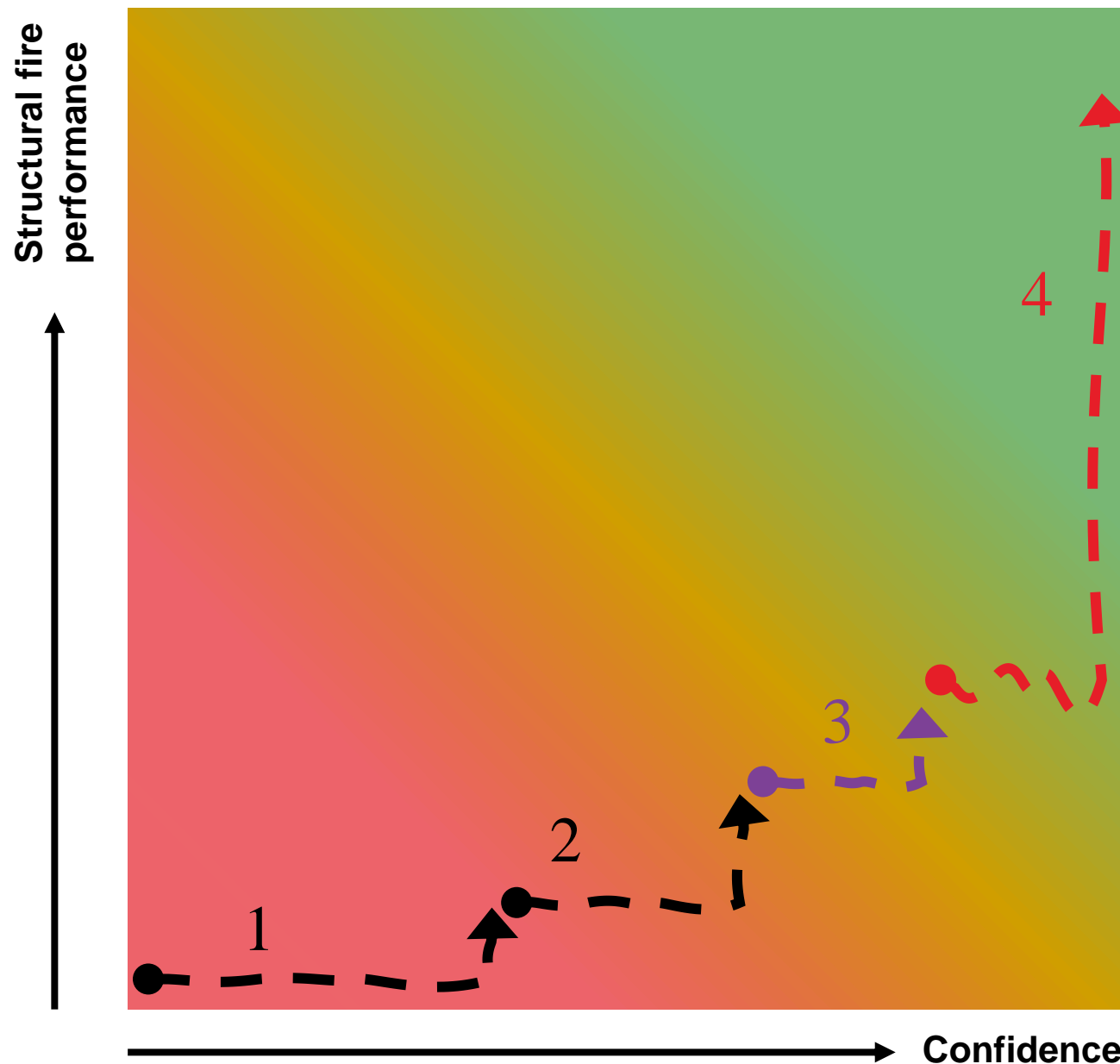
CROSS
COLLABORATIVE REPORTING FOR SAFER STRUCTURES

Published by:
The Steel Construction Institute
Silwood Park
Ascot
Berkshire SL5 7QN
Telephone: 01344 623345
Fax: 01344 622944

A framework

Routemap towards confidently demonstrating adequate structural performance in fire

