Structural Fire Engineering Modelling and Design in Practice

Angus Law, PhD (time served 2003-2010)

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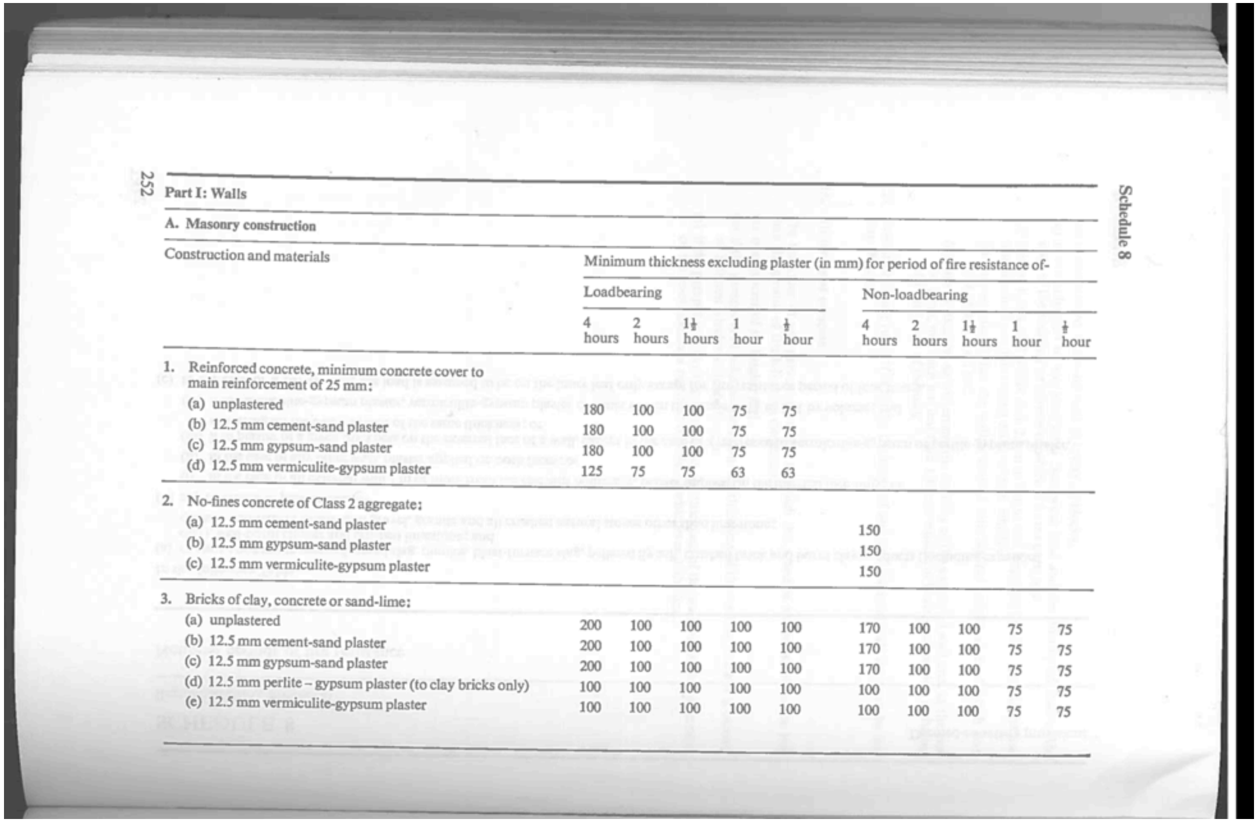
In 40 years we have progressed…

From furnaces to full frame behaviour.

From a few papers to a worldwide enterprise.

From ? people to ??? people.



252

Schedule 8

Part I: Walls

A. Masonry construction

Construction and materials	Minimum thickness excluding plaster (in mm) for period of fire resistance of– Loadbearing 4 hours	2 hours	1½ hours	1 hour	½ hour	Non-loadbearing 4 hours	2 hours	1½ hours	1 hour	½ hour
1. Reinforced concrete, minimum concrete cover to main reinforcement of 25 mm:										
(a) unplastered	180	100	100	75	75					
(b) 12.5 mm cement-sand plaster	180	100	100	75	75					
(c) 12.5 mm gypsum-sand plaster	180	100	100	75	75					
(d) 12.5 mm vermiculite-gypsum plaster	125	75	75	63	63					
2. No-fines concrete of Class 2 aggregate:										
(a) 12.5 mm cement-sand plaster						150				
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3. Bricks of clay, concrete or sand-lime:										
(a) unplastered	200	100	100	100	100	170	100	100	75	75
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(d) 12.5 mm perlite – gypsum plaster (to clay bricks only)	100	100	100	100	100	100	100	100	75	75
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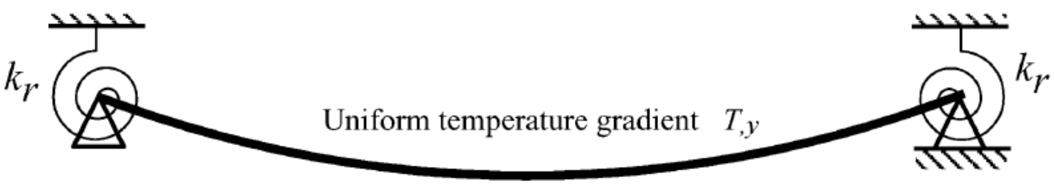
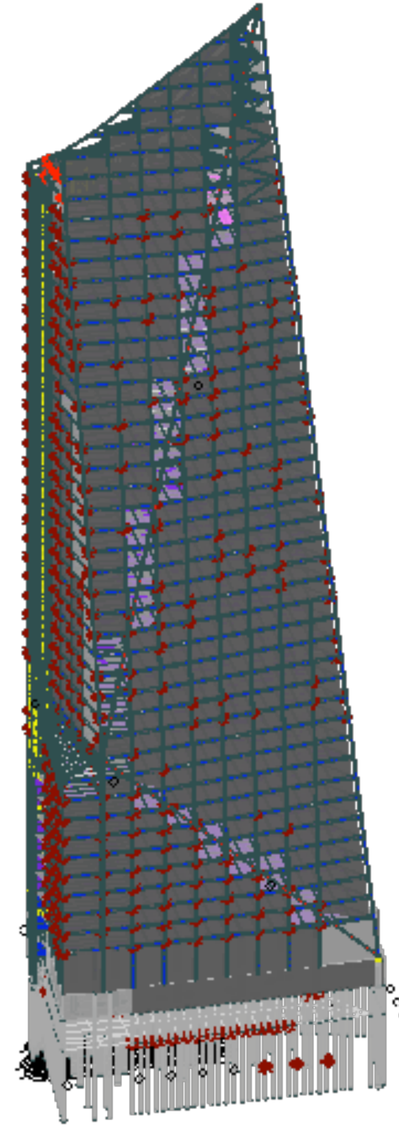
Building Regulations 1976



Usmani, 2001



Arup, 2013

Effective models are based on lessons that have been learnt from research and practice…

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The complexity of the model must be appropriate to the task at hand…

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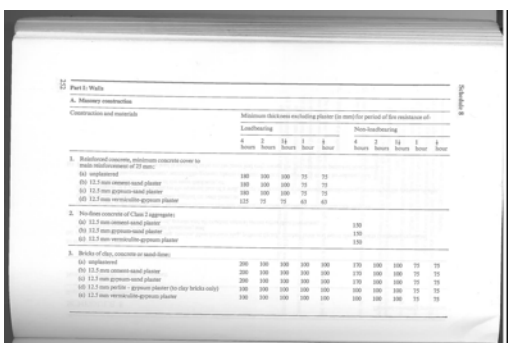

232 Part I: Walls

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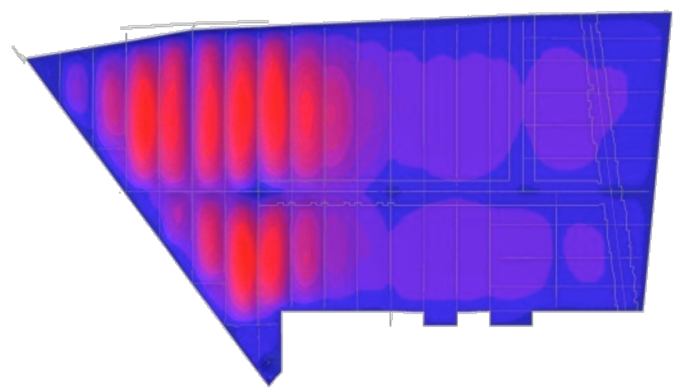

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How are models *for design* created?

