THE GOLDEN THREAD OF INFORMATION AND FIRE SAFETY IN CONSTRUCTION:

Making our buildings safer through the development of a Robust Design Specification Strategy and BIM Framework Integration.

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Related Journal and Conference Papers

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Glossary of Terms

2D – Two Dimensional Drawings that are defined on a single axis.

3D – Three Dimensional Models that are defined on three axes, typically X, Y and Z.

ACM – Aluminium Composite Material. A sheet material made of two layers of aluminium with a chemically made internal core.

Active Fire Protection – Fire protections systems, such as alarms and sprinklers, which activate when fire or smoke is detected.

AI – Artificial intelligence. Computer based software which demonstrated human like intelligence traits.

API – Application Programming Interface. Code that allows connectivity between two or more software applications.

Approved Bodies – Organisations that can certify products, systems and buildings to specific standards or develop standards that are associated to products, systems, and buildings.

Approved Documents B (ADB) – Building regulation documents that cover fire safety design in the United Kingdom, specifically in England.

Backdraught – Rapid increase of fire or explosion that occurs when a fire trapped within one compartment has consumed the oxygen within that compartment and then suddenly becomes exposed to new quantities of oxygen from another compartment or outside. i.e., if a window brakes, this could cause a surge of oxygen into an area that had become deprived through fire.

BIM – Building Information Modelling. The Process of designing and constructing a building using a digital flow of information.

BIM Level 2 – Now superseded defined stage of BIM by UK Government, where projects would use a 3D model of the building that was federated with product and construction data.

BRAC – Building Regulations Advisory Committee in the United Kingdom.

BRE – Building Research Establishment in the United Kingdom.

BS 7974 – British Standard Document for Fire Safety Engineering Principals in Building Design.

BS EN 13823 – British Standard Document that covers Fire testing of construction products.

BSi – British Standard Institute.

Built Environment – Broad term coined to describe all built entities that make up the towns and cities in which humans inhabit. This includes buildings and infrastructure.

CAD – Computer aided design. Typically, the process of drawing using a computer software.

Cavity Barrier – Construction Product Application for filling cavities or gaps in structures to provide compartmentalisation.

CAWS – Common Arrangement of Works Sections. Historic Specification Clause templates widely adopted by the building specification community.

CDE – Common Data Environment. A single place or software where all construction project data is stored and accessed by those involved in the design, construction and operation of a building.

CDM – Construction Design Management. Methodology for application in the design of buildings.

CE Marking – Certification of products to demonstrate that they meet the requirements set out by the European Standards organisation. Typically required to allow sale of products within European states.

CI/Sfb - Samarbetskommitten for Byggnadsfragor classification process. Historic classification system used to classify products and other works within building specifications.

CIRIA – Construction Industry Research and Information Organisation. Not for profit organisation specialising in construction research.

Client – Referred to in this paper as the person(s) of company commissioning the design and construction of a building.

COBie – Construction Operation and Building Information Exchange. Data template and exchange format, designed to provide a structured data set for the management of all assets within a building.

Compartmentalisation – The means to create closed spaces within a building. Particularly to create a means to control the spread of fire throughout a building should one occur.

Conduction – The spread of heat through a material or collection of materials.

Construction Product Manufacturer – A business which manufactures or distributes a product under their brand or brands for commercial benefit.

Construction Products Regulations – The regulatory authority for construction materials, products and systems within the United Kingdom.

Convection – Energy (typically heat) moving from hotter to cooler areas. In fire this typically occurs due to higher oxygen concentration in cooler areas.

CPD – Continual Professional Development. The Process of continually gaining knowledge or learning new skills to progress a professional career.

Database – A place where data can be stored and accessed, typically on a computer or server.

Descriptive Specification – The process of creating a written building specification that may include performance requirements but not depict specific manufacturer products.

Design and Build – Procurement process where one main contractor is appointed to oversee both the design, build, procurement and appointment of sub-contractors from project start to completion.

DoE – The government's department of education in the United Kingdom.

DoH – The government's department of health in the United Kingdom.

Elements – Uniclass term given to describe specific sections of a building, i.e., a wall or a roof.

Entities – Uniclass term given to describe buildings within a complex or functions of a building i.e., spa, gym, restaurant.

Euroclass – European classification system, in this paper referring to the European fire classification standards methodology.

Expert Knowledge base system – software application that uses stored expert knowledge to surface recommendations when queried through a series of set questions and responses. A mild form of artificial intelligence.

External Cladding – A system of materials and products used to create a façade on the exterior face of a building. Typically used to provide improved thermal properties and/or aesthetics in a building design.

Fire resistance – The ability of a product to withstand fire, typically measured by the time it takes for the product to deteriorate and ultimately fail when subjected to fire.

Flaming Droplets – Inflamed particles or pieces of a material that fall from a structure when subjected to fire that can increase the potential for fire to spread to other areas and materials.

Flash over – Intense spread of fire due to extreme heat.

FSE – Fire Safety Engineering. The process of designing in fire protection and resistance within a building.

FSES – Fire Safety Expert System. The title given to the development of a knowledge base expert system for fire safety design and assessment within this research.

Global Warming – The heating of the planet due to climate change.

Golden Thread of Information – Industry adopted term given to the audit trail of all construction project information, to be held digitally within a common data environment.

Hackitt Report – Name given to the post-Grenfell Tower fire report by Dame Judith Hackitt in 2018, officially titled 'Building a Safer Future – Report'.

HFS – Health Facilities Scotland.

High Rise Building – A building over 18m+ in height.

HSE – Health and Safety Executive in the United Kingdom.

Hyperlink – The means of providing a link to a webpage or website from with a digital document.

Intumescent – A process where a material swells or enlarges when subjected to heat. i.e., an intumescent strip within a façade cavity will swell in a fire compartmentalising the fire and preventing further spread of flame and heat.

IoT – Internet of Things. Name given to the subject of information connectivity via the internet.

IPCC – Inter-governmental Panel on Climate Change.

ISO – International Standards Organization.

KBS – Knowledge Base Expert System.

Main Contractor – The highest tier contractor appointed on a project.

MEP – Mechanical Electrical and Plumbing trades.

MMC – Modern Methods of Construction. Typically, when referring to buildings or elements of buildings that are pre-built in a factory and delivered to site as a whole.

NBS – National Building Specification.

NBS Chorus – Specification writing software facilitated by the National Building Specification.

NBS Source – Construction Product Library facilitated by the National Building Specification.

Passive Fire protection – The means of designing in natural fire protection within a building. i.e., compartmentalisation.

PE Core – Polyethylene core. The chemical material used within the aluminium composite cladding, apportioned to the rapid spread of fire in many building fires where cladding was enflamed.

Plan of Work – Public document managed by the Royal Institute of British Architects which gives numbered stages to a building project and depicts the work and outcomes required through each stage.

Plug-in – A software application which sits within another software application.

Prescriptive Specification - The process of specifying specific manufacturer materials, products of systems within a design.

Principal Designer – The main designer with overall responsibility for the management and outcomes of the project design.

Principal Main Contractor – The main contractor with overall responsibility for the management and outcomes of the project construction and handover.

Construction Product – Material, product or system made up of materials and products and sold as a whole.

Professional Competency – The ability or demonstration of a professional person to do conduct their role effectively and efficiently.

PV – Photovoltaic, mainly referred to in the context of photovoltaic panels which convert energy from the sun into electrical energy.

QDR – Qualitative design review, the process where the design team and other stakeholders assess and contribute to fire mitigation within the building design.

Qualitative data – Interpretated information, often text based to gain insights into what, why or how.

Quantitative data – Metrics based information, often to measure or count.

Radiation – Energy transmitted in waves, in this context the transmission of heat from an object/

Rainscreen cladding – External framed façade to prevent rain ingress on a building.

Revit – Proprietary design software used within a BIM process.

RIBA – The Royal Institute of British Architects.

SKU – Stock Keeping Unit, a code often given by manufacturers to classify and identify a product.

Smoke Emittance – The quantity of smoke given off from a burning object.

Software – Code based application for use in computing.

Specification – Written document to depict the how and what to construct a building.

Stack effect – Also referred to as chimney effect, where smoke and heat is carried upwards and out of a building due to pressure differences caused by hot indoor temperatures and cold outdoor temperatures.

Stage Gate – Process where defined assessment breaks are given to a project, an outcome of the post-Grenfell fire, building a safer future report. Assessment is required at planning, pre-construction and pre-handover and prevents the project progressing to the next stage until approval is given.

Stand-alone Software – A software that operates in its own capacity without interaction with other software.

Sub-Contractor – Contractor who specialises in a specific trade and is typically appointed by the main contractor to carry out a specific task.

System – A building product which is made up of a collection of other building materials and products.

Technical Memorandum – Advice and Guidance document for a specific subject.

Turnkey – A solution which can be operated immediately.

UKCA Marking – Certification of products to demonstrate that they meet the requirements set out by government in the United Kingdom. Typically required to allow sale of products within the UK.

UKGBC – United Kingdom Green Building Council. Not for profit organisation that provides guidance on sustainable construction.

Uniclass – Modern Specification Clause templates widely adopted by the building specification community. Particularly used in the BIM process.

Value Engineering – The name given to the process of substituting specified for products for items which provide an upfront purchase cost saving over those specified.

VisiRule – Proprietary visual programming software.

Visual Programming – Process of using a software that allows users to develop codes in a graphical manner.

W/mK – The thermal conductivity of a material or product measured in Watts per meter thickness.

Declaration
I hereby declare that this thesis is my own work, based on my personal experience and research. All materials and sources used in its production, whether they are books, articles, reports, and any other kind of document, be they analogue or digital or via communication, have been acknowledged. I also declare that I have not copied in part or whole or otherwise plagiarised the work of others.

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Dedication
For my children. Your desire to learn is inspiring. I hope that in my own continued desire to push, continually evolve and improve, I can be as much of an inspiration to you as you are to me.

Abstract
In this research, the development of a novel expert knowledge based system for fire safety building design specification and compliance is discussed. Its purpose is to create a beneficial design aid that is integrated with building information modelling (BIM), for helping to design and maintain safer buildings, to ease the navigation through a complex regulatory compliance regime and to mitigate risk of various potential contributors. The research reflects on the current status of the UK fire safety regulatory system in the construction industry, key professional competencies and the areas in which risk could be mitigated through the implementation of this technology. Whilst the system developed in this research is based upon the UK regulatory framework and guidance, it is adaptable to any international country building regulations and standards.

The high-level system framework has been developed, connecting the expert knowledge based system to the proprietary building information modelling (BIM) software and to both a descriptive and performance based specification system. The additional purpose of BIM integration is to create an auditable fire safety design trail of a digital record for the building throughout its lifecycle, from initial design through to construction and subsequent occupancy.

The feasibility of implementing an expert knowledge base system to aid both design, specification, and compliance checking was tested through the development of a system prototype. Connectivity to the building model and specification are critical in ensuring all outputs are both aligned and robust. Data is proposed to be captured within a common data environment (CDE), aligned to the UK BIM framework, thus capturing a ‘golden thread of information’.