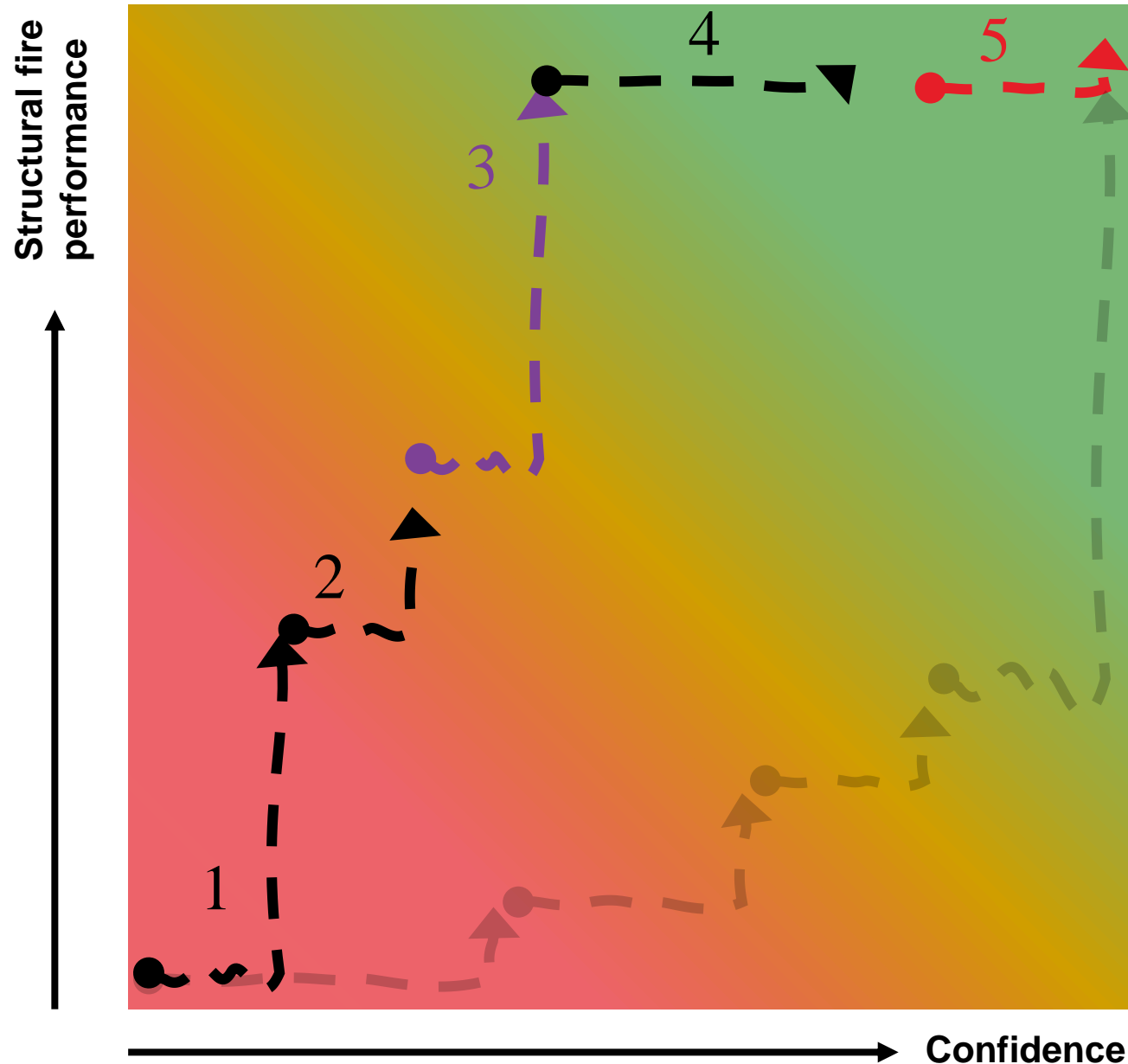
1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Evidencing – full remediation



A framework

Routemap towards confidently demonstrating adequate structural performance in fire