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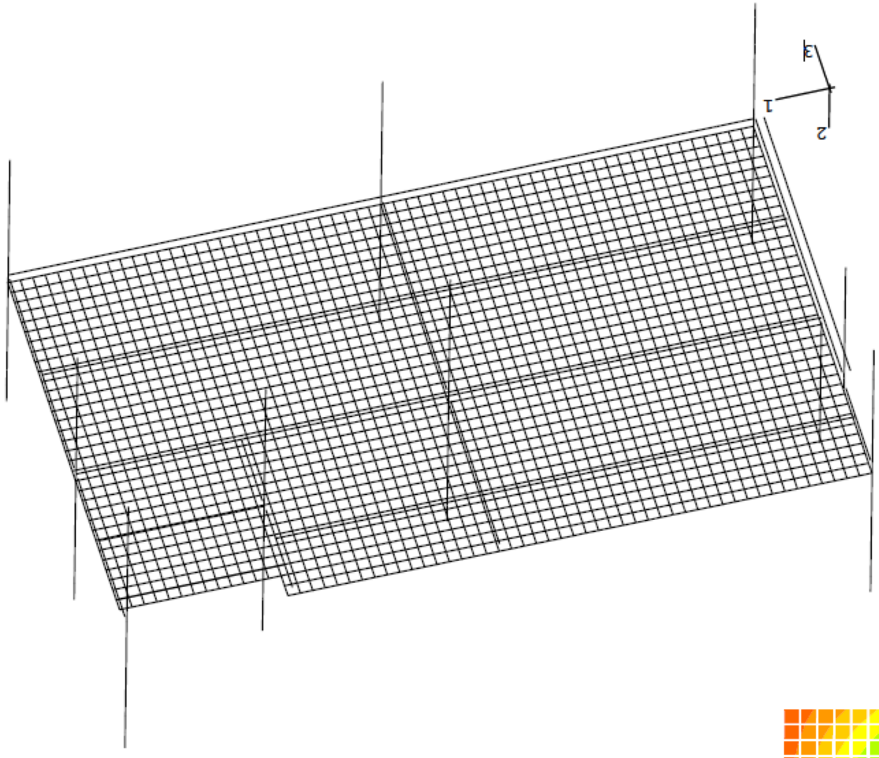
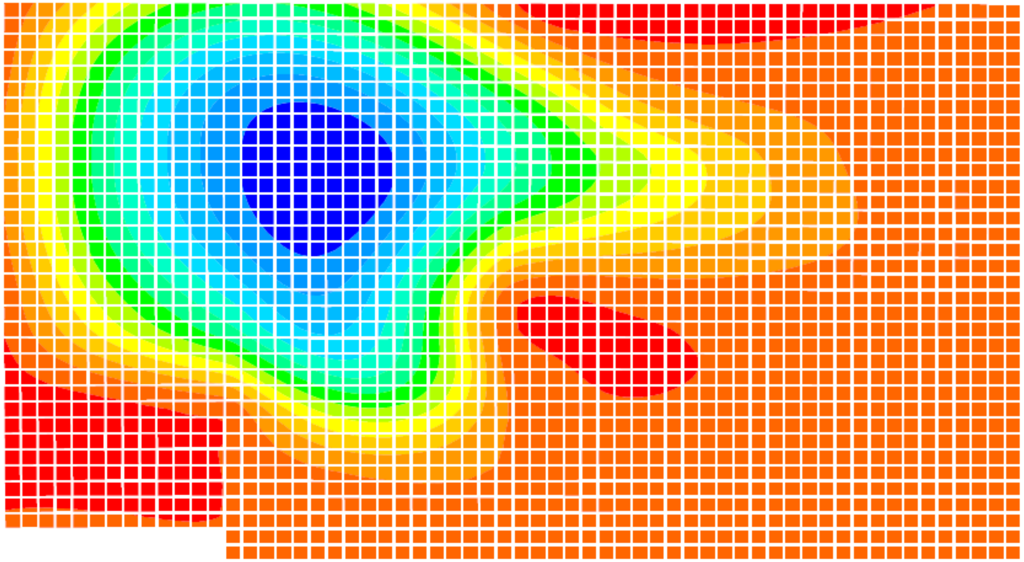
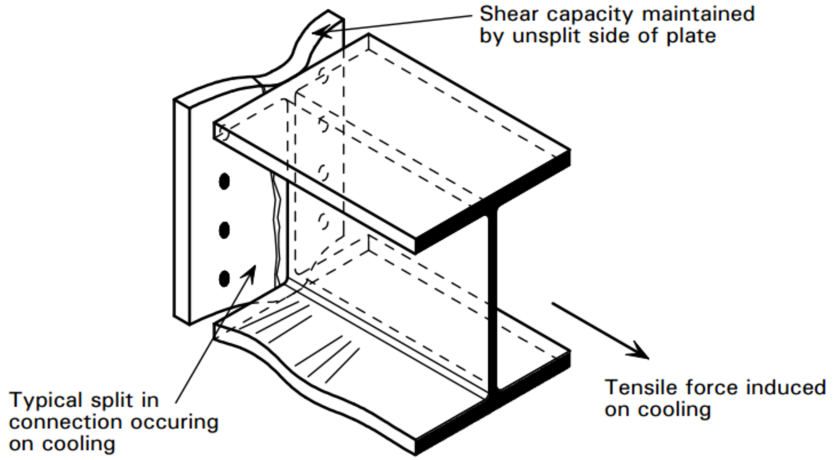
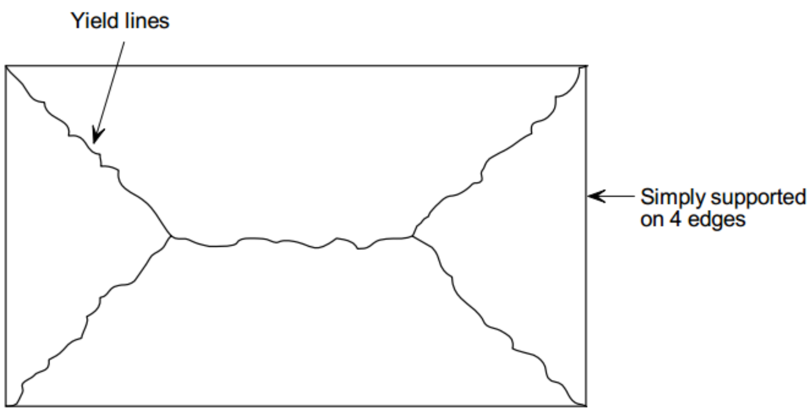
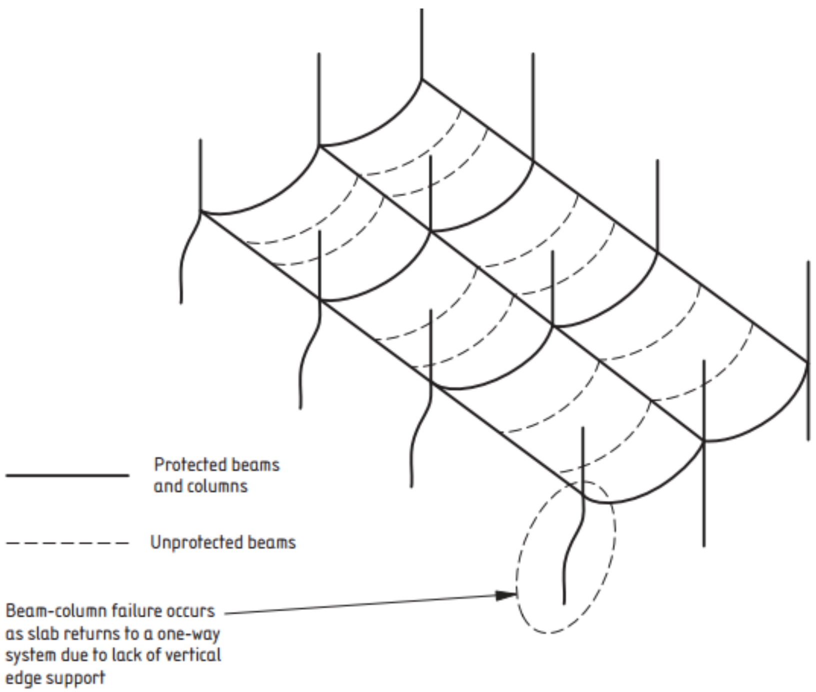




