Institution: Ulster University

Unit of Assessment: Architecture, Built Environment and Planning (13)

Title of case study: Travelling Fire Protection and Design Robustness Safety for the Built Environment: TRAVELFIRE

Period when the underpinning research was undertaken: January 2009 to December 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Ali Nadjai	Prof of Fire Structural Engineering	1995 - present
Dr Jianping Zhang	Reader in Fire Dynamics	2005 - present
Dr Sengkwan Choi	Reader in Structure	2008 -present
Dr Naveed Alam	Lecturer in Civil Engineering	2018 - present

Period when the claimed impact occurred: August 2013 to December 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

The Fire Safety Engineering Research & Technology Centre (FireSERT) has developed research that has impacted on standards, design guides and fire protection products for travelling fires in large compartments:

- **I1** FireSERT has demonstrated that the use of a new method of material protection in structural members subjected to travelling fires in buildings can provide more robust structures to avoid collapse.
- **I2** FireSERT has directly informed Eurocode regulations on fire-structural safety in relation to travelling and other fires.
- **I3** FireSERT has reduced the cost of fire protection.
- **I4** FireSERT has developed an international partnership leading to the formation of Efectis UK/Ireland enabling commercial fire testing and the employment of FireSERT graduates.

2. Underpinning research

Key research findings at Ulster in Fire Safety Engineering Protection are based on the methodology developed by Nadjai, Zhang, Choi and colleagues. It consists of the understanding of **Fire Behaviour** (**R1, R2**) and its impact on the surrounding structures based on fire scenarios in real small, medium and large-scale buildings and how such small, medium and large fires spread or travel in different sized compartments. **Advanced Fire Safe Materials** (**R3 - R5**) have been assessed by determining key flammability properties from small-scale tests and using these results in computer simulation models of fire growth and toxicity prediction. Integrating this understanding into **International and National Standards** has occurred by working with bodies that contribute to, for example, Eurocodes and promoting the increased adoption of Eurocodes (to which British Standards will remain aligned). This involves informing the national annexes with modifications of the different coefficients that must be considered in fire load assessment for different building types with these coefficients, taking into account the different active safety measures (**R6**).

In seeking to address the information deficit, research by Nadjai, Zhang, Choi and colleagues has focussed on fire safety materials and protection of compartments in large buildings. Notable awards during this period include: temperature assessment of a vertical steel member subjected to localised fire, (LOCAFI, 2012-2015, Nadjai) (**G1**, **I1**), with extended funding awarded (LOCAFI+, 2017-2019, Nadjai) for dissemination and design of regulations (**G2**, **I2**). Further FP7 projects include ENFIRO (2009-2012, Zhang) on development and assessment of environmentally friendly fire retardants (**I3**) and ELISSA (2013-2016, Zhang) on testing, assessment and demonstration of nano-enhanced lightweight steel skeleton/dry wall systems with improved thermal, vibration/seismic and fire performance (**G3**, **I1**) and H2020 project EENSULATE (2017-2021,

Zhang), on the development of innovative lightweight and insulating energy efficiency components and associated enabling materials for cost effective retrofitting and new construction of curtain wall facades (**G4**, **I1**). This and related work was of interest to Efectis (France) and led to a joint business venture with the formation of Efectis UK/Ireland with the FireSERT facility (**I4**).

Further, unique innovative research in Travelling Fires (TRAFIR) was conducted (2017-2020, Nadjai, Alam). The significance of this study is highlighted by the collaboration with major industrial steel, concrete and protection materials fabricators throughout Europe (**G5**, **I1, I3**). A further project on development and evaluation of protective clothing under extreme conditions (**G6**, **I2, I3**) was funded by the Korean Ministry of Public Safety and Security, in which a comprehensive finite element analysis model was developed and validated for coupled thermo-physical behaviour of an inorganic intumescent system (**R5**).