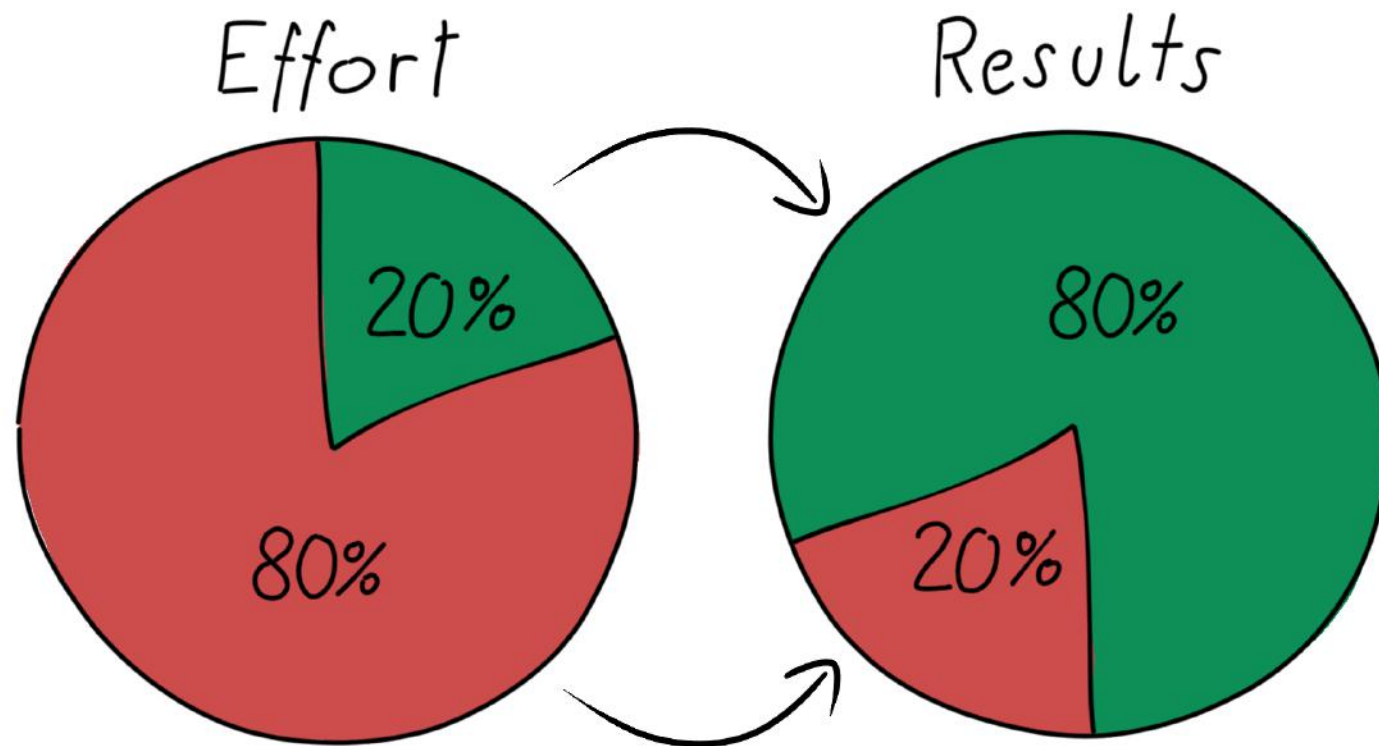
1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Understanding – full building survey
5. Evidencing – assessment shows adequate fire resistance



Proportionality

Dealing with 'tensions'

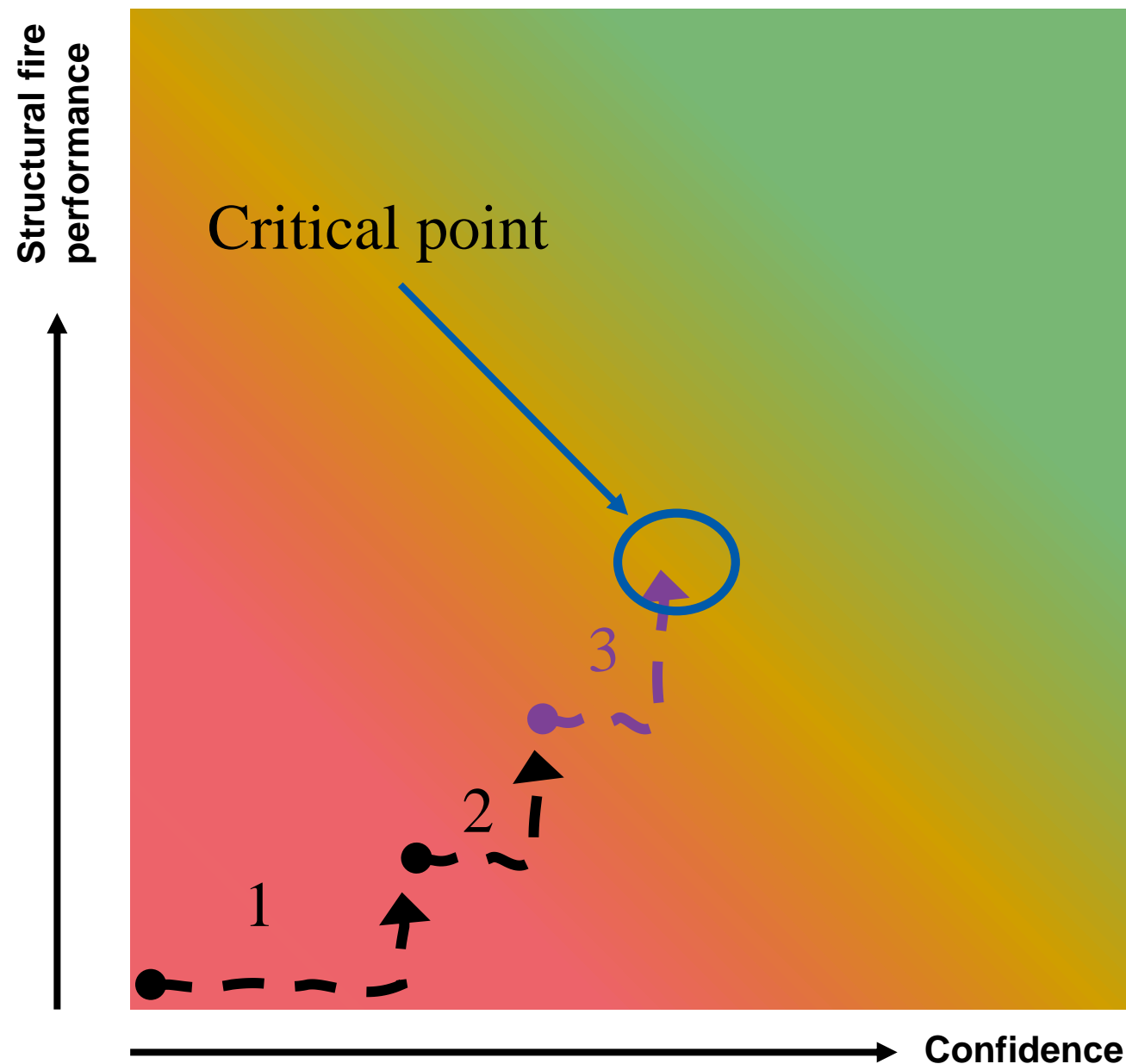
- What are the consequences?
- Multi-dis input – fire, structures, SFE
- Who are the decision makers?
- What is needed to inform their decisions?