Gillie, 2001







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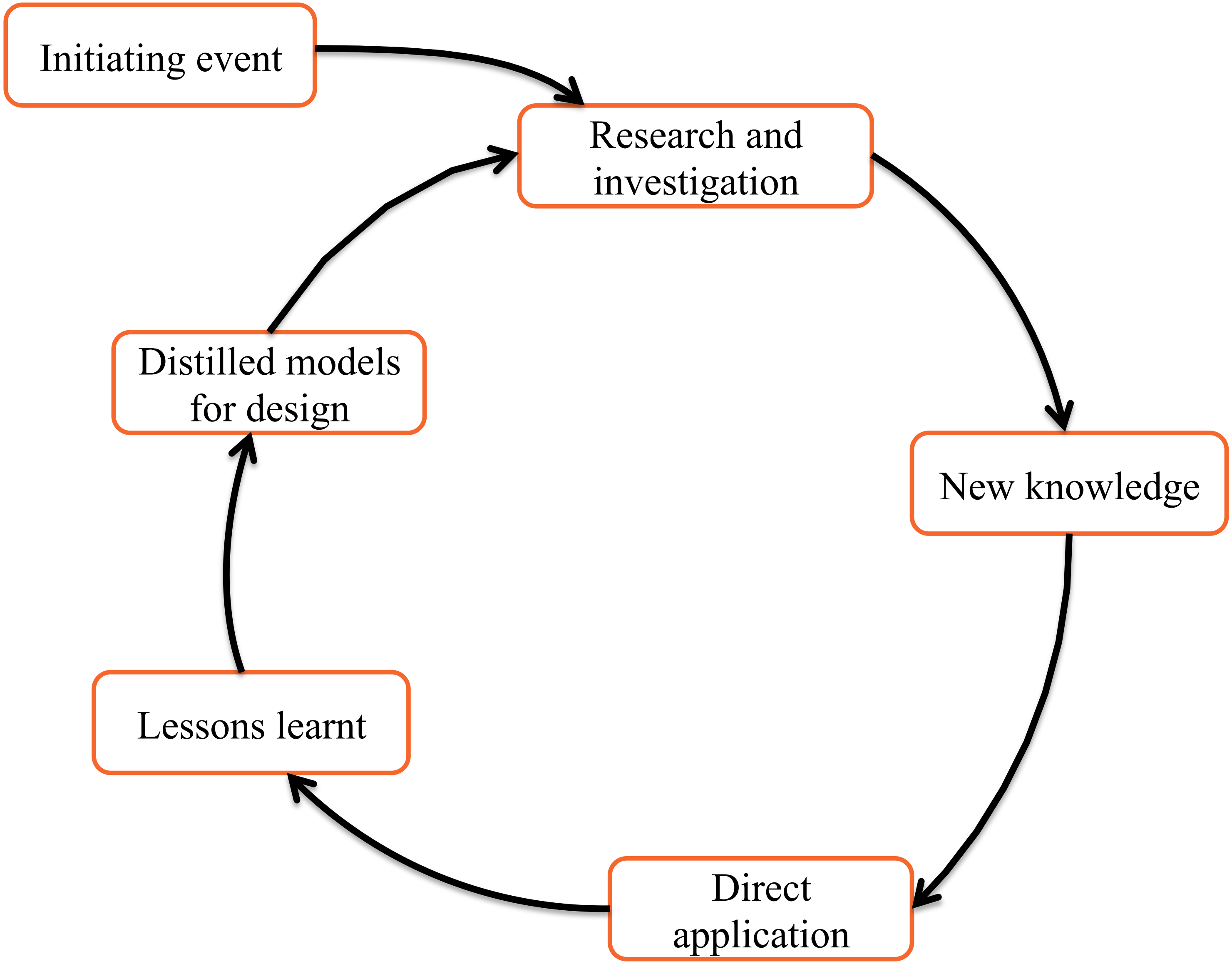
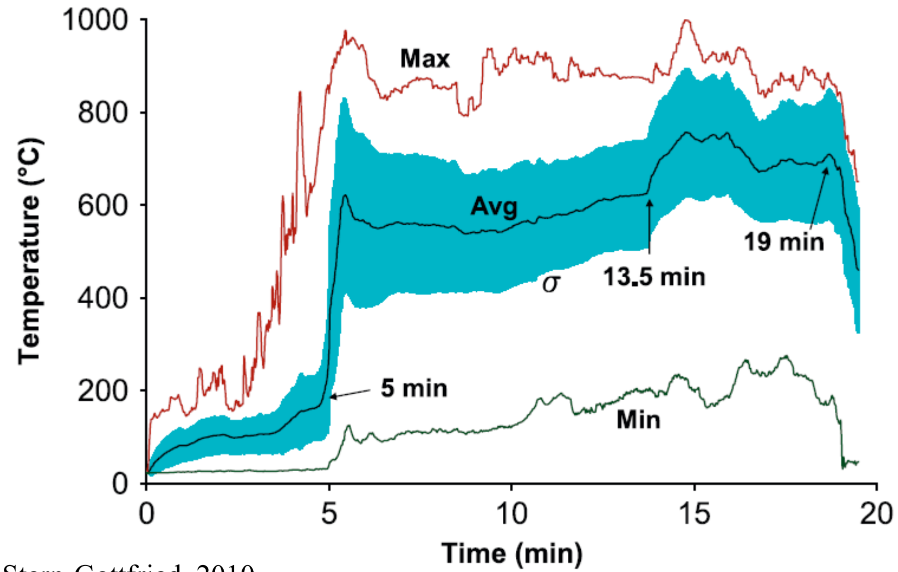
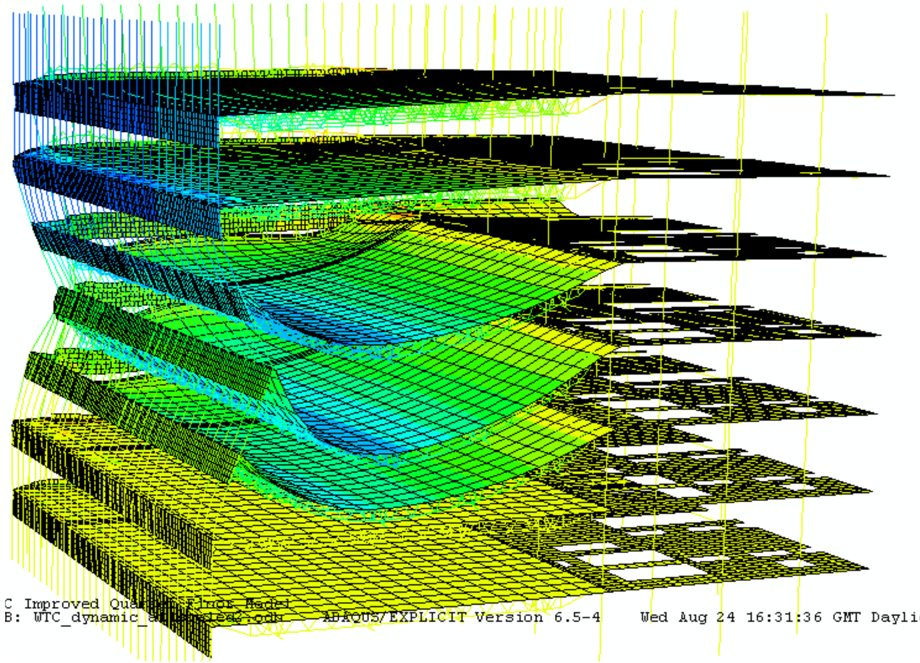
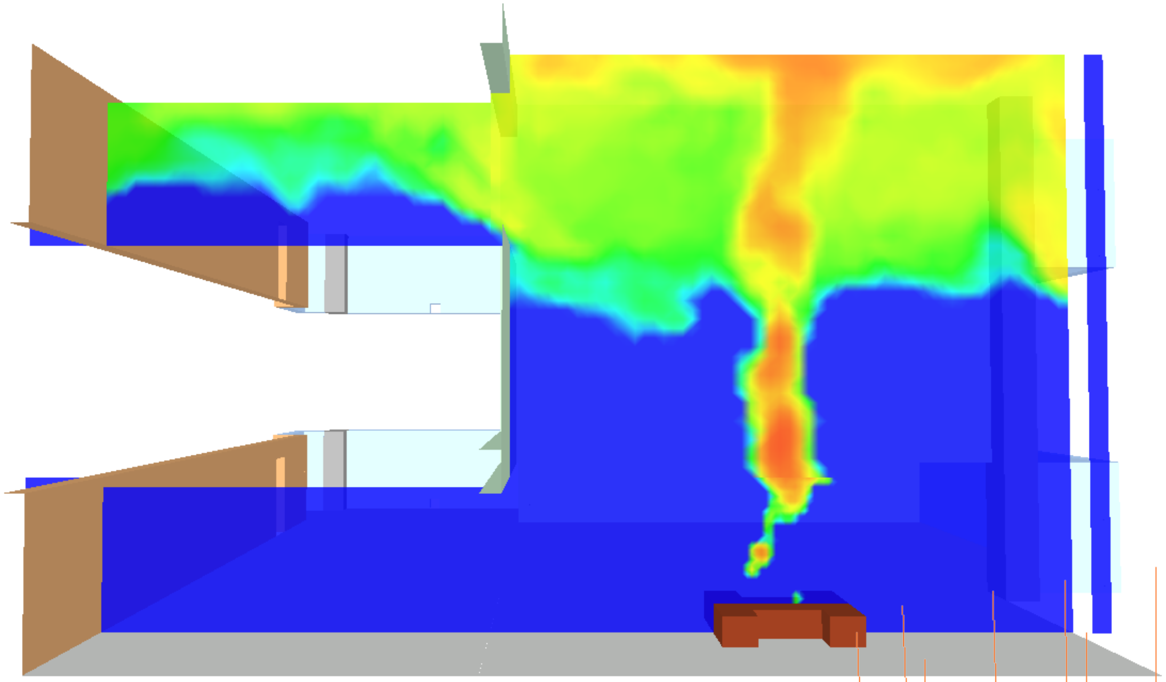

Initiating event
Research and investigation
New knowledge
Direct application
Lessons learnt
Distilled models for design