In summary, our approach in designing large open safety compartments in travelling fire consists of five parts, namely, **1:** fire safe materials (inserting additives inside the material, intumescent paint) for walls partitions, façade systems and steel structural elements, with these additives providing additional advantages for the materials and contributing significantly to their improved safety performance (**G3, G6**, **I1**); **2:** conducting real world fire performance testing from small scale to large scale using resistance to evaluate the structure performance insulation, integrity and load bearing (**G4**, **I1, I2**); **3:** large scale experiments conducted outside FireSERT in real buildings subjected to open ventilation conditions (**G2, G5**, **I2, I3**) to assess the parameters which influence the development of a travelling fire; **4:** the development of standards and design guides at European level by establishing technical rules for fire safe design of buildings made of steel construction (**G5**, **I2**). A new calculation method based on the equations contained in Annex C of EN1991-1-2 combined with the concept in Annex G were investigated (**G1, R6**, **I2**); and **5:** generating opportunities for industrial engagement where research becomes reality (**I4**).

3. References to the research

The underpinning research has been published in leading peer reviewed journals in the areas of fire structures, fire safety and design regulations for UK/Ireland and European Union countries.

R1: Nadjai, Ali, Petrou, Klelia, Han, Sanghoon and Ali, Faris (2016) Performance of unprotected and protected cellular beams in fire conditions. *Journal of Construction and Building Materials*, 105. pp. 579-588. 10.1016/j.conbuildmat.2015.12.150.

R2: Naveed, A, Nadjai, A, Faris, A and Nadjai, W (2018) Structural response of unprotected and protected slim floors in fire. *Journal of Constructional Steel Researc*h, 142, pp. 44-54, Mars 2018. 10.1108/JSFE-04-2018-0011.

R3: Asimakopoulou, E, Zhang, J, McKee, M and Papakonstantinou, P (2020) Fire retardant action of layered double hydroxides and zirconium phosphate nanocomposites fillers in polyisocyanurate foams. *Fire Technology*, 56(2). 10.1007/s10694-020-00953-7.

R4: Tian, N, Delichatsios MA, Zhang, J and Fateh T (2018) A methodology and a simple engineering fire performance model for Intumescent Fire Retardant coatings. *Fire Safety Journal*, 98, pp. 120-129. 10.1016/j.firesaf.2018.04.010.

R5: Kang, S, Choi, SK and Choi, JY (2017) Coupled thermophysical behaviour of an inorganic intumescent system in cone calorimeter testing. *Journal of Fire Sciences*, 35 (3), pp. 207-234. 10.1177/0734904117701765.

R6: Charlier, M, Vassart, O, Nadjai, A, Dai, X ,Welch, S, Sjöström, J and Anderson, J (2020), A Simplified Representation of the Travelling Fire Development in Large Compartment using CFD Analyses. Jo*urnal of Structures in Fire,* pp. 526-536. 10.14264/e1f0ecb.

The quality of the outputs of the research is also evidenced by the awarding of European and international projects with the key grants listed below:

G1: Nadjai
Temperature assessment of a vertical steel member subjected to localised fire, (LOCAFI)
01/07/2012 - 30/06/2015
RFSR-CT-2012

GBP78,185

G2: Nadjai
LOCAFIplus-Temperature assessment of a vertical steel member subjected to localized fire
01/07/2017- 31/05/2019
CEC-Coal and Steel
GBP38,438

G3: Zhang
ELISSA: Energy efficient lightweight-sustainable-safe-steel construction,
01/01/2014 - 31/12/2016
CEC FP7 - NMP
GBP285,996

G4: Hyde and Zhang
EENSULATE: Development of innovative lightweight and highly insulating energy efficient components and associated enabling materials for cost-effective retrofitting and new construction of curtain wall facades
01/10/2016 - 28/02/2021
CEC-H2020-IL-NANOTECH
GBP592,311