A framework

Routemap towards confidently demonstrating adequate structural performance in fire

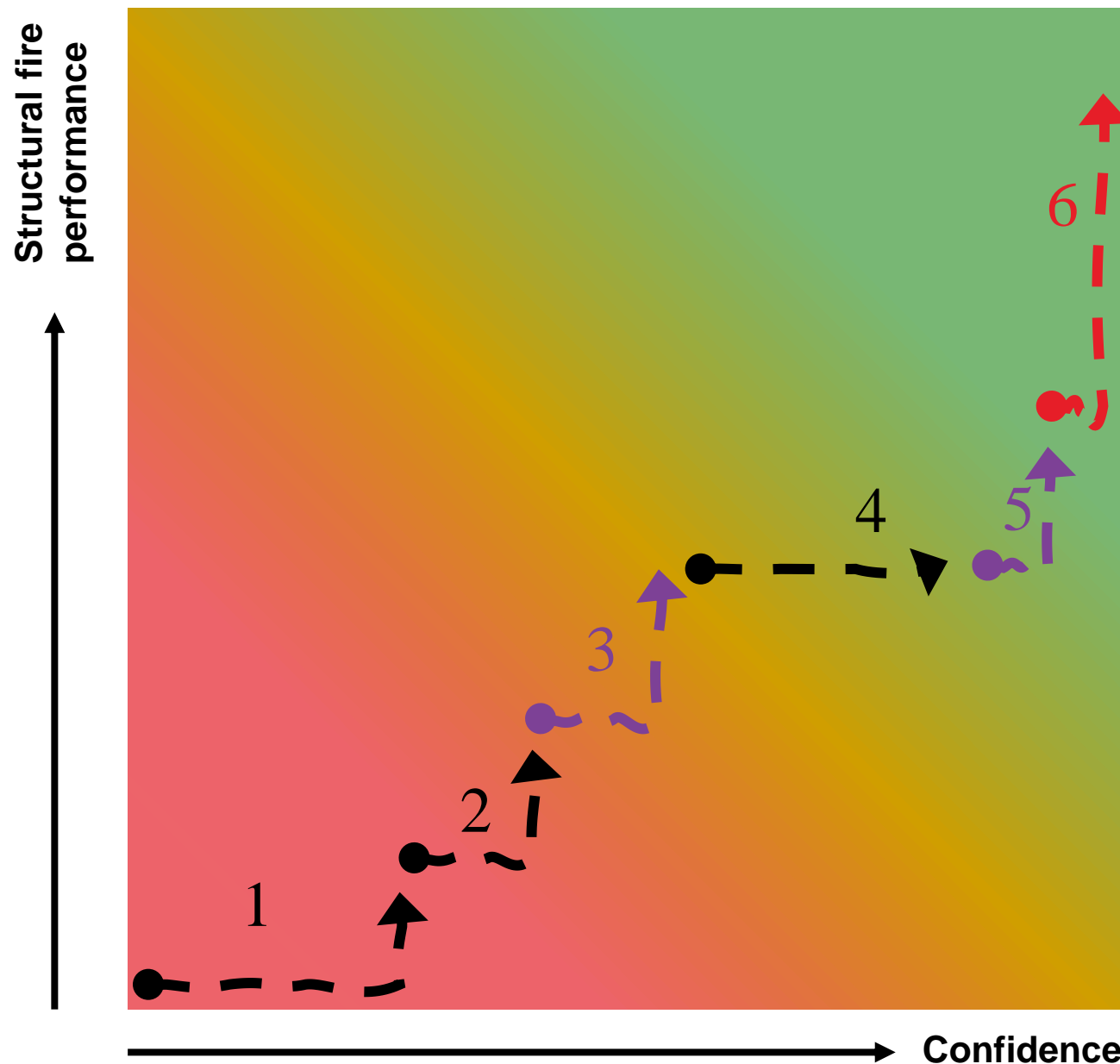
1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data