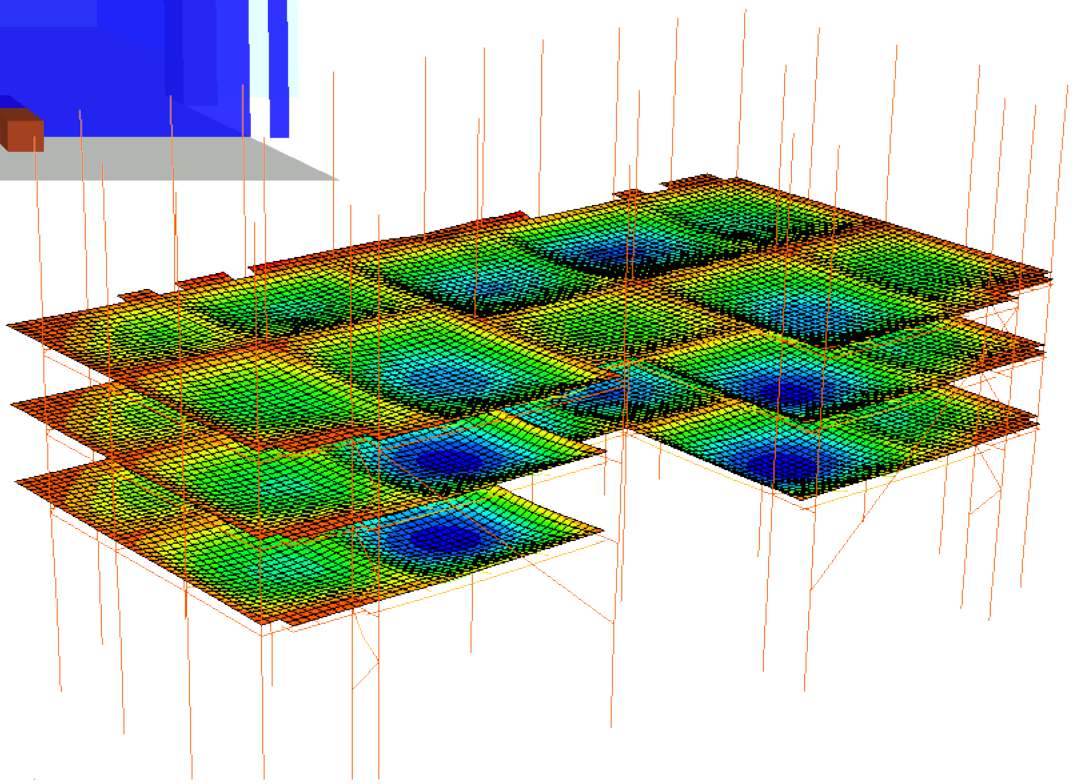


Stern-Gottfried, 2010

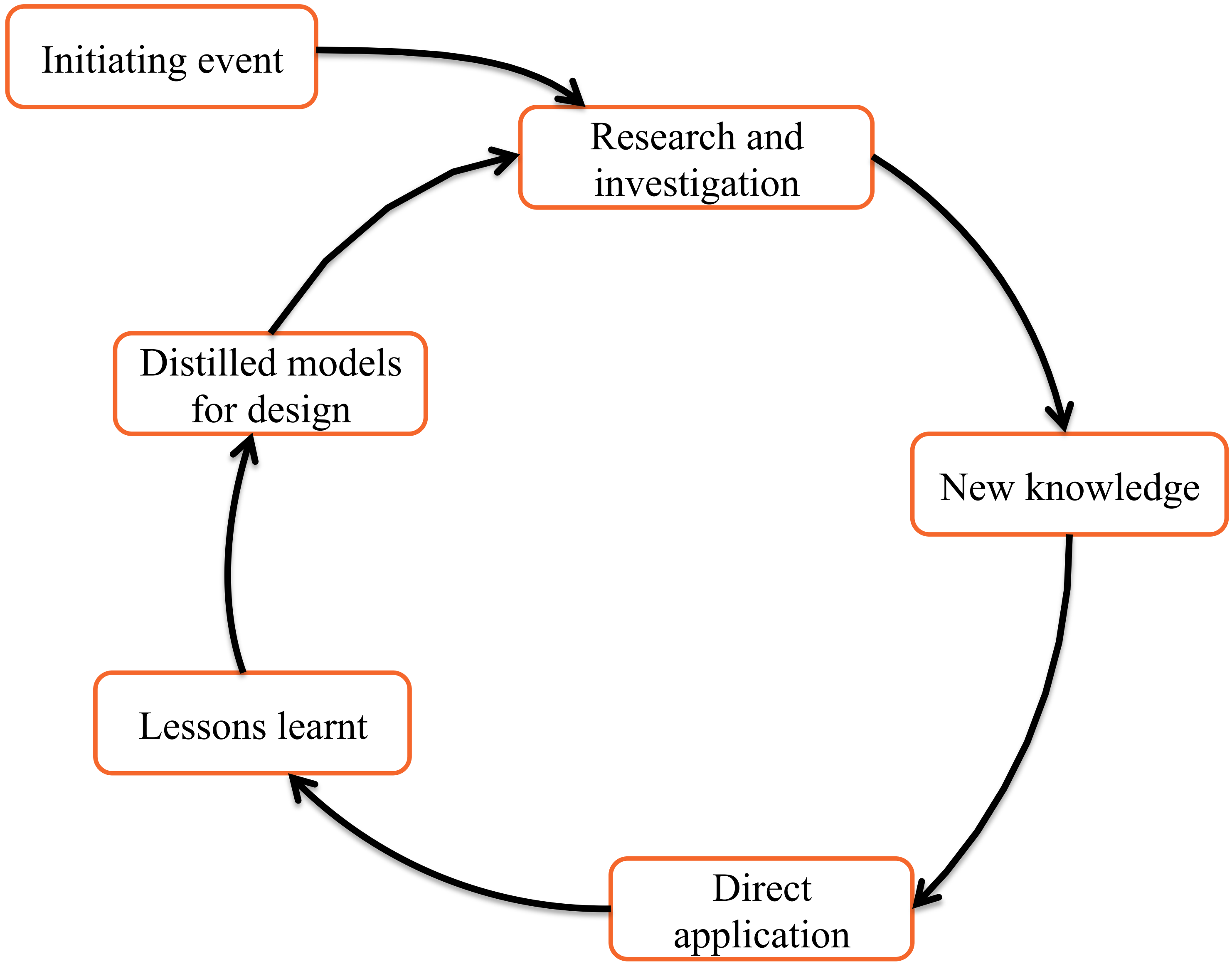


Flint, 2005





Torero, 2014


Initiating event
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Where are we, how did we get here, and where are going?

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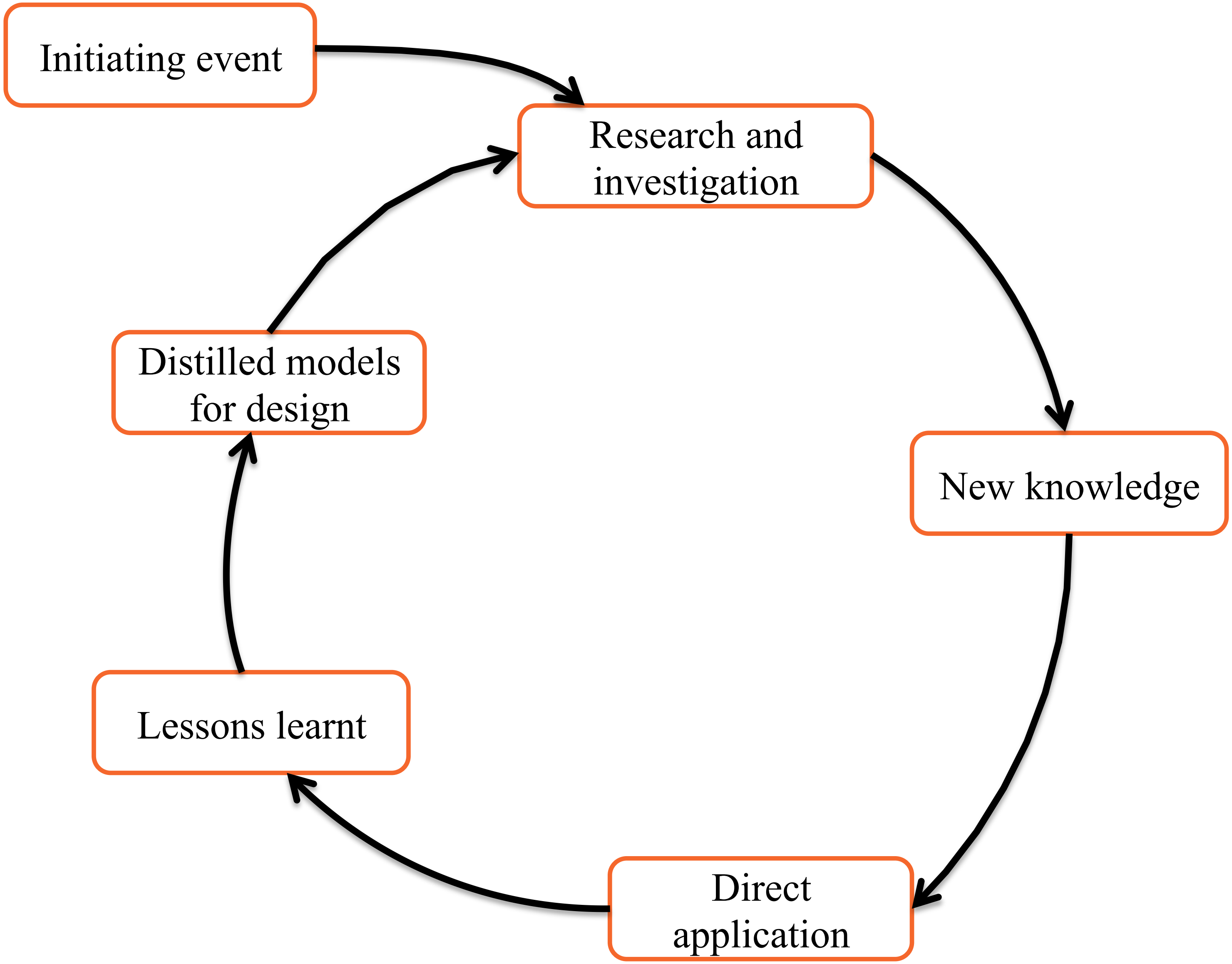
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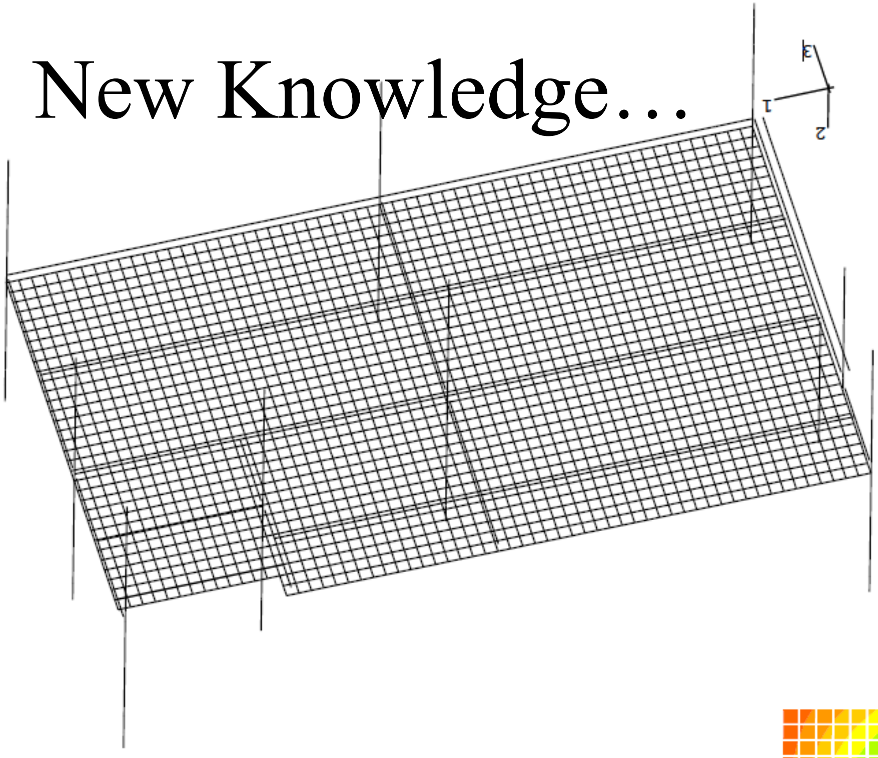
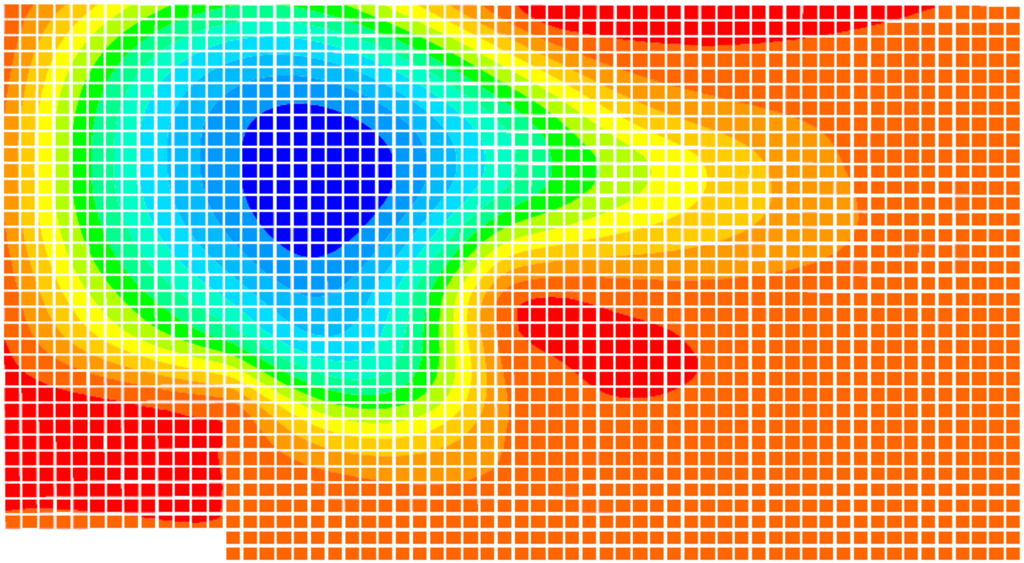
Research and investigation…