The outcome from testing of the proposed expert knowledge base system demonstrates strong potential for an effective technological aid to mitigate risk of failure or non-compliance of designed and built assets in respect to fire safety.

CHAPTER 1: INTRODUCTION
1.1 Background

"It is better to prepare and prevent, than it is to repair and repent".

Ezra Taft Benson

The built environment is in the midst of radical change. In a sector noted for its reluctance to adopt change (Borowska, 2020), there are two key influential areas that are creating disruption; sustainability and safety (ARB, 2022). Whilst both are key to survival, sustainability is notably a process which has only in recent years become a priority. Publications such as the Inter-governmental Panel on Climate Change reports and the recent conference of the parties have made light of the immediate responses required in all walks of life to reduce the impact of climate change (IPCC, 2022). In terms of safety, many sectors have been pushing boundaries with their due diligence, mitigation of risk and introduction of modern technologies for a long time. Whilst not without any history of failures (Macleod & Richardson, 2018) (Marsh, 2020), sectors such as automotive, aerospace and oil and gas can be viewed as leading sectors when it comes to safety. In particular, the introduction of digital technologies to aid safety are clear (Sedacca, 2010). For the construction sector, sadly this has not happened as rapidly and recent tragedies have highlighted the inefficiencies, complexities and general 'cutting of corners' in our industry. In the UK alone, there is a significant number of documented cases of fire and tragic loss of life in the built environment, throughout history. Looking back to the Great Fire of London in 1666, one of the most notable fires in history, the reason for the fire spreading so quickly was a combination of flammable materials and the close proximity in which each building was built to the next. This fire was implicitly responsible for the introduction of what we today refer to as the Building Regulations.

Notably in recent years, the Grenfell Tower fire in London, has resulted in what is deemed the most radical shake up of the building regulatory system in modern history. On 14th June 2017, a fire broke out on the 4th floor of the 24-story residential tower in North Kensington, London. The initial fire was due to a malfunctioning freezer appliance in one of the resident's apartments. However, fundamental issues with building design changes made during a refurbishment in 2015 and additional complications in building management, alongside how the fire was tackled that evening, resulted in the untimely deaths of 72 individuals (Kernik, 2021). The enquiry into the events that led up to that fatal night and the reasons why such an aggressive fire could occur in a residential tower block, has only just completed at the time of writing this Thesis. During the initial stages of enquiry, the UK government commissioned a report, which became known as 'Building A Safer Future' but is often referred to as 'the Hackitt Report' (Hackitt, 2018). The initial investigation and report were overseen by Dame Judith Hackitt and identified key failures within all aspects of the construction industry. Notably, what has been coined as 'the race to the bottom' where upfront costs can lead to corner cutting, often in a process to increase or balance profit margins, is amongst the most notable flaws (Lea, 2021). Alongside this, professional competency is also questioned (CSG, 2020). These two issues are fundamentally difficult obstacles to overcome, as not only does regulation impact the way in which these issues may be addressed, but human error and a negatively perceived general culture are even more complex to resolve. Amplifying those two issues, the complexity of the building regulations increases the risk of non-compliant project delivery. These risks may be connected to a lack of understanding or potential loopholes within the complexity of those regulations (Architects' Journal, 2021).

The 2015 refurbishment of the Grenfell Tower saw the installation of external cladding, a process widely used to retro fit to many older high-rise buildings to improve thermal efficiency and to modernise the aesthetics of a property (NIDirect, 2022). It was the cladding that has been deemed the most significant factor as to why the fire spread so rapidly. The enquiry into the Grenfell Tower fire has shown that both the polyethylene cored Aluminium Composite Material (ACM) cladding and the installed insulation that attached to the existing structural walls of the building acted as fuel to the progressing spread of flame.

Alongside the material choices, there were a high number of other factors that also contributed to the intensity of the fire. Cavity barriers are required by the building regulations to prevent spread of smoke and flames through the internal cavity in any wall on a high-rise residential building. In the case of the Grenfell tower, cavity barriers were missing from the design in certain cases and where they were designed in, had been installed poorly. This caused a stack effect which resulted in the air displacement through the cavity increasing the rate of fire and smoke spread. The decision to use certain materials on Grenfell and other towers has been widely publicised and is still the topic of vast argument over remedial works. Notably the decision to specify or use such materials has been a great error of judgement.

Alongside the types of products specified and used, the enquiry also discovered that certain product manufacturers had made false claims about fire classification of their products. Fundamentally, many of the issues that contributed to the tragedy were due to a lack of competence, experience and importantly care and/or foresight by numerous stakeholders when delivering the refurbishment (Kernik, 2021) (BBC, 2019).

What is obvious from all tragedies relating to rapid fire spread in buildings, is that the industry approach is flawed. For hundreds of years, we have documented these disasters, yet today we still experience failures of a similar vein. The industry tends to legislate following disaster and is not pro-active in predicting fire risks and hazards.

"Changes to the regulatory regime will help, but on their own will not be sufficient unless we can change the culture away from one of doing the minimum required for compliance, to one of taking ownership and responsibility for delivering a safe system throughout the life cycle of a building."

Dame Judith Hackitt

1.2 Building Safety - Key Challenges

'Building a Safer Future' the independent review of the building regulations and fire safety undertaken by Dame Hackitt in 2018, highlighted four key flaws with the construction sector related to fire safety (Hackitt, 2018). These flaws were noted as; ignorance, indifference, lack of clarity and inadequate regulatory oversight/enforcement tools.

- Ignorance relates to the dismissal or lack of realisation of the importance of understanding and implementing regulations that are set to mitigate risk and prevent unnecessary failures, or worse case, deaths.

- Indifference referred to the 'race to the bottom' (Hackitt, 2020), where project profit margins are prioritised over quality, notably in relation to profit over safety. The introduction of the design and build process has been widely noted as a major contributor to this outlook. Main contractors often bid for jobs at fixed prices; in many cases these pitches are offered at lower ends of pricing bands to win the contract. In attempt to claw back the profit lost, 'value engineering' occurs. Many main contractors will have full time staff, often highly capable quantity surveyors who will be tasked with the full-time role of substituting specified products for those of a similar fit, but ultimately at lower upfront cost (TQS, 2020). This can often lead to materials, products or systems being substituted for inferior performance types. In a design and build scenario, the architect is employed by the main contractor and often has little jurisdiction over any design change decisions that may be made to reduce costs.

- Lack of clarity discusses the ambiguity of responsibility, in relation to ownership of decisions within any given project. This covers the whole project timeline through design, construction, and in-use phases. The regulatory system has been amended post Grenfell, to recognise the importance and responsibility appointed to the 'principal main contractor' and 'principal lead designer', in an attempt, to remediate the risks of failure in this area (Darley PCM Ltd, 2020).

- Inadequate regulatory oversight and enforcement was the fourth issue noted. There has been a lack of an overseeing body within the sector, which has resulted in the Health and Safety Executive being appointed as the new regulator (HSE, 2021). The follow-on issue from a lack of overseeing organisation was that in many cases, failure to comply with regulations did not result in any amount of severe punishment for those who chose to flaunt the rules. In her speech at the 'construction leader's summit' held in Birmingham, February 2020, Dame Judith Hackitt emphasised that the new regulator would have 'real teeth'. From the new implementations, we will likely see a clear strengthening of regulations not only in how they are positioned but by the repercussions possible for those who fail to align to them (Hackitt, 2020).

The above flaws, demonstrate a cultural issue, embedded deep within the sector that must be addressed.

Cultural shift does not stop with the previously discussed issues; the construction industry is notoriously slow to adopt change or adapt to new ways of working. Research by McKinsey and Company discovered that the construction sector was the third slowest industry in relation to the adoption of digital technologies (McKinsey Global Institute, 2017). The only two sectors below construction were fishing and shooting. Whilst this may come as a shock to some, to others it is obvious. If we look at other sectors with a model surrounding design and manufacture, the likes of automotive and aerospace are vastly ahead in relation to the use of digital technology. Whilst the product is not comparable, the fundamental way in which projects are co-ordinated and how data is managed, should be transferable.

In 2016 the government mandated the use of BIM (Building information modelling) on all public funded projects (HM Government, 2012). The main driver for this was to reduce costs during the in-use phase of a project by having a more structured and importantly digital asset management register for facilities management. It was for this reason that COBie (Construction Operation and Building information exchange) formed the basis of the BIM level 2 information exchange requirements (Autodesk, 2016). The *Building a Safer Future* report recommended that 'a golden thread of information' be mandated for all high-rise residential buildings moving forward. Similar to the BIM level 2 asset management requirements, this would demand a log of all assets at component level within a project and BIM would provide an ideal platform to which this could be derived. Going further than the asset register though, the golden thread would require a clear audit trail of information relating to decisions made on each project. This will potentially mitigate risks, and any error of judgement has an improved opportunity to be picked up early in the project timeline. Furthermore, the audit trail would log whom made what decision and when, providing a clear responsibility decision trail. In an industry notably slow to adapt change, this will be a challenging obstacle to overcome.

The final challenge to discuss relates to the competency of the professionals who work in the construction sector (Farmer, 2016). For many professions, the individual will have a specific skill set that is applied to their specific task. However, due to the nature of how projects are built, different requirements also occur on every individual project. This places in many cases a need to 'learn on the job'. In the cases of large projects, a large practice may be appointed whom will have specialist personnel for specific design tasks. For the smaller practice, the architect will have to be the one that tackles a variety of specialisms. Two key challenges are created here:

1. In relation to the larger practice with delegated tasks to individuals, quite often these may be fulfilled by younger less experienced staff, particularly for the more mundane duties (Waite & Tether, 2021).
2. For the smaller practice or single practitioner, there is great responsibility placed on them to be complicit in the design aspects of all building systems, regulations, laws and standards.

1.3 Rationale and Justification of the Research
Following the extensive literature survey, it was identified that within all the planned regulatory changes and the challenges identified within the industry, that multiple problems exist that may be served by a technological solution. Whilst technology in its individuality cannot solve the entire problem, the four main challenges raised in the prior section could be aided by the use of the expert knowledge based technology, namely:

- Complexity of regulatory framework
- Lack of professional competency and expertise
- Better understanding the interrelated performance of the systems and assemblies
- The requirement for 'The Golden Thread of Information'

If a technological solution could be developed to assist the above challenges, then it may be feasible to provide a 'benchmark' level of assessment to mitigate errors on construction projects and in tandem, through digital data records, to facilitate the Golden Thread of Information.

To the best of authors knowledge at the time of writing, no existing solution was known that addresses the requirements of all four points above in aiding the building design specification, and in light of recent changes to the UK fire safety regulations.