A framework

Routemap towards confidently demonstrating adequate structural performance in fire

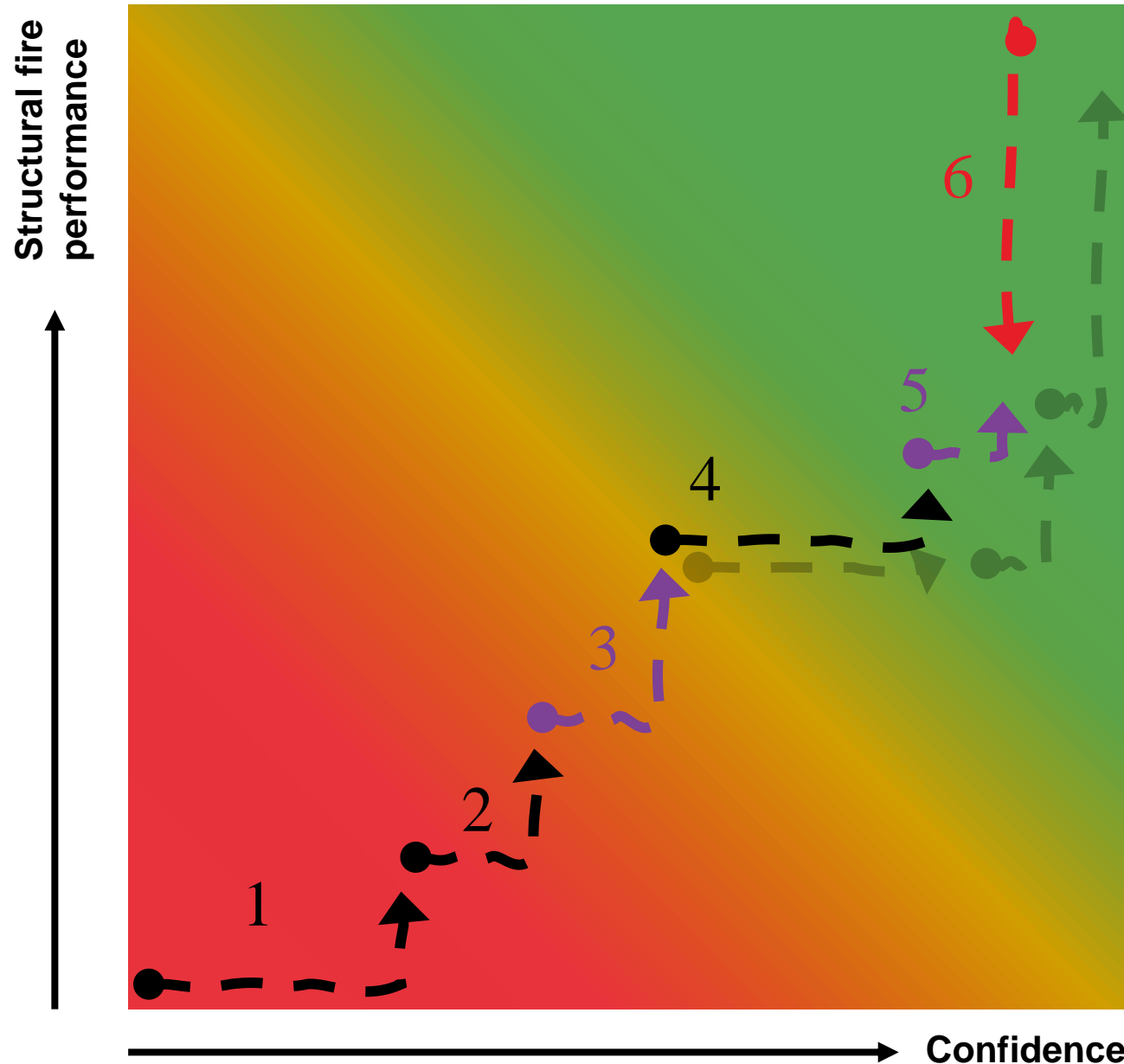
1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Understanding – full building survey
5. Assessing – assessment of survey data
6. Evidencing – full remediation