New Knowledge…





Gillie, 2001

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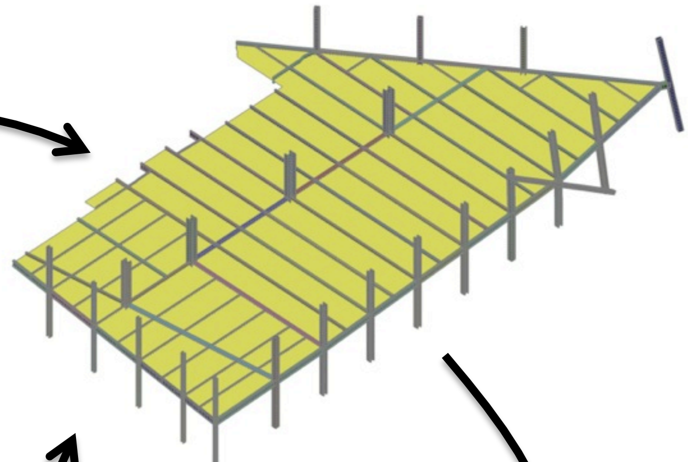
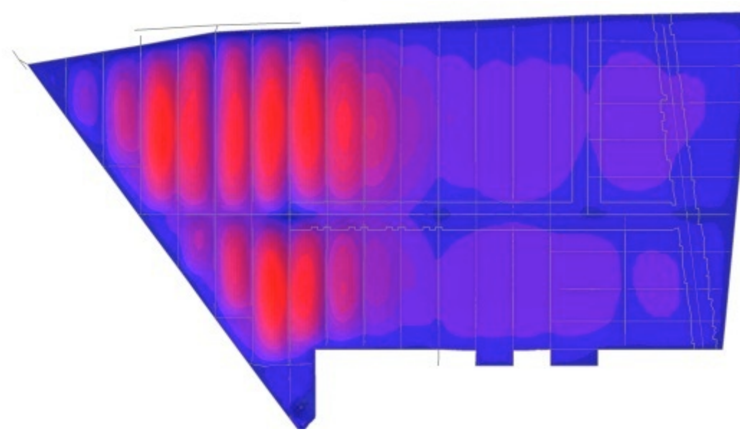
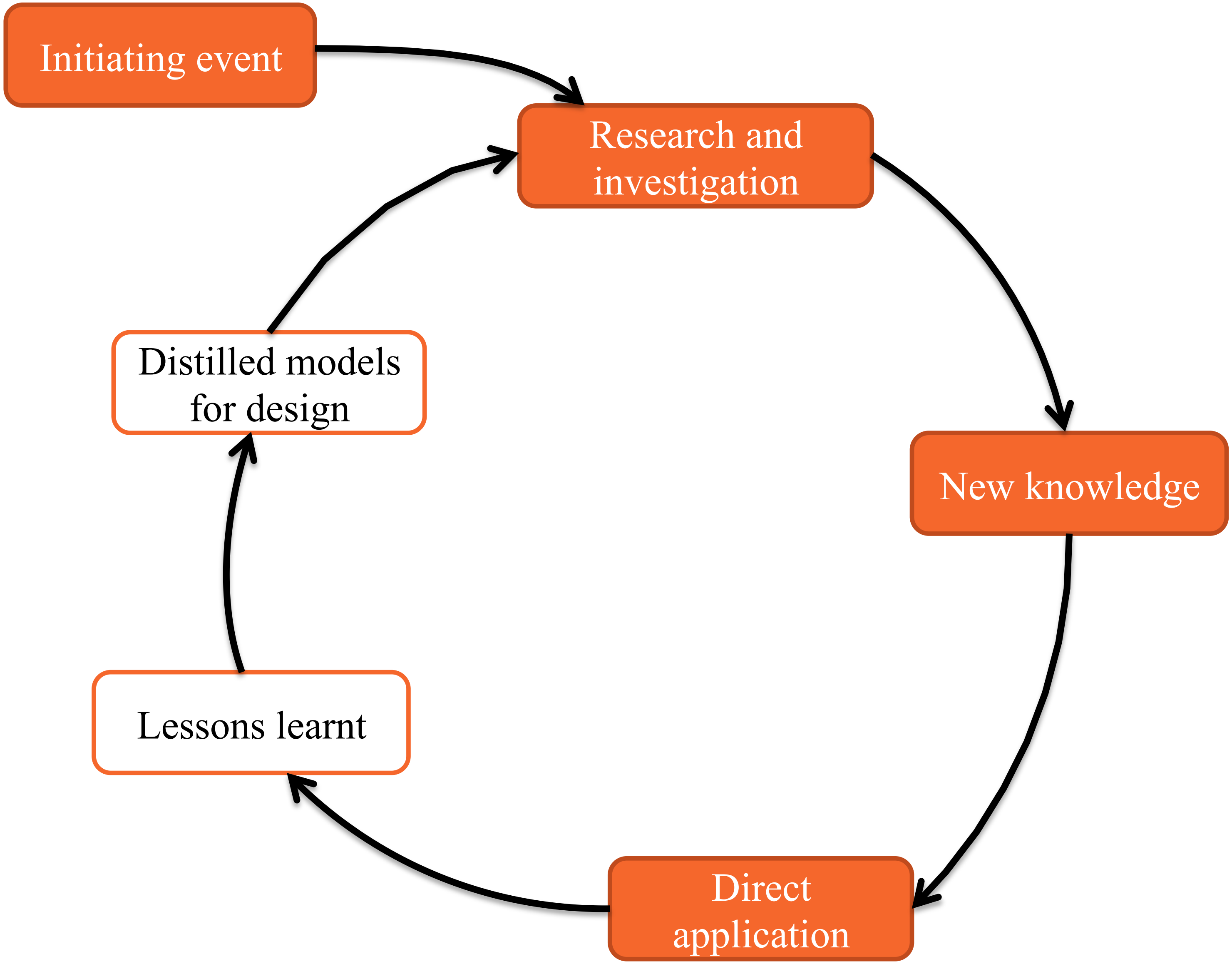
Direct Application...