1.4 Building Design Standards and Regulations
Current regulations are extremely complex. This was a key point noted in Dame Judith Hackitt's speech to the manufacturing sector at the Construction Product Leaders' summit in Birmingham on 13th February 2020 (Hackitt, 2020). Dame Judith was appointed by the government to review the current building regulations following the Grenfell tower fire tragedy in London 2017. Dame Judith was previously the Director of the HSE and subsequently, it is the HSE that will be overseeing the regulator changes planned for the sector in the imminent future (HSE, 2021). Having

a background in chemical engineering it was with a fresh set of eyes from another sector, where fire safety is paramount, that made this realisation apparent to an otherwise inattentive industry.

In addition to regulatory complexity, the number of potential avenues to route for design, construction and general compliance are diverse. This research provides an in-depth review of the approved documents B (ADB) volumes 1 and 2, and BS 7974, two very distinct approaches to fire safety design. Both the regulation and the British standard approach offer potential avenues to design compliance, with the former being prescriptive and latter being a performance based approach. However, ADB is what the regulator will base checks upon. The system realistically needs one identifiable approach to regulation.

1.5 The golden thread of information

The building regulations advisory committee summarise the Golden Thread as 'both the information that allows you to understand a building and the steps needed to keep both the building and people safe, now and in the future' (BRAC, 2021). The golden thread, therefore, is effectively two pieces of information; the information that relates to what is within a building and the information that is required to maintain said building and ensure its occupants are safe. The Golden Thread is proposed as a live document, held digitally in a centralised location, likely a CDE (common data environment) where all relevant stakeholders to the project can freely access information as and when required (Valra, et al., 2020).

To date, information relating to a built asset can be unclear or in certain cases not recorded at all (Schneidera, et al., 2016). For example, during the technical design stage, the Architect may specify a certain building product or material for a specific purpose. During the procurement stage and construction, it is possible that the contractor or sub-contractor may use a similar product or material to that specified but may have differences to the original intended spec (CPA, 2019). If none of these changes are documented, then it is almost impossible to know exactly what is in a building when it gets to the in-use phase. This makes facilities management extremely difficult. Furthermore, throughout the in-use life of a building, products, materials, and systems often get replaced, because of general maintenance and changes of use. If no records are kept at these stages, then the spiral of missing data gets even longer (Braaksma, 2012).

The Golden Thread places reliance on all records being kept digitally, this allows the information to firstly be stored as a single source of truth in a common location and secondly be kept up to date as a single ongoing development. This ensures that whenever the data is accessed, the user will be viewing the latest information. In the case of replacements or substituted elements, unique identifiers will be expected to be attributed to details of superseded/replaced assets, in case of the scenario where historical information is to be referred to (BRAC, 2021).

BIM is referenced heavily in ‘Building a Safer Future’ as the proposed under-pinning process to the golden thread. A BIM approach to project data management facilitates the early inclusion of project data, whilst subsequent revised 3D models will also capture any design changes. Industry research has identified that approximately 70% of the construction industry has adopted BIM to date (Bain, 2020). Thus, BIM has great potential to provide the basis for the journey towards achieving the golden thread. There is more than just the BIM model to consider however, the building specification for example is typically a stand-alone document, procurement documents are often stored separately, evidence of sign off and snagging are also typically separate. There is a multitude of various data sets that must be consolidated for *The Golden Thread* to work, that are currently siloed.

1.6 Professional competency

Professional competency will naturally vary in any profession, and we all experience this in day-to-day life. In being human, we are all different and our capabilities, understanding, intelligence and drive all vary by default. However, in certain disciplines, there must be a minimum level of competency for the role in which a professional may undertake.

In the construction sector, many roles require years of study or hands on training before professional qualification is achieved. However, ongoing assessment of skills is not equal across all professions (Wall & Ahmed, 2006). Furthermore, whilst an individual maybe trained in a specific profession such as an Architect or Engineer, the varying types of buildings combined with individual details and requirements on each project can result in the employment of perfectly qualified professionals on a project, but potentially without the necessary skills or experience to suit that specific building.

When looking at the skills required to develop a high-rise residential building, ‘Building a Safer Future’ highlighted inconsistency in the approach to competency of the professions involved. As a result, the Competency Steering Group was set up to address the issues. One outcome of this group was the report ‘Raising the Bar’ which was published by the construction industry leadership council (CSG, 2020). The report was the result of 12 steering groups across various disciplines required to develop a high-rise residential building and depicted the need for improvement. The suggested improvements were defined by 67 recommendations detailed within the report. The recommendations included the proposal to increase competency frameworks across all disciplines in relation to high rise residential buildings. Those disciplines included the most crucial roles in these types of projects, from the designer/Architect to the contractor and right through to building control. Further competency training was suggested for the building safety manager, principal designer, and principal contractor. Whilst the principal designer in particular may likely be an Architect and if chosen to remain chartered must already complete a minimum of 35 hours of CPD each year, these new recommendations would focus solely on high rise residential design. Still, even with increased competency, the complexity of the current regulatory system will never entirely mitigate risk.

1.7 Energy Efficiency vs Building Safety

Global warming is a risk to all species on planet Earth like nothing ever witnessed before by humankind. However, it is the human species that have caused the rapid and excessive increase in the Earth's temperature (NASA, 2023). Since the dawn of the industrial revolution, the planet has warmed by 1.1C due to the burning of fossil fuels. This may not seem a high number, but the impact is severe. The Intergovernmental Panel on Climate Change anticipates that by 2040 it is likely that we will see an increase to 1.5C and at worst case by 2100 this could be as severe as 4.4C (IPCC, 2022). At 1.5C there will be mass displacement of many populations as their homelands become inhabitable, we will see extinction of many species of animals and the severe weather that we have experienced around the globe in recent years will only get worse.

The built environment is estimated to be responsible for approximately 40% of all carbon emissions (UKGBC, 2022) and with an ever-increasing population, will continue to contribute highly, unless change happens rapidly. In response to this, the built environment is being called upon heavily, to reduce both the embodied carbon within the building fabric but also the energy demand through the in-use phase of the building's life (RIBA, 2021). The rapid urgency to change both how we build and the materials that make up both the building fabric and the furniture, fixtures and equipment are resulting in the use of innovative and non-traditional materials, new methods of construction and manufacture. Whilst these are helping to reduce emissions from the built environment, they can pose new risks to fire safety (Crawford, 2011).

Notably, external cladding, photovoltaic systems, battery storage and timber frames have been apportioned to a number of catastrophic building fires in recent years (Aram, et al., 2021) (Zalosh, et al., 2021) (Brandon, et al., 2021). The below points identify the key considerations in relation to risk of fire caused by each:

- Timber frame is a sustainable low carbon material used for millennia, though the risk posed by timber frame in terms of fire load is an obvious one (Schmid & Frangi, 2021).

- Battery storage fires can be attributed to heat and electrical failure however the greatest problem posed is that of extinguishing a fire involving batteries. Lithium-ion batteries have evolved technology in electrical storage incredibly, yet the material itself if ignited burns incredibly hot and flames spread at a rapid rate. This makes it very difficult to extinguish. Batteries can also explode causing further damage through both the blast and projectile ignited material igniting surrounding items (Diaz, et al., 2020).

- Photovoltaics (PV) are widely used to reduce energy demand from the grid. In any UK housing estate, you don't have to look far to see houses retro fitted with PV panels. PV fires typically will be caused by one of two underlying factors, either faulty products or poor installation. Regardless of whether the manufacturer or the installer is at fault, what contributes to ignition will either be overheating or electrical faults creating a source of ignition. However, what can further worsen a fire caused by PV roof panels in particular, is that they create a robust secondary external layer over the roof of a building. If the PV panel or immediate connection system is the root cause of fire, then by default it will almost certainly be the roof that catches fire as a result. The PV panels can then act has a shield to the below fire within the roof, preventing the fire brigade from efficiently extinguishing the flames (Namikawa, et al., 2017).

- External cladding is the most infamous of all the modern energy saving materials that are responsible for fire. As with photovoltaics, poor workmanship in the installation of external cladding is an issue, with incorrect cavity details, missing components or out of tolerance component assembly being some route causes. However, it is also the materials which make up various external cladding materials that provide the most risk. In the case of the Grenfell Tower fire and other reported fires involving external cladding, the aluminium composite material has been apportioned to the cause of rapid fire spread. Notably, polyethylene core material in its nature is highly flammable and can act as a fuel in a fire, providing a catalyst for rapid spread of flame (Chen, et al., 2019).

It is due to the factors listed above that, whilst all new builds and refurbishments must consider sustainable outcomes, they must not compromise fire safety. Innovative materials bring uncertainty to the specification due to the designer or specifier potentially not having experience of utilising these materials in any prior design. The use of innovative materials, products and systems also pose risk through installation, particularly due to those that specialise in their installation and have the relevant experience to do so, will be few and far between. The industry is continually being challenged to lower carbon emissions, which in turn requires innovation, with the risk to fire safety becoming increased in this challenge (Hanson, 2005). Thus, evolving regulations and standards in respect to sustainability also pose a need to further adapt and amend the fire safety regulations in the future.

1.8 Procurement routes

All new-builds and refurbishment projects of a certain scale will typically follow one of two procurement routes. These are *Traditional*, often referred to as general contracting, or *Design and Build* (Scott, 2020). In the case of design and build, there can be many benefits including less responsibility for the client and potentially faster delivery. However, design and build has been apportioned to many downfalls in the construction sector in relation to overall quality of delivery and critically safety, which will be discussed in this section. This section also further outlines the difference, benefits, and potential risks between the two procurement approaches, as shown in Fig. 1.