A framework

Routemap towards confidently demonstrating adequate structural performance in fire

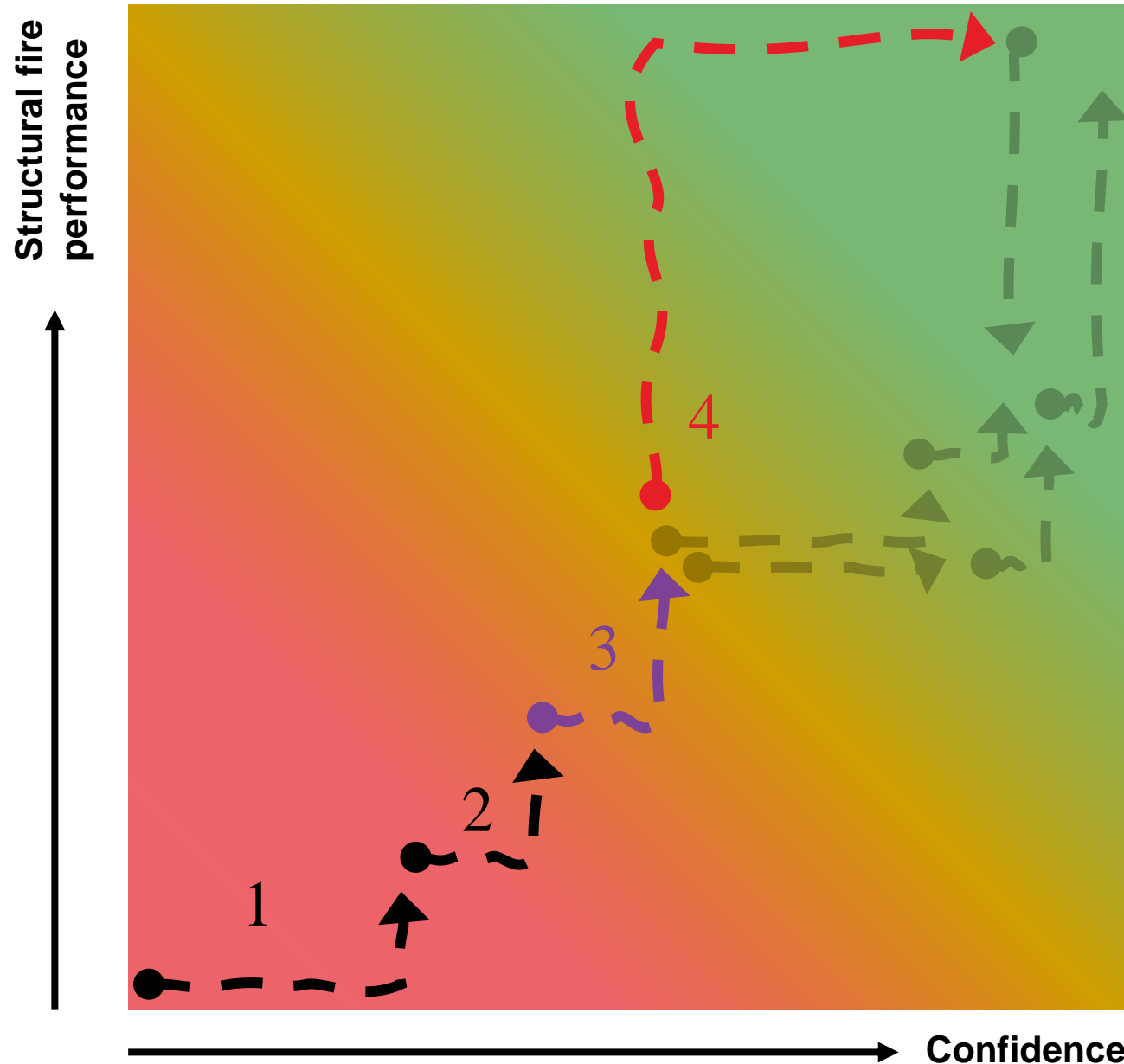
1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Understanding – full building survey
5. Assessing – assessment of survey data
6. Evidencing – adjustment to fire strategy lowering the required fire resistance