Direct Application…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Lessons learnt…

Fire Technology
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Recent Lessons Learned in Structural Fire Engineering for Composite Steel Structures

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Received: 12 December 2011/**Accepted:** 21 July 2012

Abstract. The knowledge in the field of structural fire engineering has been greatly advanced through assessment of a number of real fires (WTC, Torre Windsor, Broadgate, etc.) and, especially, by the Cardington series of full scale structural fire tests. This knowledge has been used to validate and verify the use of computational finite element models that have expanded the range of structures that can be investigated under severe fire exposure. This paper presents a selection of key lessons learned by the authors through the assessment of structures in fire for real commercial building projects. The key areas of sensitivity that have been encountered are described and a discussion of each point presented. The paper is aimed at describing potential weaknesses that have been observed in the commercial work of the authors, often driven by the requirements for efficient ambient structural design. The paper concludes with some suggested advice for structural engineers aimed at increasing the general robustness of building structures. This is based on designing out as far as possible in the ambient design of a structure the potential weaknesses identified in past project work.

Keywords: Structural fire engineering, Fire, Structures, Finite element modelling, Composite steel frame, Connections, Restraint, Thermal expansion

1. Introduction

Recent decades have significantly increased the fund of knowledge available in the field of structural fire engineering and a number of buildings have been designed to withstand credible design fires based on an understanding of the performance of the structure in fire.

Starting with the Broadgate Phase 8 fire in 1990 [1] and through the extensive testing completed on the Cardington test frame [2] it has become apparent that composite steel framed buildings generally perform well under severe fire loading. However as demonstrated in the collapse of the World Trade Center (WTC) buildings, in particular buildings 1, 2 [3] and 7 [4], the full range of building response to severe fires are not yet known.

This paper presents a number of lessons that have been learned through the assessment of a variety of steel framed structures with steel–concrete composite floors under fire conditions over the past 10 years. All these lessons have been

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Flint, 2012

Collapse mechanism proposed by NIST in April 5 Presentation Report

The basis of NIST's collapse theory is also column behaviour in fire.

However, we believe that a considerable difference in downward displacement between the core and perimeter columns, much greater than the 300mm proposed, is required for the collapse theory to hold true.

Why upward expansion of the column would act against the mechanical shortening.

Crude initial calculations indicate that the elastic downward deflection at half the modulus (say at approx. 500C) will be roughly 38mm.

Assuming plastic strains, a maximum yielding of approximately 190mm is possible.

If the downward displacement is 300mm as assumed, the rotation at the perimeter connection would be 300mm vertical over an 18000mm span - extremely small.

The floor elongation must be less than 2.5mm to generate tensile pulling forces on the exterior columns as a result of the column shortening in the core.

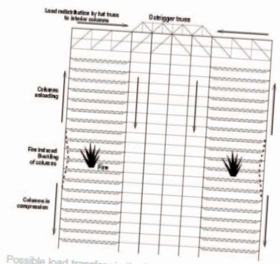
Thermal expansion of the floor truss would be 65mm at 300°C over a length of 18000mm.

Therefore the 2.5mm is swamped by thermal expansion and the core columns cannot pull the exterior columns in via the floor simply as a result of column shortening.

The NIST collapse theory also states that "floors weakened and sagged from the fires, pulling inward on the perimeter columns. Floor sagging and exposure to high temperatures caused the perimeter columns to bow inward and buckle—a process that spread across the faces of the buildings. Collapse then ensued".

This is similar to some of our collapse proposals but no mention of thermal expansion is made, the floor buckling and lack of support to the columns seems to be entirely due to loss in strength and stiffness in their view which we would consider to be only part of the story.

However we await the publication of the final NIST report in this regard.



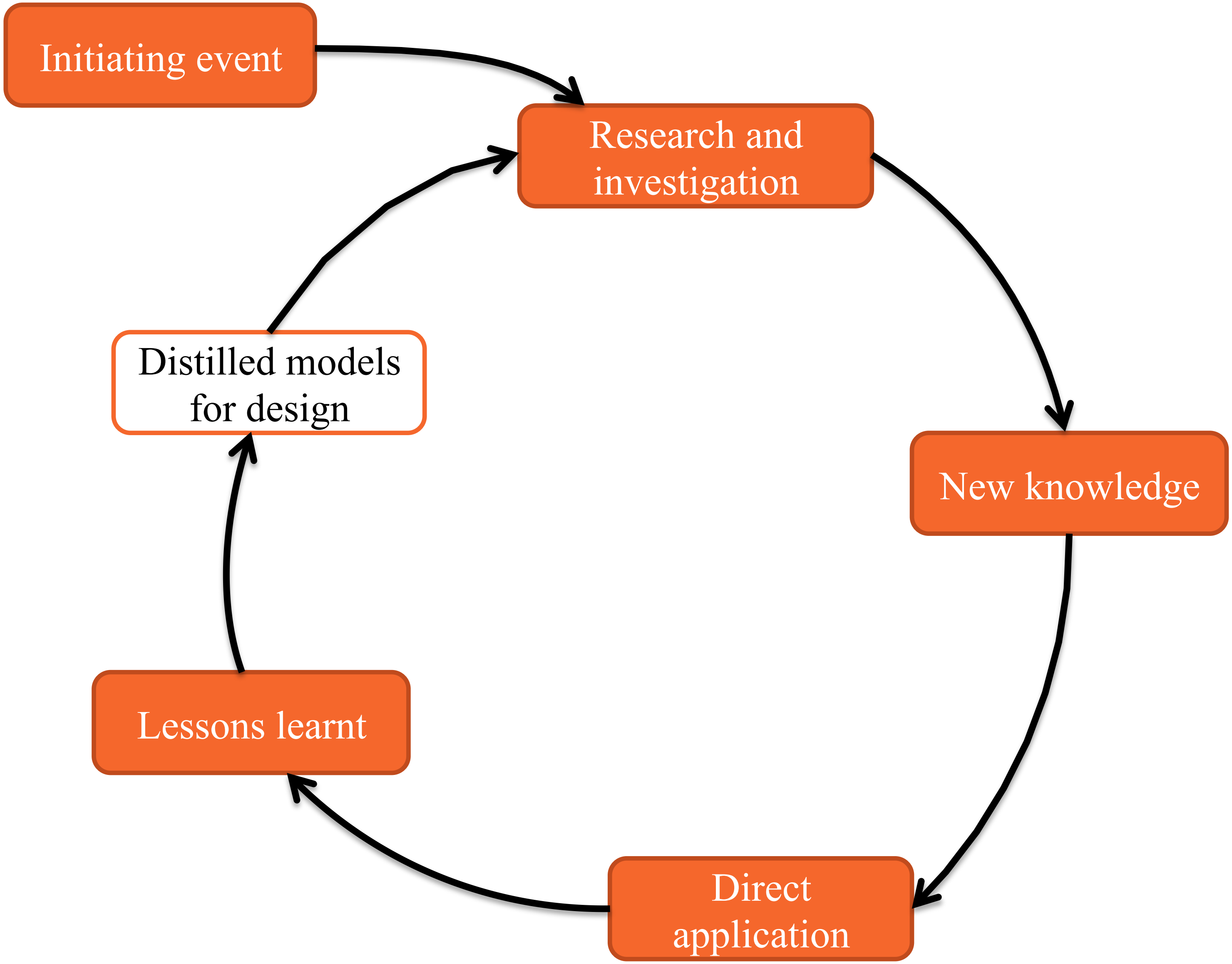
Possible load transfer via the hat truss at the top of one the tall building studies

Influence of the hat truss on the buildlings performance

We have analysed models with and without a hat truss at the top of a tall-building and found that - a hat truss significantly improves stability in multiple floor fires.

In the image above, the Hat Truss shows clear redistribution from outer columns to the core (primarily the outer core columns). NIST have also observed load transfer via the hat truss. Such issues could become the basis for future fire-related structural design guidance.

Lane, 2005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The **next logical step** is to succinctly capture the lessons learnt…