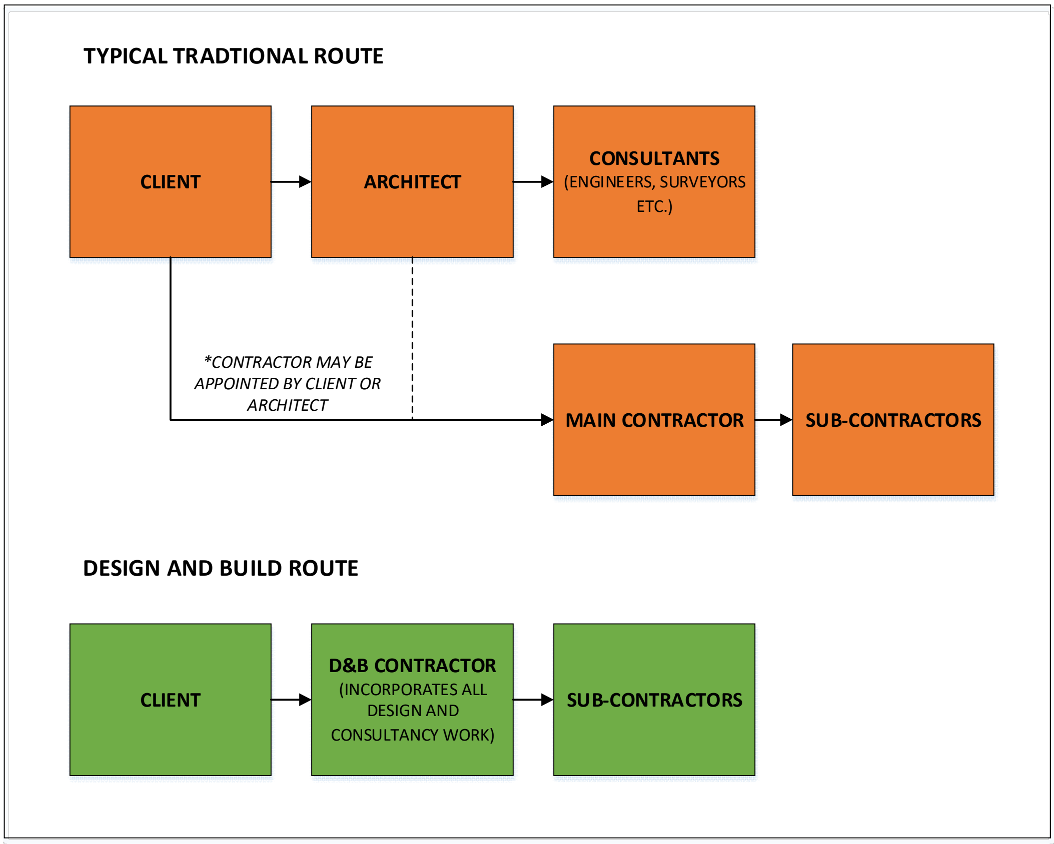


Figure 1 - Traditional Vs Design and Build procurement routes (Source: Author)

The traditional procurement route is named such as historically this is how most construction projects were procured (JCT, 2021). The client would separately appoint an Architect to develop the design and associated documents required for the construction of the project and then appoint an independent contractor or contractors to construct the project. This route places responsibility upon the architect to ensure that the design criteria will sit within the clients advised budget but leaves the client at risk of over-spend in the case of material price increases, oversight by the architect or potentially delays resulting from the construction process. The main advantages of going down a traditional route for the employer are that they have much more control over the project, particularly the involvement in the design process, ensuring that their vision is met via the architect's input. However, traditional methodology places more onus on the employer to manage various aspects of the project such as time and complexity constraints and will often be the more costly option. In progressing a design and build route, the onus of managing the whole process is placed upon the main contractor and will often be the more cost-effective solution for the employer, whilst improving delivery time.

Design and Build was developed as a ‘turnkey’ solution for the client. Through a design and build contract, the client appoints a main contractor who provides a start to finish service incorporating the design and construction processes and project management (Seng & Aminah, 2006). This is typically done for an agreed fee from the outset. As the main contractor is responsible for ensuring that the project comes in within budget and has more control over the design and specification, this has potential to be at detriment to the end result. The in-house or appointed design team in a design and build contract will develop the design and documentation in mostly the same way as an architect would in a traditionally procured project, however due to the ability to control the outlay costs, it is common throughout the process for value engineering to take place. By reducing the spend on materials, the contractor can at minimum protect themselves from a shortfall in margin should any occurrence such as project delivery overrun but could also be practiced to simply increase the margin made on a given project. Value engineering is in its most simple form the replacing of prescriptively specified materials, products or systems with similar items that are more cost effective to procure. In many cases, this will not be an issue i.e., if floor tiles were swapped from one manufacturer spec to another that offers equal performance criteria but lower cost.

In all walks of life people will shop around to find the best deal, however, in the case of design and build, risk can be built in when replacing materials, products or systems with similar items that may not be of as high a quality or at worse, do not perform adequately. For example, swapping windows for types which have higher U-values would negatively impact the thermal performance of a building. If safety critical products were to be substituted for lesser performing items, then the results could be catastrophic. The founding director of Project Compass, a procurement campaign group, famously quoted that ‘design and build’ was the UK’s ‘dirty little secret’ (Curtis, 2020). For example, components which are hidden within a structure such as cavity barriers are virtually impossible to assess following completion of a building, though approved document Part L does now require photographic evidence of installations (MHCLG, 2023). There are numerous systems being developed that aim to tackle this issue, such as BSi identify (BSI, 2021), where scanning walls with a device could detect transmitter chips within materials with the wall structure and link back to manufacturer data templates. However, the most significant development sits with the regulatory changes and the implementation of the ‘Golden thread of information’ (BRAC, 2021).

In the context of fire safety, there are fundamental aspects that must be considered when considering both procurement routes. For a traditional route, the variety of individual professionals involved can become complex in terms of liability and ensuring that roles and responsibilities are fully understood between each party. For design and build, whilst complexity of the project management and contracts are eased, the largest area of risk comes from the way in which the project is financed.

In a report published by the building research establishment (BRE) in 2017, it was reported that of all building fires investigated by their team during a research project over a decade, more than 30% of all those fires were attributed in some way to poor workmanship (Holland, et al., 2016). Whilst poor workmanship can be due to varying factors and not specifically apportioned to design and build, the risk in 'rushing' a project to retain deadlines and avoid financial delay penalties increases that risk. Compartmentalisation is an area discussed in the BRE report, particularly in relation to cavity barrier installation within the building envelope, where cavity barrier installation did not meet specification or in some cases were not present at all. The poor workmanship aspect here will likely not be witnessed until a fire breaks out, in most part, because the cavity barriers are concealed with the structure.

The implementation of the golden thread of information, requires a digital record of all assets within a building alongside the associated decisions and approvals that led to those materials being procured, installed, and signed off (MHCLG, 2020). Whilst regulation changes have placed more onus on the principal contractor, the staged gates throughout the timeline have also been developed to mitigate risk through both design and build. Stage 2 will see the design and specification scrutinised by the regulator prior to being allowed to progress to construction, whilst Stage 3 will scrutinise the as built asset by checking that what was procured met the intended specification. Workmanship also places a part in this scrutiny. However, in the context of value engineering these new practices will only strengthen the original prescriptive specification (Greene, 2022).

The roles of 'lead appointed designer' and 'lead appointed contractor' within the new building regulatory reform (DLUHC, 2022), aim to place higher onus on the responsibilities of these appointed parties via any procurement route. Subsequently, higher due diligence will be required and to maintain accurate records in relation to workmanship, compliance checking will be required at key stages within the construction process.

1.9 Research Aim and Objectives

1.9.1 Aim

The intended study aims to research and critically assess approaches and strategies for robust design specification in construction fire safety. Its particular focus is the development of a novel BIM integrated framework to form a basis for a robust design specification strategy in fire safety and provide guidance as to how these could be integrated within the BIM framework in the UK to facilitate the golden thread of information.

1.9.2 Objectives

The research objectives were to:

1. Carry out an in depth and detailed study of subject specific literature to assess, interrogate and inform an innovative approach to the development of an integrated BIM framework for fire safety design. Focus would be given towards existing approaches surrounding construction product fire testing, record keeping and change control processes.

2. Investigate and critically evaluate current design techniques, protocols and strategies in construction design and specification in relation to fire safety design, and through the use of digital techniques highlight the potential issues for failure within designed and constructed entities.

3. Develop an original Expert Knowledge Based System and accompanying guidance to support the proposed BIM framework, from which an effective fire safety design digital workflow and accurate asset information capturing can be simulated and tested, either retrospectively or progressively.

4. Critically evaluate the findings and potential of the proposed expert system, and as a result initiate creation of new guidance for robust design specification strategy in fire safety models and frameworks.

5. Indicate how the developed processes can form part of the UK BIM framework, including integration with the proposed Golden Thread of information.

1.10 Research Brief

The research sets out to investigate the key challenges currently faced within the construction sector in terms of fire safety in design specification. Prompted by recent high-profile tragedies, the brief is to assess the current landscape and investigate the potential for implementing new technologies or existing technologies not currently utilised within construction design, to provide a means of mitigating risk. The following sections of this Chapter discuss in depth, the fundamental aspects of the research, the originality of the project and how it contributes novel approach and the methodologies that will be used to achieve the aim and objectives.

1.11 Research Originality and Contributions

The original contribution which this research possesses is in a novel method of assessing building design specification against compliance with fire safety regulations, whilst providing a BIM integrated digital audit trail, aiding the golden thread of information. By developing an Expert Knowledge Base System for fire safety design specification, mapped to the latest UK standards and regulations, the proposal offers a solution to the design problems which, to the best of the authors knowledge, have not been wholly resolved. The approach offers simplicity to the checking of the specification through different design approval stages and alleviates risks that may occur from the complexity of regulatory framework and varying competency between different professionals.

In addition, an integration of the fire safety expert system within the BIM environment has been developed to provide a means of capturing and editing specifications which align to fire safety design standards, but take full account of other performance requirements, such as thermal, resistance to moisture, acoustic and aesthetic criteria.

To further progress its aim, the research has also developed a process alignment for a Fire Safety Engineering (FSE) and Qualitative Design Review (QDR) approach for high rise residential dwellings. The QDR process is usually reserved only for complex commercial developments (BSi, 2019). The FSE approaches and the QDR process that sits within them are seen to be more tailored to improved fire safety design, based on each project being individual and the benefits of utilising these for residential design is explored.

1.12 Thesis Structure

CHAPTER 1: INTRODUCTION

The first chapter in this thesis discusses the key challenges facing fire safety in the construction sector. An overview of the approved documents and fire safety engineering approaches is given, alongside the various approaches to fire safety within building design. The aim and objectives, as well as the research originality and contributions are also detailed.

CHAPTER 2: RESEARCH METHODOLOGY

Chapter 2 discusses the philosophical and methodological viewpoint given to the research alongside the methods taken to achieve the research outcomes. This chapter also includes an approach to the literature review conducted during the initial stage of the project.

CHAPTER 3: REGULATIONS, STANDARDS AND GUIDANCE

Chapter 3 discusses the myriad of legal documents and supportive guidance which provide the basis for compliance within the UK construction industry relating to fire safety design. An in-depth review of the current regulatory framework is discussed. Mitigating the risk of fire is paramount to this research. The numerous processes which interact, influence and lead to fire safe delivery, or failures are discussed. The changes to regulations following the Grenfell Tower tragedy are also covered. The research then narrows to specific areas of fire safety in this chapter, where external cladding and the use of technology within the construction sector are considered. Finally, this chapter overviews building specifications, why they are critical to achieving fire safety and how the process evolves across the construction timeline. Recent changes to classification of materials are also included, plus how various procurement routes can influence the outcome of the delivered built asset.

CHAPTER 4: TECHNOLOGY IN CONSTRUCTION
Developing from the previous chapter, this section provides insight into the adaptation and use of technology within the construction. Chapter 6 also critically evaluates the resilience to change within the sector and the potential barriers evident that appear to contribute to failure modes within the sector. The final sections of this chapter discuss how knowledge base expert systems are utilised within other sectors to aid efficiency and improve delivery and how they could potentially be adapted to suit construction processes in relation to fire safety.