A framework

Routemap towards confidently demonstrating adequate structural performance in fire

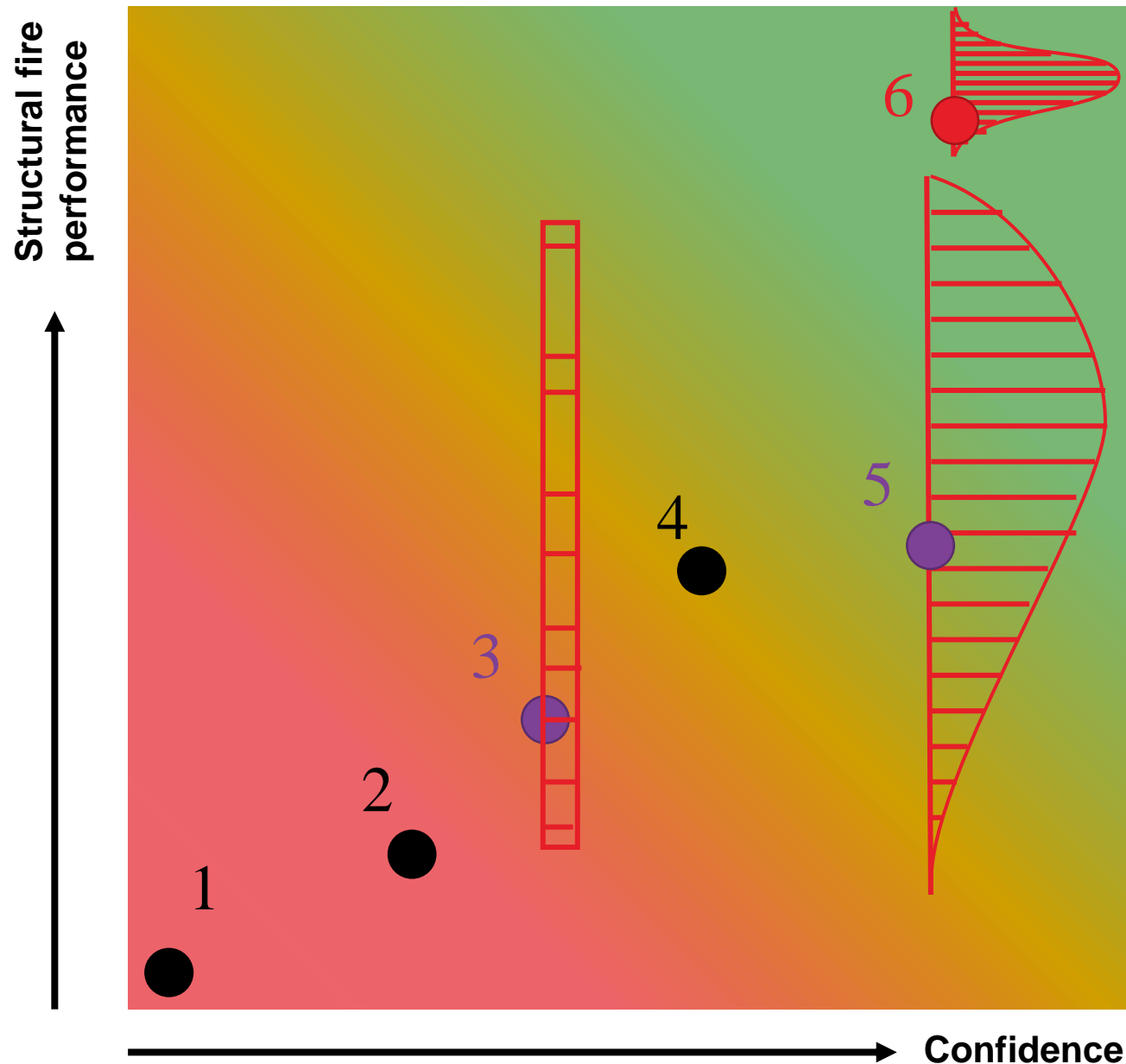
1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Evidencing – performance based fire & structural analysis



A framework

Routemap towards confidently demonstrating adequate structural performance in fire