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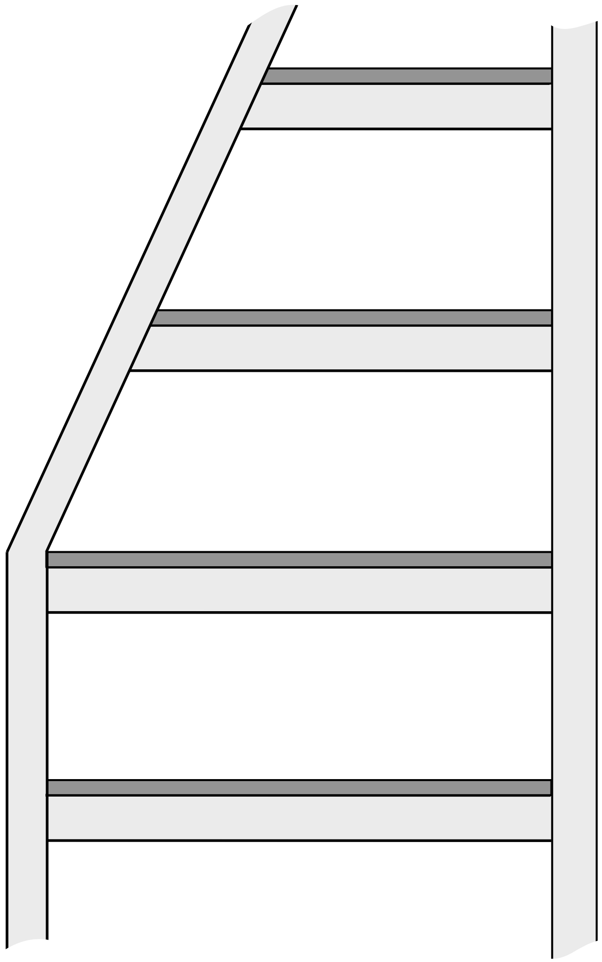
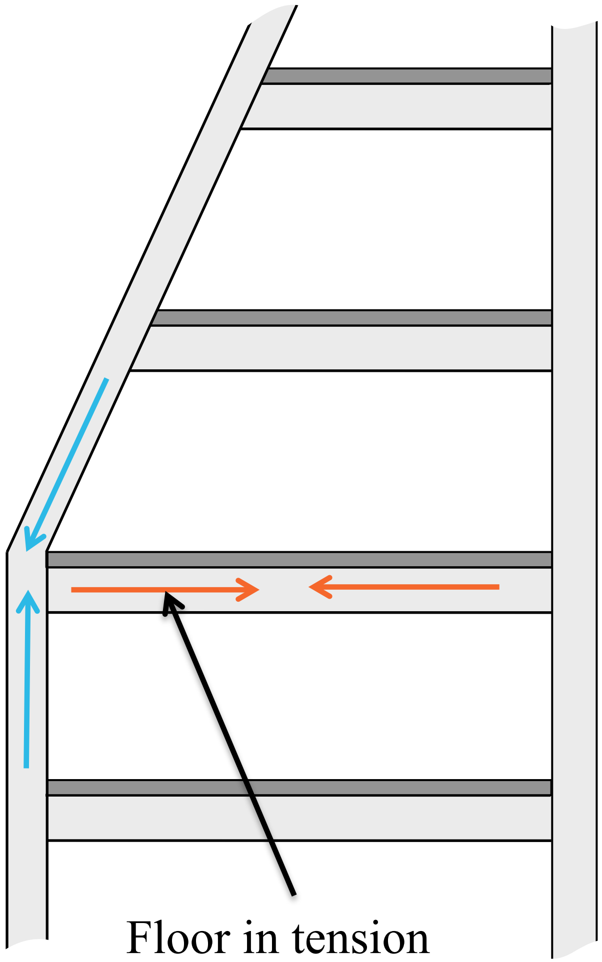
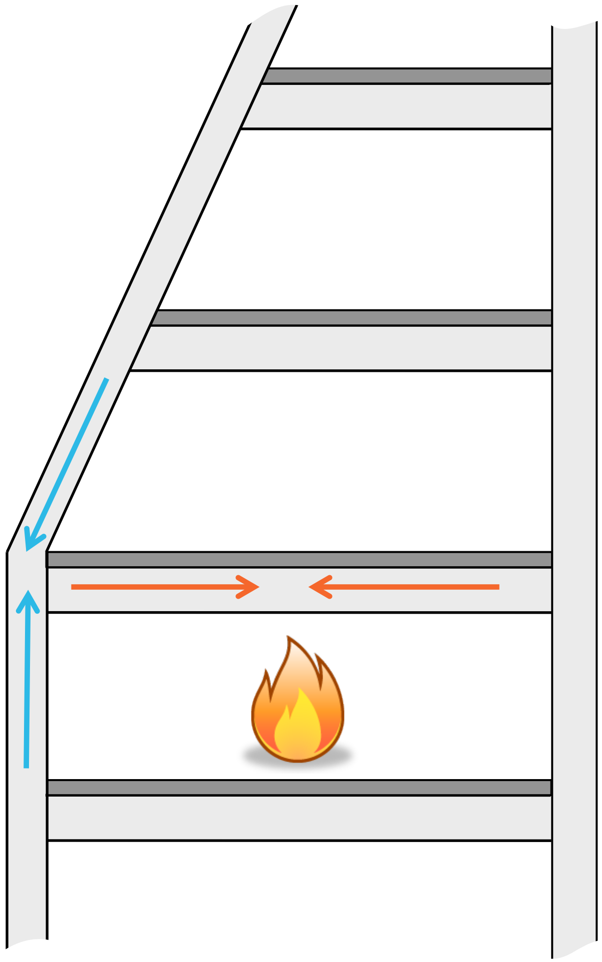



Floor in tension



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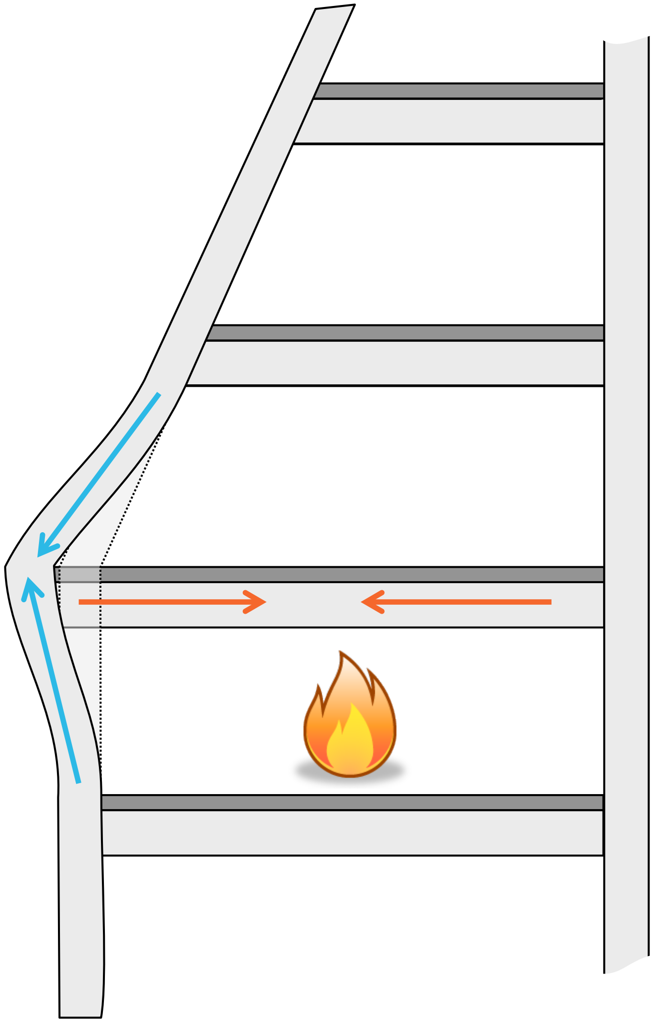

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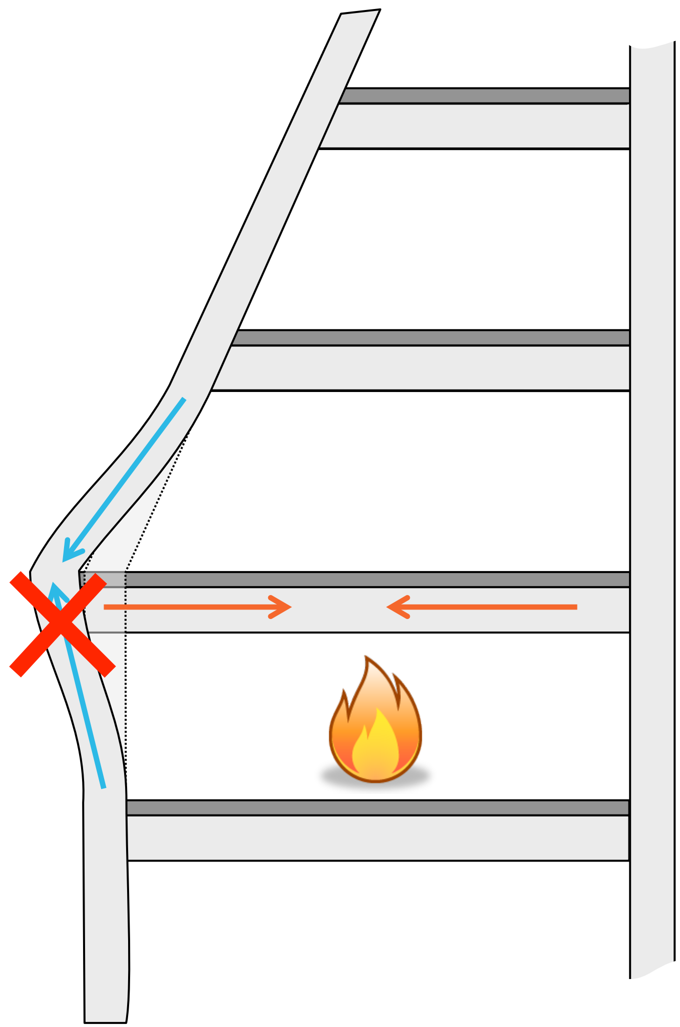