CHAPTER 5: DEVELOPMENT OF A FIRE SAFETY EXPERT SYSTEM (FSES)
Chapter 5 discusses development of a proof-of-concept FSES (Fire Safety Expert System), including a functional proof of the concept. Integrating the FSES ~~into~~ with the building specification process is also discussed. This chapter also details how the FSES can support the golden thread of information proposals, expected to become mandatory for high-risk buildings. It also discusses the integration of the FSES into the BIM framework. Further proof of concept is detailed in the development of the bespoke visual programming solution within proprietary BIM design software, which aligns both the graphical and non-graphical data with the BIM model and that of the FSES.

CHAPTER 6: SYSTEM ANALYSIS AND VALIDATION
Following the development of a functional proof of concept FSES and BIM framework in Chapter 5, the validation and critical analysis of the proof of concept is conducted and discussed within Chapter 6. Simulation of a real world case study scenario, involving the production of the BIM model for an external cladding solution and subsequent assessment via the FSES are detailed. This Chapter also provides insight into the peer reviews conducted following the development of the proof of concept for the system.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS
Chapter 7 discusses the outcome of the research. Achievements of the research aim, objectives, the novel contribution, and limitations of the research are evaluated. The chapter concludes the research and provides discussion on the considerations for future work relating to this project.

1.13 Chapter reflective summary
Chapter 1 introduces the research and provides a background towards the current construction industry fire safety design status. The review discusses the key challenges impacting building safety, as well as reviewing relevant building design standards and Regulations. The planned regulatory reform is also discussed, notably the requirement for a golden thread of information, which will see increased legislation relating to a digital audit train of compliance and decisive data.

The research within the introduction discovers that the construction industry is in a pivotal moment of change (Minett, 2022). Recent high-profile tragedies due to fire spread within structures have highlighted the need for more effective control over how buildings are designed, constructed and how the data collected via these processes is used and stored. Critically, regulatory compliance is noted as a complex field with many potential avenues and areas of risk.

The findings of the introduction set out the rational for the research, with aims, objectives and contributions mapped out for the project. All of which are linked to addressing the key challenges faced by the industry. Ultimately, a novel approach to fire safety design and specification compliance is proposed, to provide a means of reducing the complexity of fire safety design and specification compliance, and related data capture through the implementation of an assistive technological expert knowledge based solution.

CHAPTER 2: RESEARCH METHODOLOGY

2.1 Introduction

Chapter 1 described the aim and objectives of this research, the intention of which was to critically evaluate the current regulatory framework in respect to building safety and set the scene for the development a novel expert knowledge base system and BIM integration tool, which will allow industry professionals to better navigate through design specification in relation to the fire safety compliance. This chapter provides insight into the methodology and philosophical approach to the research.

2.2 Philosophical Viewpoint

Research philosophy provides a systematic approach to obtaining knowledge about a subject matter to develop an understanding and make judgement on that subject. The scholarly articles on research philosophy are widely published. Whilst some suggest differing numbers of philosophical types, the majority categorize research philosophy into four main types, these being Interpretivism, Positivism, Pragmatism and Realism. Each philosophical approach to the research is said to have three paradigms, these being Epistemology, Ontology, and Methodology, (Easterby-Smith, et al., 2008).

Epistemology depicts how the knowledge will be gained and how valid the knowledge is considered. The ontology concerns factual existence, and the methodology sets out the roadmap to achieving the research as a whole.
In their book on the research methods (Saunders, et al., 2009) state that any "particular research question rarely falls neatly into one philosophical domain", referring to many research projects which take a pragmatic stance where multiple approach types are used to reach a conclusion.

Fig 2 highlights the complexity and interconnectivity between different philosophical domains (Saunders et al. 2009).

'Content removed due to copyright restrictions'

Figure 2 - The research onion (source; Saunders, et al.)

The proposed research is interdisciplinary in its nature as it connects the built environment discipline which in itself is interdisciplinary, with that of the information technology and computing. Given that the research focuses on the resolution to a specific problem on the intersection between number of disciplines and professional competencies, the approach to research will predominantly involve both positivism and interpretivism, therefore being a pragmatistic approach to the research.

Positivism focusses on a quantitative data research strategy, where the ontology is objective, and axiology does not focus on value. A positivist approach to the research will involve observations of accounts and data in order to attain facts. Interpretivism focusses on a qualitative research strategy, where the ontologies are subjective, and axiology is focussed on value. An interpretivist approach to the research will see data collation through observing real world scenarios and consultation with the experts.

2.3 A Multi-Methodological Approach

A mix of qualitative and quantitative research methods have therefore been proposed in this research. The research progress has been divided into four key stages, as follows:

Defining scope: This stage focused predominantly on qualitative research with the intense literature review and identifying the industry problems. Data collection at this stage formed part of the quantitative research and provided a basis to begin development of the fire safety expert system (FSES).

Development: Further quantitative research was conducted by means of researching approaches to existing safety systems and observing fire safety testing and design processes. Through quantitative research, data collection continued in tandem with the development of the fire safety design specification expert system. This focussed on the approved documents B (ADB) volumes 1 and 2, and BS 7974 which offer two very distinct approaches to fire safety design, the RIBA plan of work and qualitative design review processes. Each approach was compared and aligned to the UK BIM framework with a view of integration and golden thread of information.

Testing: This stage continued with the fire safety observations as qualitative research. System testing also formed part of the quantitative research at this stage.

Evaluation: Understanding the research significance required a qualitative approach. Comparison to other similar solutions within industry and discussions with industry experts were both utilised to assess the significance of the proposed research.

Further planning towards research was also set out in the following diagram, with the definition of the objectives forming further in-depth processes:

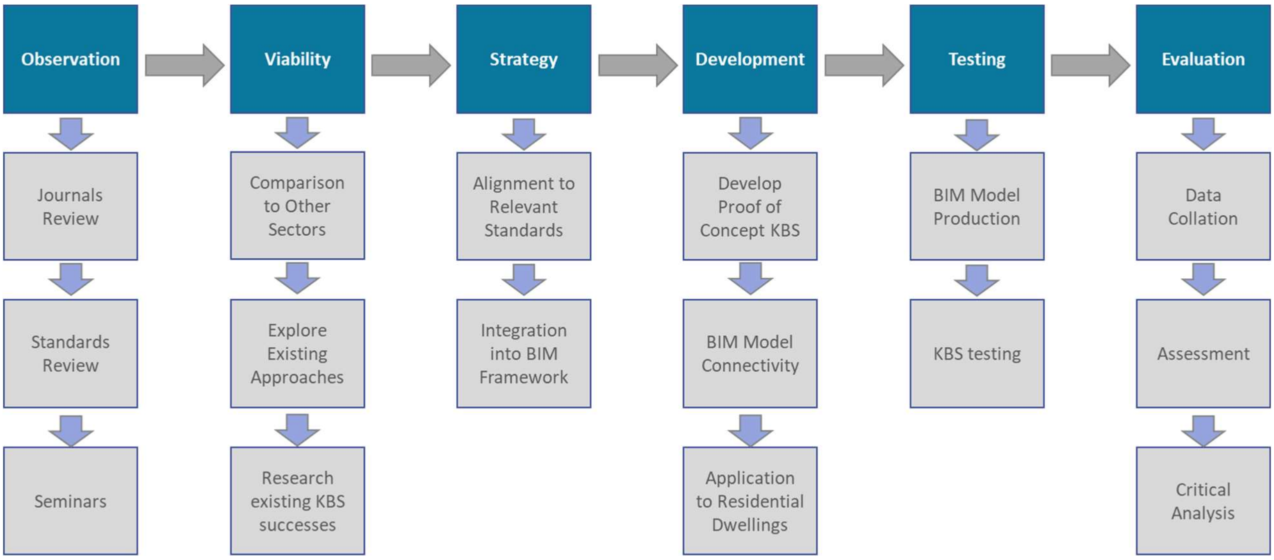


Figure 3 - Research development diagram (source: Author)

2.4 Literature Review

An intense literature review was conducted as the secondary research, with literature review continuing throughout the project. The literature review was aimed at understanding the current situation in terms of fire safety design and fire risk mitigation in building design and construction. Literature reviewed included predominantly academic journals, industry white papers, reports and associated fire safety standards. Furthermore, expert reviews within the technology sector were also included.

The literature review highlighted that knowledge base expert systems provide a means of using expert knowledge to provide a robust assessment of circumstances and that to date this is not a widely adopted technology for use within the construction sector. The main topics covered within the literature review included:

1) Fire failure modes in construction
2) Fire safety regulations and standards
3) Failure modes effect analysis and consequence modelling
4) Modern methods of construction
5) Professional competency
6) Knowledge base expert systems

Detailed findings from the literary review are outlined in chapters 3 and 4.

2.5 Methods Applied for Primary Data Collection

Initial research was to understand the fundamental cause of fire failure modes with high rise residential buildings. The research progressed to include the development of the FSES (Fire Safety Design Specification Expert System). As the research narrowed down, data collection began to focus on fire spread over external walls of buildings and the developed system was tested by a robust simulation of assessment of an external wall cladding system.

The project focussed upon a technological solution to real world and human problems. Therefore, a pragmatistic approach to research data collation was taken, incorporating both a positivist and interpretivist methods.

2.6 Systems Development

The systems within this research project were developed at a time when the legislative landscape in construction was changing following the results of the Grenfell Tower fire enquiry. As a result, an agile systems development was necessary to counteract any methodologies or standards updates that would impact the FSES system design. In terms of agile systems development, Abrahamsson, P et al describe this process as; "*development methods emerged as a response to the* *inability of previous plan-driven approaches to handle rapidly changing environments*” (Abrahamsson, et al., 2017).

Conceptually, the system development was informed by the Bruner J.S et al (1956) who in their book ‘A Study of Thinking’ define three key stages:

1) The formation of the concept
2) Data interpretation
3) Application of the principals

They also go on to state that the researcher attempting to attain the concept will typically work within a familiar area but with unfamiliar aspects (Bruner, et al., 1956). This resonates with the systems development in this research project, in that the problem and industry were familiar, but the application of the technology explored was not.

The FSES system was developed by following the three principles highlighted above, combined with an agile systems development approach.

2.6.1 Systems Development Methodology

The systems development follows a process methodology outlined by Nunamaker et al. (1990), outlined below:

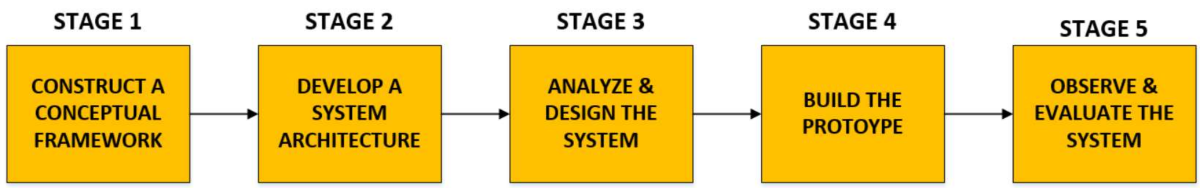


Figure 4 - Systems development path (source: Author)

Stage 1 involves the development of the concept framework. This predominantly involved the creation of an outline system draft that would align the FSES to the regulatory framework within the UK and provide a means of connecting this to both the specification and the BIM software.