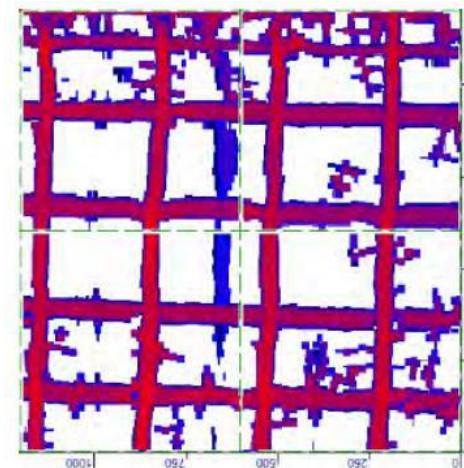
1. Understanding – identify floor type
2. Understanding – pilot survey
3. Assessing – assessment of survey data
4. Understanding – full building survey
5. Assessing – assessment of survey data
6. Evidencing – full remediation



Understanding 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

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)

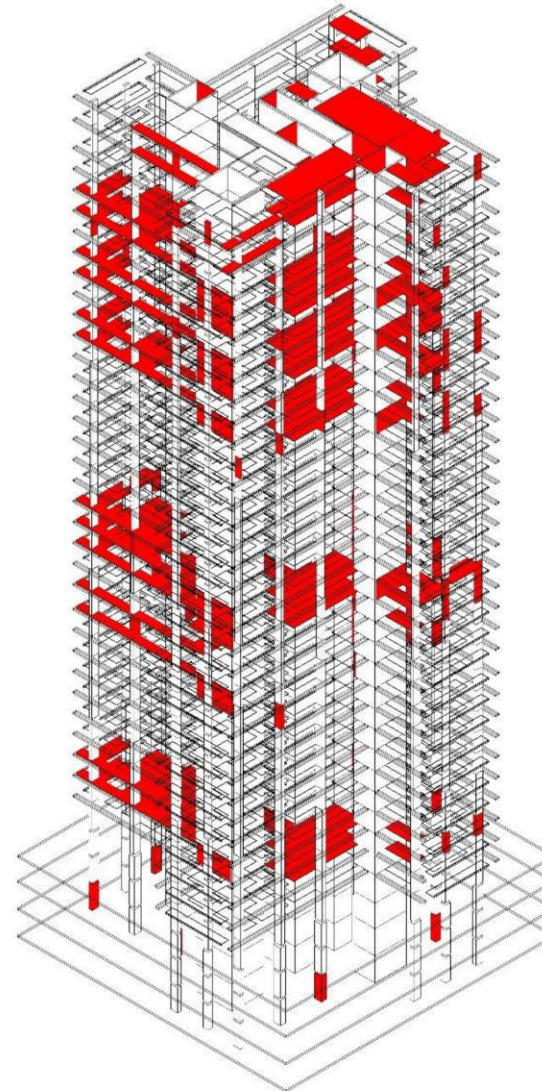
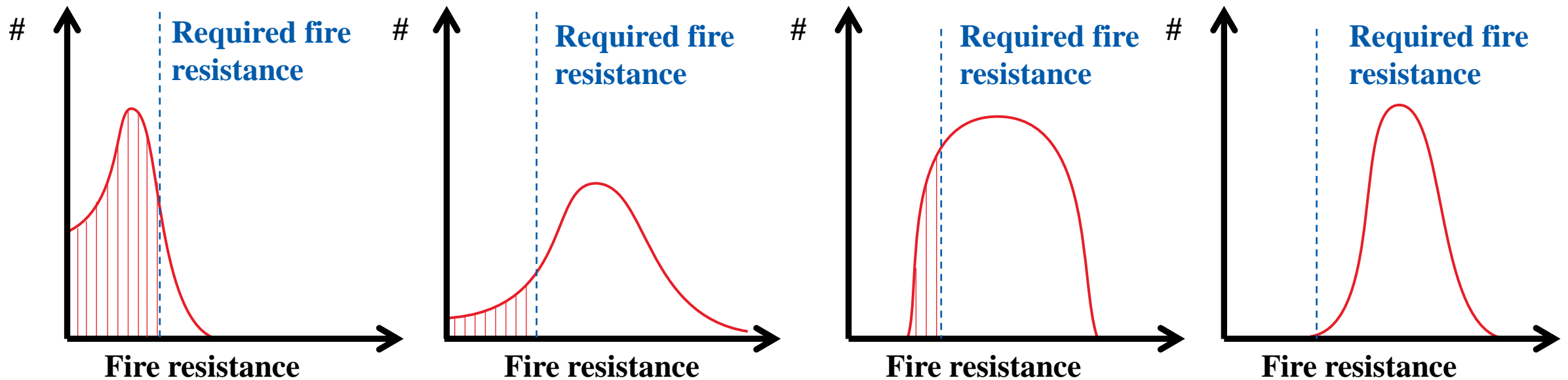


Table 6: Summary of covermeter data – number and floor of Sandberg's survey locations

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?

Thank you

Questions and discussion