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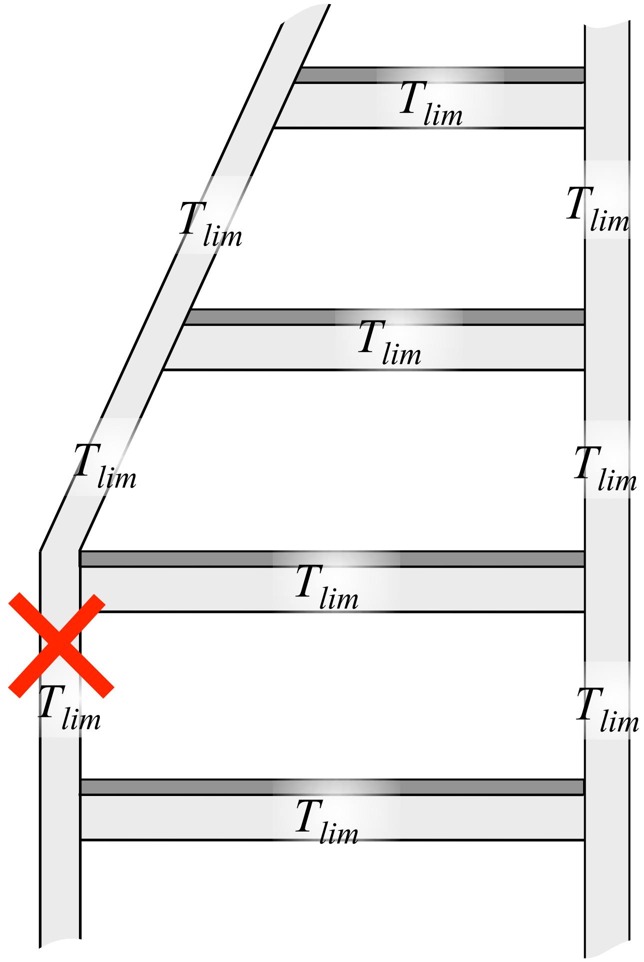
If all elements are considered **individually** the structure will not deliver the specified fire resistance…



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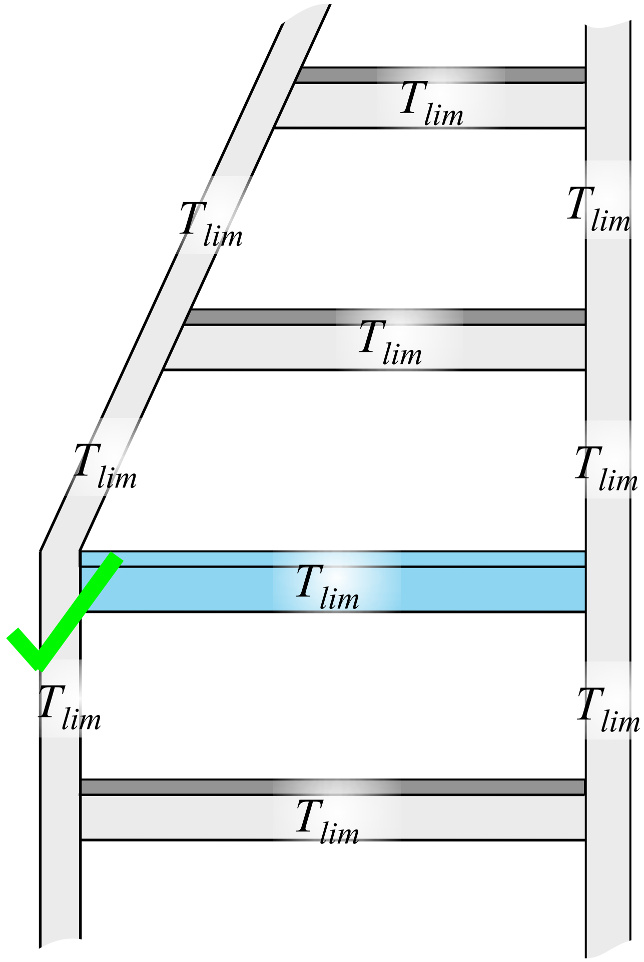
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This information can be readily captured and disseminated…

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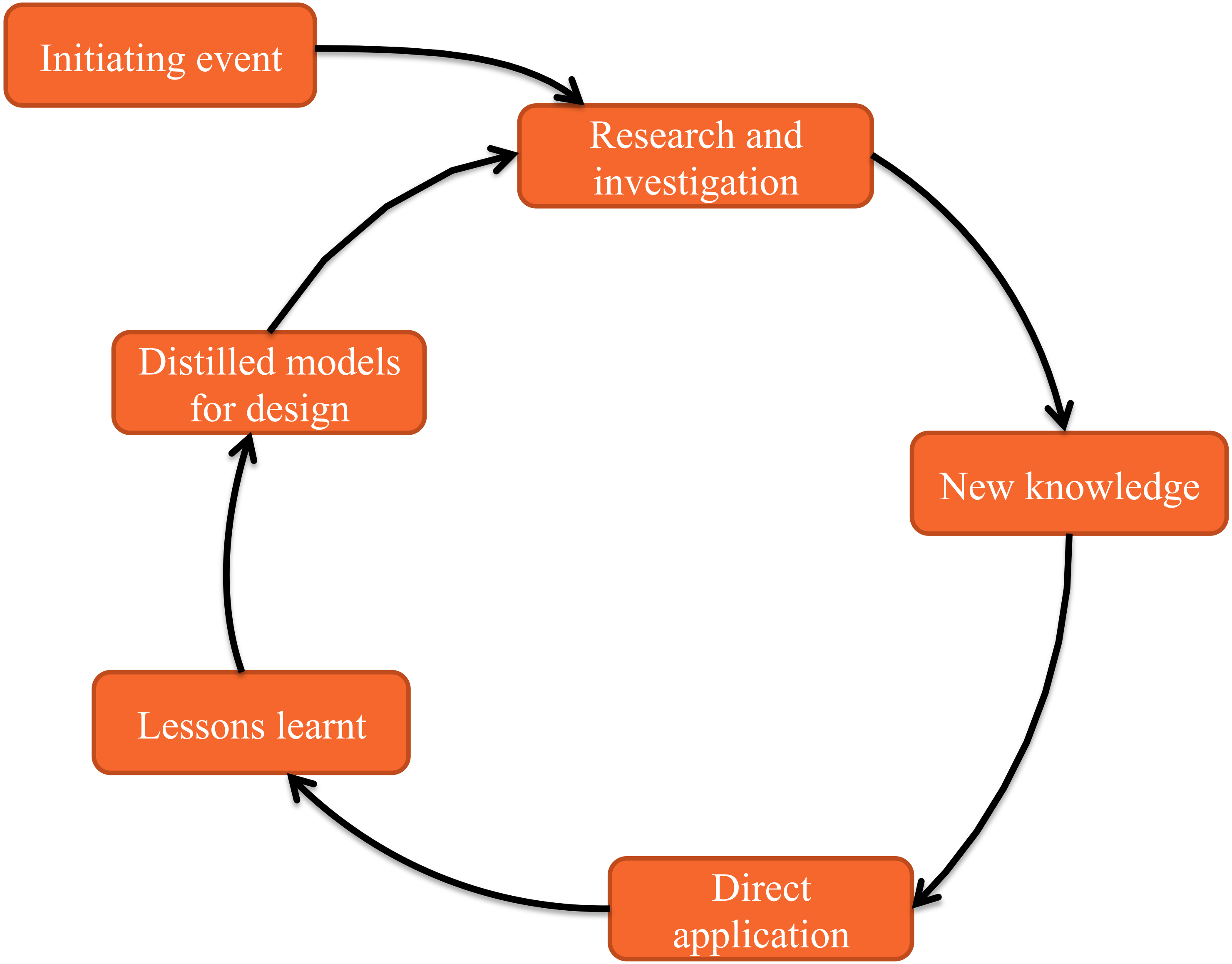
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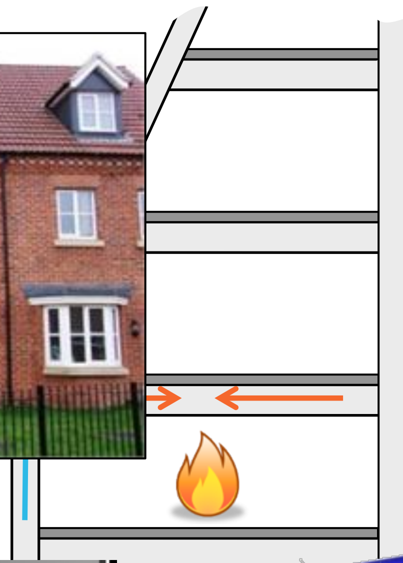

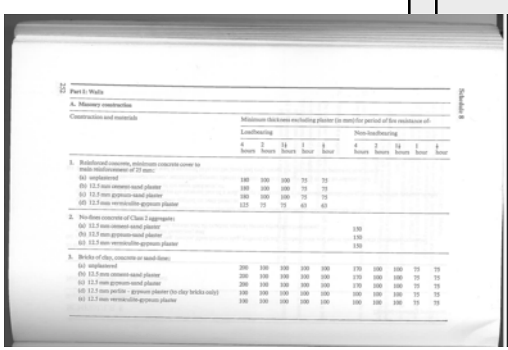

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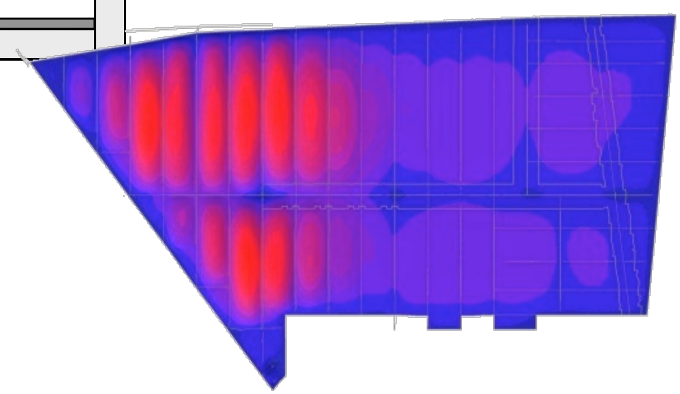

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We can **increase the benefits** of SFE by capturing lessons learnt and widely disseminating them…

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