Stage 2 is a critical piece of research which entails classification of the regulatory standards and input from domain experts, to provide a rule based tree decision system and domain knowledge that could be surfaced in response.

Stage 3 builds from Stage 2 by creating a first version of the system that was analysed and refined prior to the prototype build.

Stage 4 had two key components. The first being the translation of the draft into a fully working prototype. Secondly as the system was intended to integrate with the BIM framework, development focused upon visual programming to allow data to be retrieved from the BIM model and to provide a 'backward compatibility' functionality that allows the FSES system to be integrated with the BIM model but also allow alignment or correction of the model from the FSES system.

Stage 5 was a critical evaluation of the system via testing and simulation of real-world examples of which the system is intended to assist and assess. Following testing and evaluation, the system has been iteratively refined until it converged to the desired solution.

2.7 System Validation

Once the FSES has been developed, it was necessary to perform critical evaluation to assess the validity of the system and its benefits to fire safety design specification in construction. Qualitative analysis formed a key role in establishing validation of the system. Further to the testing simulation, expert peer reviews were conducted, and the data collected was assessed in line with an open coding methodology. Chapter 6.6 explores this process in detail, though a summary of the process is outlined in the remainder of this chapter section.

To best assess the potential for the FSES system a broad range of relevant professionals were selected for interview. The professionals interviewed were provided with a demonstration of the FSES proof of concept and interviewed on both the system, fire safety regulations and other closely related topics. The following professions were selected by the author as they were deemed critical for the feedback due to their responsibilities and competencies, plus their likelihood of playing key user roles with a system such as the FSES:

- Architect: Has overall responsibility for the design in a traditional procurement route. If principal designer, then the competence of the Architect will be the main point for compliance within the design process.
- Architectural technologist: Has the responsibility of developing the design to a functional working detail. Ensuring that material selection and detail are compliant.
- Fire safety expert: Consultancy and/or regulatory role in design for fire safety on an appointed project.
- Manufacturer: Responsible for guiding the designer on appropriate material selection from their range of products to ensure compliant provision to the individual project. Responsible for ensuring products perform within regulatory requirements.
- Facilities manager: Responsible for ensuring that the building is maintained to a safe standard and is reliant on as built data to ensure correct and timely

maintenance and replacement of materials are conducted. The FM must know what is in their building and why.
- Software development expert: Interviewed to ensure that the FSES was a viable development from a software perspective.

The aim of the interview process was to understand first person views on the impact specific topics researched within this project may have, to validate those issues discovered through prior research methods. Secondly, the interview and specifically the demonstration section of the interviews, aimed to gather feedback relating to the potential benefit to the industry that a system such as the FSES would bring and to determine any other further developments which could improve its robustness.

Interviews were conducted face to face with a pre-set series of questions, though occasionally the conversations did develop additional questions that were not on script. All response data was collected and tabulated. This was then assessed in line with an open coding methodology. Each data point (response) being given a code and all subsequent responses analysed both individually and collectively to assess commonalities and potential considerations for additional development of the FSES and contributions to the thesis initial research data.

2.8 Chapter reflective summary

Chapter 2 researches and discusses the multi-methodology and philosophical viewpoints which were to be applied to the research, identifying a pragmatistic approach mixing qualitative and quantitative analysis. The research methodology outcomes then identify a basis for planning out of the scope, development, testing and analysis of the proposal. A key research methodology discussed in this chapter is the undertaking of an intense literature review. Whilst the following two chapters of the thesis discuss the literature reviewed in detail, chapter two identifies the key literature topics reviewed. Notably, Fire failure modes in construction, related regulations and standards, modern methods of construction, professional competency, and the implementation and development of knowledge base expert systems.

The chapter progresses to discuss systems development. Through the literature review and research of previous work. An agile approach was defined for this project. Following Nunamaker's agile methodology (Nunamaker, et al., 1990), five stages are set out which plan the development work of the proposed fire safety expert system, these being; conceptual framework, system architecture, system design, prototype development, and concluding with system testing and analysis. Chapter 2 ultimately, researches and defines the approach taken to the project, with literature review forming key considerations for the approach, alongside ethical and practical considerations. Following chapters 3 and 4 provide detailed analysis of the initial research findings, with the proceeding stages of concept through to testing and analysis discussed from chapter 5 onwards.

CHAPTER 3: REGULATIONS, STANDARDS AND INDUSTRY PROCESSES

3.1 Approved Document B summary

ADB provides guidance on achieving fire safety in design of new and existing buildings (HM Government, 2019). ADB does also refer to BS7974 and notes that a fire safety engineering (FSE) approach may be better suited to certain buildings (i.e., complex designs and multi-use buildings). The main aims of ADB are, as follows:

Requirement B1: Means of warning and escape.

When there is a fire, ensure both:

1. satisfactory means of warning by sounding an alarm
2. Satisfactory means of escape for people.

Requirement B2: Internal fire spread (linings)

Inhibit the spread of fire over internal linings of buildings.

Requirement B3: Internal fire spread (structure)

The building must be built such that all of the following are achieved in the event of a fire:

1. the premature collapse of the building is avoided.
2. sufficient fire separation is provided within buildings and between adjoining buildings.
3. automatic fire suppression is provided where necessary.
4. The unseen spread of fire and smoke in cavities is restricted.

Requirement B4: External fire spread.

Restrict both:

1. The potential for fire to spread over external walls and roofs.
2. The spread of fire from one building to another.

Requirement B5: Access and services for the fire service

Ensure both:

1. satisfactory access for the fire service and its appliances
2. Facilities in buildings to help firefighters save the lives of people in and around buildings.

Regulation 38: Provides fire safety information to building owners.

These documents clearly depict the minimum details required to achieve a fire safety approach to design. However, it appears imperfect in some areas. For example, in section B4 – External spread of flame, if a new building is to be fitted with sprinklers, then the ‘safe’ boundary distance between it and the neighbouring building can be halved to a minimum of 1m. An internal sprinkler system will not protect from external fire spread if for example a fire from an outdoor bin caused the external cladding of a building to ignite. It will only limit the potential of fire originated from inside the building. BS-9999 allows changes to risk profiles (and thus travel distances extensions) based on sprinklers, so distances are above recommendations for periods of sprinkler isolation. Other factors to consider are that sprinklers can also be isolated for maintenance. Whilst document B does give clarity and make robust recommendations for fire safety design, there is scope for improvement (Duncan, 2019).

A specific note when reviewing any fire safety document, is that they all refer to other documents for more in depth detail. This obviously complicates the approach and will hinder in-depth understanding. Secondly, no reference is made to product performance as systems. Fire doors for example are noted with their respective Euro classification, and wall linings are also given advisory minimum classifications. How these products and systems are affected when fabricated and assembled to form part of a building system, however, is not covered. Finally, no discussion is produced in relation to workmanship. Throughout the approved documents, the term ‘reasonable’ is also used a lot. This offers the potential for variation and individual interpretation. Clear minimum standards or improved compliance wording should be provided.

3.1.1 BS7974 Summary

BS7974 provides a framework for the Application of Fire Safety Engineering (FSE) principles to the design of buildings (BSI, 2019) (Manes & Rush, 2019) (Hadjisophocleous, et al., 1998). It is supported by 8No. Published Documents within the ‘PD 7974 series’, which provide guidance and information on how to undertake analysis of the specific elements relating to the over-arching parent standard. The series cover Design approach, Acceptance criteria, Analysis, Data, and Reference. For many projects, an FSE approach is a preferred method to achieving fire safety in design. The intentions of BS7974 are to provide the designer with a disciplined approach to fire safety design, allow the safety levels for alternative designs to be compared, provide a basis for selection of appropriate fire protection systems, provide opportunities for innovative design (something that can be restricted by ADB) and lastly, provide information and assessment methods to the design, construction, management and operation of the built asset.

The framework for the BS7974 code of practice is applied in 3 stages:

1. Qualitative Design Review (QDR). The scope and objectives of the fire safety design are defined. Performance criteria established and one or more potential design solutions proposed. Key information is also gathered to enable evaluation of the design solutions from the quantitative analysis.

2. Quantitative Analysis. Engineering methods are used to evaluate the potential solutions identified within the QDR. Quantitative analysis can be time-based analysis using appropriate sub-systems to reflect the impact of fire on people and property at different stages of its development. Steady state and limit state analysis can also be used.

3. Assessment against criteria. The output of the quantitative analysis is compared to the acceptance criteria identified in the QDR to test the acceptability of the proposals.

Within a FSE approach, the above three design stages are followed and documented and should be made readily available to relevant third parties in the project or building. The relevant PDs are used to break down the design during analysis.

The main aspect of the FSE approach from a design perspective, is the QDR which is set out in clear stages as follows:

A. Review architectural design and selection of materials, including their suitability and fire properties, occupant characteristics and client requirements.
B. Establish functional objectives of fire.
C. Identify fire hazards and possible consequences.
D. Establish trial FSE designs.
E. Set acceptance criteria.
F. Identify method of analysis
G. Establish fire scenarios for analysis.
H. Document outputs of QDR

3.1.2 Comparison of Approved Document B and BS 7974

Whilst it is acknowledged that ADB provides ‘reasonable’ prescriptive guidance to avoid failure in structures or the building envelope, BS7974 addresses the consequence scenario directly, through a performance based approach. Neither process, however, goes into any in-depth detail about the approach to fire testing of the products that make up the building, other than stating minimum performance classifications. BS 7974 could address this, if set as a requirement within the QDR, but would be down to the engagement forum and requirements set upon necessary stakeholders.

3.2 Testing construction products for fire safety

Today most products marketed in the UK for construction use, must be CE or UKCA marked. CE marking is only applied if products have been tested to a harmonised European Standard (Norm). UKCA marking replicates the methodologies of CE marking but was introduced as a result of the UK’s withdrawal from the European Union, where new products to be sold on the UK market with no existing CE mark must be tested by UK approved bodies and attributed the UKCA mark to be legally sold within the UK (HM Government, 2019) (HM Government, 2020). Previously local standards in the UK would have been the main point of reference. In this case the BS 476 series of documents are prevalent.

Today, most CE and UKCA marked products are tested to BS EN 13823 as required by The Construction Products Regulation (EU) No 305/2011, with the exception of doors, which are typically regulated by BS 8214 and BS 476: Part 22: 1987 or BS EN 1634 -1: 2008. BS EN 13823 provides test methodology for reaction to fire of single burning items. Single, being the key word, where individual tested materials are then given a classification against BS EN 13501-1. This classification is often referred to as Euro class, as the scheme replaced the historic UK classification system. Euro classifications are provided in 3 tier codes. Fire resistance, smoke emittance and flaming droplets. A typical code would therefore read as follows; 'C-s2,d0' which breaks down as below:

- C is the resistance to fire. A1 being the best through to F as the worst case.
- s2 is the amount of smoke generated, 1 would be best, 3 the worst.
- d0 is the relative number of flaming particles falling, 0 is best, 2 the worst.