G5: Nadjai
TRAFIR - Characterization of TRAvelling FIRes in large compartments
01/07/2017- 31/12/2020
CEC-Coal and Steel
GBP120,316

G6: Choi
Protective Clothing under Extreme Fire Conditions
01/01/2016 - 30/06/2020
Korean Ministry of Public Safety and Security
GBP146,842

4. Details of the impact

I1 Impact on Industry

FireSERT research has led to the manufacture of new fire wall partitions for compartments, the development of intumescent coatings with improved fire performance, and high fire resistance wall and floor insulation for new lightweight dry wall construction elements used in prefabricated steel buildings. The *significance* of the research lies in the impact it has had on production systems in these areas and ultimately their incorporation into products used in a range of circumstances embracing domestic and commercial environments. Thus, the *reach* of the impact while initially with specific companies has, through incorporation into products, been extended to other applications.

The methodologies underpinning the research have been applied by companies beyond the UK and Ireland. In addition to Efectis (France), Iris Vernici Ltd (**R4, C1**), an Italian based SME specialising in the production of coatings for the building and manufacturing industry, has used FireSERT's research in improving the fire resistance of intumescent coatings by the inclusion of nanoclays. The underpinning research has played an important role in the development of several commercial intumescent coatings and an unsaturated polyester intumescent system. As an example it has been stated by the CEO of Iris Vernici that "*These new developments have assisted in surpassing the regulation requirements and in increasing our sales*" (**C1)**.

Other examples of impact on industry include CrossFire, a UK company specialising in fire protection for building materials such as varnishes, paints, coatings and thinners, who have confirmed that "*As an industrial leader in this field, CrossFire Specialist Contracts Ltd have utilized this research and took the lead role in implementing this knowledge as part of the design process in several prestigious projects in the UK & Ireland and overseas including the Middle East*" (**C2**). The research conducted in the ELISSA project (**G3**) contributed to the development of a new nano-

based intumescent coating formulation for steel structures with ArcelorMittal steel manufacturer stating that the "*Steel Industry will certainly gain significant market share of steel columns and beams used in construction around the entire globe with increase of further employment of fire engineers in the industry in the different corners of the world*" (**C4**). The product meets the standard EN 13381-4, for the protection of metal structures inside plasterboard walls. The significance of this research is the development of a new lightweight dry wall construction element to be used in prefabricated modular construction.

I2 Impact on Regulations

The impact of the underpinning research from FireSERT on localised (LOCAFI) (**G1**) and travelling fire (TRAFIR) (**G5**) in large compartment structures such as airports, large railway stations, and other complex buildings such as multi-storey car parks is apparent within modern architecture and the associated built environment. In particular, there have been a number of significant contributions to fire safety regulations via committee membership of British Standards FSH/22 - Fire resistance tests and cost savings, as noted in various contributions to corroborating evidence from industry (**C1, C2**). The reach of this impact extends beyond industry with benefits to wider society in terms of safer energy efficiency within steel construction as well as better recyclability and durability of infrastructure in the event of fire. These contributions to the regulatory environment are further evidenced by the implementation and development of a new design method for compartment localised fires in the National annexes of EN 1991-1-2 (**C5**) based on FireSERT research and updated with the development of user-friendly tool O-zone software (**R5**)**.**

The significance of the impact of the research is evident in the design guidance provided to industry as highlighted by the corroborating statement from Cundall Ltd who state that "*We utilise the cutting-edge techniques developed by the FireSERT research centre at the University of Ulster to optimise the building response to fire conditions and improve the structure performance*" (**C3**) and from ArcelorMittal which highlights benefits such as cost savings and increased employment opportunities in design and building construction. This latter contribution was made at an international workshop (November 2018) organised by Ulster University in conjunction with Engineers Ireland and chaired by Nadjai, to disseminate recent research and developments in the area of structural fire engineering, giving consultants the tools to provide clients with the most cost-effective design solutions (**C4**).