Reaction to Fire		Smoke production		Flaming droplets production	
A1	Non combustable	s1	No smoke	d0	No droplets
A2	Almost combustable				
B	Difficult to combust				
C	Moderately combustable	s2	Limited smoke	d1	Limited droplets
D	Well combustable				
E	Very combustable				
F	Combustable	s3	Vast smoke	d2	Droplets

Figure 5 - Visual Euro Classification Chart (source: Author)

This is arguably a more robust classification system than the subsequent British Standard classification of 0-4 and then 'unclassifiable' where BS 0 = Euro A2 and BS 'Unclassifiable' = Euro F. This is because it allows a more accurate listing and flexibility of classification against materials by breaking down the code strand to 3 specific elements of failure.

3.2.1 BS EN 13823 Summary:

Construction materials are generally tested to 'BS EN 13823:2010+A1:2014 – Reaction to fire tests for Building products – Building products excluding floorings exposed to thermal attack by a single burning item' (BSI, 2014). Products tested under this standard are generally 'sheet materials' and not fabricated products. During the test, all materials are assembled into a rig at set sheet sizes and exposed to a burning flame. Fire spread is timed, and smoke emittance is measured via sensors in the ventilation system, with flaming droplets captured by video and manually assessed by size and quantity. This test procedure is the minimum requirement to achieve CE marking.

3.2.2 What is the current problem with construction product testing?

Current issues with product fire testing seem to lie in the way in which tests are carried out. Most are based on now historic testing methods and crucially only apply to 'sheet material'. They do not factor in variables in fire propagation, nor do they consider fabricated assemblies to enough extent. Systems such as SIPs (Structurally Insulated Panels) could be tested by applying the insulation to the relevant substrates and testing this way. However, the sample size is limited, and no consideration is given to fabrication. A 30-minute rated fire door for example may prove to reach this standard in 'test conditions' but how does installation affect this, gaps may occur through misaligned door hangings, walls may have components attached, holes are cut into materials and so forth.

At the construction product leaders' summit, Dame Judith compared procuring a building to buying a car. Her comment was quoted widely in the construction media and was as follows: “"This is a great car, but I can't tell you anything about the parts or where they're from, and if it goes wrong don't come back to me. Would you buy the car? “ (Hackitt, 2020). This refers to how buildings are built, particularly in a design and build scenario, highlighting the fact that little is known about the integrity of the building components at handover. The same could be applied to construction product fire testing.

A similar comparison from another sector is where vehicle manufacturers must quote fuel economy and emission Figures in all marketing literature, though these are from test conditions. No car ever performs the same out in the real world, something clearly identified following the VW 'diesel gate' scandal of 2015 (BBC, 2015). So, can construction products be assumed to perform correctly when based on sheet material only tests in a test site condition? The answer is likely, no. More research and vigour are required to better test products in a real world, i.e., the installed assembly type scenario.

3.3 Defining building types to ensure compliance

Whilst regulations govern all building types within the United Kingdom, depending upon the region within the UK and the type of building being designed, there are various regional differences. In respect to fire safety, there has been considerable focus on the reform of regulations to ensure that tragedies such as Grenfell never happen again. However, these remain somewhat disjointed due to various jurisdiction within the United Kingdom.

In England and Wales, the regulatory reform order defines a relevant building for non-combustible cladding materials as a building with a storey at least 18 metres above ground level which: contains one or more dwellings; contains an institution or contains a room for residential purposes (UK Government, 2005). Scotland recognises domestic buildings, entertainment and assembly buildings, residential care buildings and hospitals with specific rules where the storey height is more than 11 metres (Scottish Government, 2019). The Republic of Ireland recognises assembly and recreation buildings, residential buildings, institutional buildings, flats, and maisonettes with specific rules where the storey height is more than 15 metres (DHLGH, 2022).

3.3.1 Fire failure modes in buildings

When considering the mitigation of failure in buildings due to fire, it is important to understand how fire is initiated and how the resulting characteristics and affects that heat, flame spread, and smoke impact the integrity of a building. Research conducted by the National Fire Protection Association in the U.S. identified the five most common causes of fire within residential buildings. Whilst this is not a concise list of every possibility that could result in fire, statistically in most cases the likelihood of the instigating accident will likely be due to one of these errors (NFPA, 2020).

According to the National Fire Protection Association, the top five causes of fire in residential building are:

1. Electrical defects: Wiring and plug defects or miss-use are the largest contributor to home fires. Typically, the majority of fires relating to electrical start in the bedroom within properties, suggesting miss-use or faults connected to soft furnishings or unattendance whilst occupants are asleep.

2. Cooking and associated equipment: Typically, again this is largely down to cooking equipment being left unattended with frying being the lead cooking method that contributes to fire. Cooking materials are the number one ignition source and in the US fires which started as a result of cooking account for 21% of all fire related deaths.

3. Candles: Whilst candles have been used as a light source within homes for many years, today they are typically used for ambience and in recent years, there has been a strong incline in the use of scented candles within homes. Celebration candles are also a common factor. Fire can rapidly spread from the naked flame of a candle and often these can be left unattended and when positioned too close to flammable materials such as curtains or décor can easily ignite the surrounding materials. Candles being knocked over and igniting surrounding items are also attributed to this statistic.

4. Heating: This is a mixture of solid fuel heaters not being maintained properly (i.e., flus not cleaned and flames spreading in the unintended direction), or portable heating appliances being placed too close to flammable items such as curtains or other flammable soft furnishings.

5. Smoking: This is an obvious factor but one that has declined over the past decades as smoking has become more socially unacceptable and awareness increased as to the health impacts caused through smoking. Discarded cigarettes and other smoking materials, not correctly extinguished or unattended are the most common reason for smoking related fires.

It is established that fires can begin in numerous ways and commonalities have been identified above. Regulations and product safety standards exist to help mitigate the risks associated with potential resulting fires, however human nature will always see accidental reasons. Once fire begins, to limit the impact, it is important to understand the characteristics of building fires. As this research is focussed on residential buildings, research was conducted to understand how fire spreads within residential scenarios. It was found that fire typically spread in the following six ways (NFPA, 2020) (Fire Protection Online, 2020) (Johnson, 2020):

1. Direct contact. Objects being stacked to close together can cause efficient fire spread. If we look at building and town design from before the great fire of London, streets were narrow, buildings had over hung upper floors and were in close proximity to one another. Today minimum space requirements are set out in ADB to prevent this from happening. The forestry commissions also use similar tactics to stop the spread of wildfires by culling rows of trees to create gaps in existing forests or only planting trees certain distances from one another to avoid spread of flame due to proximity. The same thing can happen in the home, a piece of furniture may catch fire which then spreads to the curtains, which then spreads to timber flooring above and so on. Space can be the greatest barrier to preventing fire spread.

2. Radiation. As fire increases in intensity, it gives off more radiant heat. If we consider a radiator when at low temperature or high temperature, the distance you can feel the heat projected increases or decreases accordingly. This is because radiant heat can travel through magnetic waves. If a house fire increases in intensity enough, simply the radiant heat can cause opposite facings and materials to combust.

3. Conduction. Building materials such as steel beams, which are conductors can transmit heat between rooms and potentially heat from a fire source to another flammable material, generating a secondary fire. Again, designing in space within structures or the use of non-conducting materials can prevent fire resulting from conduction from happening.

4. Convection. Heat rises due to warm air being less dense in oxygen content than cold air, so this naturally occurs. If heat intensity increases enough, then the rising heat can cause separate fires to occur alongside the initial fire at higher levels through a building. Convection is a common reason for fire spread through multiple floor buildings and can happen very quickly.

5. Flash over. This is when hot gases which have risen through convection, give off radiant heat that ignites materials at low level. As rooms increase in temperature flash over becomes a higher risk for fire spread.

6. Backdraught. Fire requires oxygen to burn and if a fire is contained within a sealed room, then the initial fire will begin to die as the oxygen from within that

room is consumed. A backdraught occurs when oxygen is introduced quickly into a previously enclosed room fire. For example, if a door is opened to access a room currently on fire, or if a window shatters through heat exposure, the oxygen from the outside environment rushes into the room and fuels the fire again. Backdraughts have a common characteristic which sees the flame explode out of the given room when an opening is created; as oxygen is fuel for combustion, an existing fire if still intensely burning within a sealed room will burst out into the outer environment as the heat and flame connects with the fresh supply of oxygen should a door open.

High rise residential buildings are compartmentalised according to the building regulations guidance set out within ADB: Volume 1. In the case of the Grenfell Tower tragedy, an open window allowed the initial fire which was identified as beginning with an electrical fault (one of the top five causes of fire in the home) to spread out onto the fascia of the building (Kernik, 2021). The subsequent events and rapid fire-spread were then attributed to all the above types of fire spread except backdraught. Poorly designed and installed fire barriers allowed conduction, convection, radiation, and flashover. Conduction occurred through the cladding which was identified in the enquiry into the fire as not being suitable for the application. Negligence in design and construction to this magnitude must not be repeated.

3.3.2 Passive and Active Fire Protection

Fire safety can be engineered into any building using a combination of two key principals. Active and passive fire protection (Mróz, et al., 2016) (Moushtakim, et al., 2018). The term active refers to a physical response, whilst passive is the opposite, passive measures require no external force to provide a solution (Firerite, 2022).

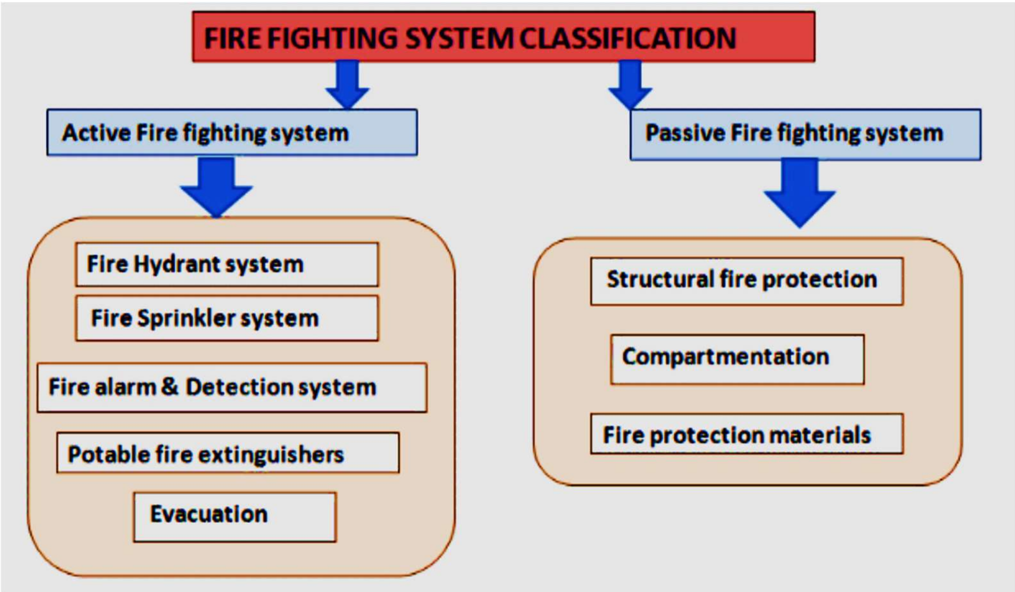


Figure 6 - Example grouping of Active and Passive Fire Protection Types (source: Moushtakim, et al. 2018)

Active fire protection refers to components or systems that can be installed into a building and require activation to provide protection. Many active fire protection systems are automatic, such as smoke alarms which work through detection of light reflection in a sensor when smoke is present, or automatic sprinkler systems which are triggered when a room hits a specified temperature. Active fire protection systems can also be manually operated, for example a fire alarm where a protective glass barrier must be broken in order to access the switch that triggers the alarm.