The findings emanating from FireSERT are also directly applicable to industry and the impact of the research is providing the construction industry with more economic and safer solutions that meet structural performance criteria as illustrated by the corroborating letters from ArcelorMittal: **"***This collaborative, European research project should supplement the structural Eurocodes and provide guidance on travelling fire missing from those codes"* (**C4).** An official invitation from the Northern Ireland Assembly for Nadjai to present oral evidence about Building Regulation in Northern Ireland is of note as the session was scheduled to be televised live throughout Parliament Buildings and on the BBC Democracy Live website (**C6)**.

I3 Impact on the Environment

In modern buildings and infrastructure, a major environmental consideration is the embedded energy and CO_2 burden that is included in the construction of the structure itself. FireSERT experimentation and subsequent modelling has identified the level of protection required for the entire structure while maintaining optimal safety. This is linked to less consumption of protection materials in a manner that also decreases the energy and carbon footprint of the structure itself.

An example is found in the opinion offered by Iris Vernici where it is stated that "*These and further developments are the result of advancing the use of nano-particles (silica, nanoclays, and fibres), phosphorous (phosphates, phosphinates), environmentally safe fire retardants and intumescent coatings*" (**C1**). Additional impacts in this regard are evident in the provision of structures that have better recyclability and durability. Nobody is able to predict how fire protection materials such as intumescing paint will react after 20 years and hence research on how these materials may affect the recyclability of the structural elements in a negative manner is thus important to optimise their effective application (**C7, C8**).

The international nature of the research published by Nadjai and colleagues in FireSERT has continued to result in new collaborations with, for example, a Knowledge Transfer Partnership established with FP McCann Ltd to develop new fire protection materials for precast sandwich panels used in high rise buildings (**C8, C9**). The outcome of the KTP is challenging the new industry standards needed to develop the next generation of Fire-Rated Precast Concrete Sandwich Panels (PCSPs). This is introducing advanced construction materials that are scientifically tested with proven fire rated performance measures. This enables FP McCann to change the perception of precast concrete panels within the industry and is allowing the company to go to market to promote the new 'fire rated' system as best in class (**I1, C9**).

Evidence of the importance of this industrial development was recorded by the BBC News (2019), 'Fire tests in Fermanagh, all about the science of safety' (**C7).** The study focused on updating knowledge and enhancing public safety with particular attention to 'transient heating' which has huge implications for the safety of those in the building, those tackling the fire and of the actual building itself.

I4 Partnership

The establishment of Efectis UK/Ireland into the FireSERT facilities with subsequent UKAS accreditation builds directly on FireSERT research and expertise, particularly in the area cladding/façade fires testing evaluation (**G4**).

The impact of this development has resulted in an additional FireSERT annual income of approximately GBP100,000 per annum. In addition, Efectis currently employs 20 people which includes 3x Master, 2x Research Associates and 4x PhDs who have been trained at FireSERT (**C10**). Efectis (France) has stated that "*We have seen Efectis UK/Ireland become a company of approaching 20 employees and with an annual turnover of over £1M*".

5. Sources to corroborate the impact

C1: Corroborating statement: CEO, Iris Vernici.
C2: Corroborating statement: Director, CrossFire Ltd, UK.
C3: Corroborating statement: Director, Cundall Fire Engineering, UK.
C4: Corroborating statement: Director, ArcelorMittal, Luxembourg (related to research on steel construction).
C5: Corroborating statement: Director, ArcelorMittal, Luxembourg (related to regulation Eurocode).
C6: Invitation by the Northern Ireland Assembly: Committee for finance, Parliament building: Amendments to the building regulations Northern Ireland 2012.
C7: FireSERT BBC Prof Nadjai feature: Enhance Public Safety, June 2019.
C8: FireSERT & FPMcCann: Precast Concrete New Product for Better Safe Environment.
C9: Corroborating statement: Director, FP McCann Ltd, UK.
C10: Corroborating Statement: CEO, Efectis.