Irrespective of whether these systems are automatic or manually operated, active fire protection will typically serve one of two purposes; the first is to provide an alarm that can alert occupants to escape or for fire Fighters to tackle a fire. Secondly, they can be fire suppressing, for example in the case of sprinklers, they will douse any breakout of fire with water, either surpassing the fire to a lower level of reaction than would have occurred with no sprinkler system in place, until human input can fully extinguish the fire, or if comprehensive enough could completely extinguish the fire without human input.

Passive fire protection relies on the products and system which make up the building providing fire resistance or preventing smoke spread. Compartmentalisation is a critical aspect of passive fire protection. By containing a fire in one location, the risks of total building failure or serious injury to occupants is drastically reduced. The same applies to smoke spread, which can cause respiratory failure in occupants but also provides radiant heat that can spread to further areas of a building if not contained. Compartmentalisation requires the compartments such as rooms, corridors, and stairwells to be treated as closed spaces in respect to their design. This is achieved by ensuring adequate containment features, such as walls and fire doors, but also in voids such as between floors and ceilings or structural walls and external cladding. The makeup of these components must be specified using fire resisting materials such as fire rated doors and wall systems. Compartmentalisation will also use fireproof linings but in places where ventilation may be required, may be assisted by active fire protection systems such as intumescent cavity barriers. Intumescent cavity barriers allow an open void in a typical situation which allows air to travel through for thermal performance, but when subjected to heat they expand, and close the void, creating the compartment required to restrict spread of smoke and flame.

Intumescent cavity barriers are an example of active and passive fire protection working together to provide an overall better design (MCRMA, 2022). Active and Passive fire protection systems, however, should always be designed in together. Compartmentalisation will not put out a fire for example, but it will contain it from spreading to other parts of the building. If a fire breaks out and is compartmentalised, it still needs to be extinguished and occupants still need to be alerted to the fact that there is a fire in the building. This is where an alarm and sprinkler system would work in tandem with compartmentalisation.

3.3.3 What has changed since Grenfell

The following proposals from building a safer future have been put into action, with legislation being updated accordingly as certain areas are approved from the building safety act.

- A golden thread of ‘digital’ information is required in respect to all products specified, procured, and installed on all buildings of high risk. This will require all named products to be specified and followed through to hand over, complete with digital asset information for future reference.

- Three stages gates have been proposed to help mitigate risk throughout the project timeline. Gate 1 has been implemented and now requires a fire safety statement to be issued at planning stage. Gate 2 is yet to be actioned but is planned to cover the review of design and specification prior to the project moving to the construction/manufacture stage. Gate 3 will require a full review of what is as built, prior to allowing handover to the client. Gate 3 as Gate 2 is yet to be implemented.

- Each project will require the appointment of a ‘lead appointed specifier’ and ‘lead appointed contractor’ whom will be liable for ensuring that all aspects that impact their specific scope of work are conducted to the highest safety levels and meet all other new requirements as recommended from building a safer future.

- The construction products association has launched the ‘Code for Construction Product Information’ initiative. This has clear government backing and calls for manufacturers/vendors of construction products to be clear and unambiguous with their product data and performance claims, whilst recommending third party certification against safety critical products. Safety critical products being those which, where if failure occurred, the outcome could result in the loss of life of inhabitants of the applied building.

- Lastly, ADB were updated in 2019 to reflect the ban on flammable cladding materials for residential buildings above 18m in height. The 18m height is also still under consultation to potentially be lowered to 11m, which is the height limit, for flammable cladding in Scotland. Further changes made in 2020 focussed on the other fire safety provisions, particularly in blocks of flats. Mainly in respect to sprinklers, where a reduction in the trigger height from 30m to 11m is now mandatory and secondly, wayfinding signage for the fire service has been included for blocks of flats with storeys over 11m.

'Content removed due to copyright restrictions'

Figure 7 - The severity of the Grenfell Tower Fire (Source: The Times)

3.3.4 External cladding

The concerns over flammable insulation within external cladding have been documented since their introduction (Ruxandra, 2012). As noted in the review of the Grenfell Tower tragedy, the exterior cladding was apportioned to the rapid spread of fire across the exterior face of the building. This was due to the polyethylene cored materials acting as a fuel but also due to poor design and workmanship of the cavity barriers within the substructure of the cladding itself. In respect to the panel material, for future builds, this could simply be substituted for fire rated materials, however with the supporting framework and cavity barriers these are often hidden. Similarly, at least 16 other high rise residential buildings have all seen fire spread apportioned to installed external cladding, since Grenfell. These include The Torch Tower in Dubai, The Cube in Bolton (UK) and the Torre Dei Moro, Milan amongst others (Haag & Hubbard, 2017) (GMFARS, 2019) (Carlsson, 2021). These fire mode failures have simply not received the same level of media coverage as Grenfell for the simple reason that they thankfully did not suffer the tragic loss of life that was apportioned to the Grenfell tragedy.

The following outlines the potential issues with cavity barriers identified through desktop research and the interviews with design and cladding specialists.

- ADB are now relatively straight forward in terms of understanding external spread of flame since the updates in 2019. The reliance on the diagram in the previous iteration was deemed unclear, particularly where it showed class 0. However, other parts of the ADB remain quite complicated.

- During the design stage, the cladding supporting structure is often overlooked when designing and ideally requires input from a specialist manufacturer.

- Responsibility for the design and installation of cavity barriers can be problematic. Drawings can typically be simply marked up with red lines and the cladding installer gets left with the responsibility of determining what must go where.

- In both design and installation, the need to keep cavity barriers continuous can be overlooked. Typical details can often allow cladding supporting mullions to run through with breaks in the cavity barrier install.

- Manufacturer’s opinion is that designers understanding of the different system types of cladding can be limited.

- Ad hoc fixtures on site can cause issues. Often what is on site can be different to what was intended at design, or problems with the erected structure can create obstacles that have to be overcome during the installation process.

- Interaction with other products/systems can also cause issues to arise, if not co-ordinated fully. A siloed approach to packages can amplify this.

- Product availability can cause issues, particularly if products are substituted without consultation with at least the principal designer. It is recommended to always consult manufacturer.

- Junctions to external walls with internal compartment walls is not always detailed clearly. Compartmentalisation ‘maintained to external facing’ is not a clear requirement.

- What material cavity barriers should be is not covered within the Approved Documents and could be misjudged. E.g., a 0.5mm thick metal section could in effect be a cavity barrier, however metal at this gauge cannot achieve thermal requirements and could potentially contribute to ignition through heat transfer. Ideally, the cladding should require a purpose fit cavity barrier, which is potentially not always what is specified.

The prior points were outlined are a result of in-depth interview with members of Kingspan Insulated Panel’s technical team. Upon reflection of their responses and further review of the ADB and other guidance it has been concluded that the cavity barriers are a common theme where confusion or potential risk through misunderstanding or ambiguous regulations could cause failure.

3.3.5 Issues with cavity barrier guidance in Approved Documents B.

The approved documents provide clear guidance as to the location of cavity barriers. However, no guidance appears to be noted in respect to the dimensions of cavity depths vs min/max cavity barrier intumescent expansion. The depth of the void between things such as cladding and the structure, the top of a wall and a soffit are critical in the function and selection of intumescent cavity barriers. Guidance should really be included for this area. Furthermore, throughout a building's life, especially in high rise situations, buildings move and shift with the movement of the earth, wind, and general settling. What may be a minor differential settlement at ground level could result in the difference between a cavity barrier being suitable for the cavity at installation and inspection but potentially failing later down the line. Guidance on the use of movement joints exists for masonry structures, the principles of these considerations, should also be applied to cavity depths and the provision of intumescent cavity barriers within the regulatory framework (LABC, 2022).

3.3.6 Validation of installed materials

Typically, the installation requirements for any material, product or system should be highlighted within the execution clauses of the specification but they are often left to the specialism and expertise of the installing contractor or manufacturer. The gap between the design and the installation instructions could create room for error with for example no dictated specification of void depth and cavity barrier types. Furthermore, it is crucial that in the case of high-rise residential buildings that the materials specified prior to any procurement and materials that are bought and installed meet that same specification.

3.3.7 Specification selection vs system requirements.

For any system specification, it is typical for the system outline specification to be created with general requirements of items such as fire performance specific to the make-up components which form the system whole, i.e., ACM Cladding Fire performance etc. The subsequent components are then typically specified under their own clause and template later in the specification.

3.4 Building specifications

The Oxford dictionary definition of the word specification is 'a detailed description of how something is, or should be, designed or made' (Oxford University Press, 2022). In respect to a building specification, this definition remains pretty much the same. The building specification is the document that describes everything from the types of materials, products or systems that are to be used to construct the building, all the way through to the way in which the building is constructed and to what level of workmanship.

The building specification is structured in form and is set out typically using standard templates referred to as 'clauses'. The building specification cannot control aspects such as material availability or pricing data, which can adversely impact the specification and result in changes to it. Effectively the building specification is the non-graphical element of the buildings design, where aspects are described that cannot be communicated visually with the graphical data depicted within the drawings or model.

3.4.1 Descriptive vs Prescriptive specifications

Building specifications can be classified in two types: descriptive and prescriptive. A descriptive specification includes clauses for the required elements within the design but leaves the decisions on what, how and why to the appointed contractor responsible. With fast changing legislation and clear responsibility being apportioned as a result, it is becoming more prevalent for specialists such as manufacturers and sub-contractors to be engaged earlier in the specification process. This is in order to enable a robust prescriptive specification to be generated. Prescriptive specifications go further than a descriptive specification and include explicit details of the materials/products used, such as manufacturer, product name, SKU (stock keeping unit), performance characteristics and any options. Prescriptive specifications often also reference the compliance to relevant standards and regulations, and in many cases including specifications relating to installation requirements (NBS, 2020).

The installation specification is typically written through preliminary clauses. As the design progresses through its RIBA Stages the specifications become more prescriptive (see Fig 8).

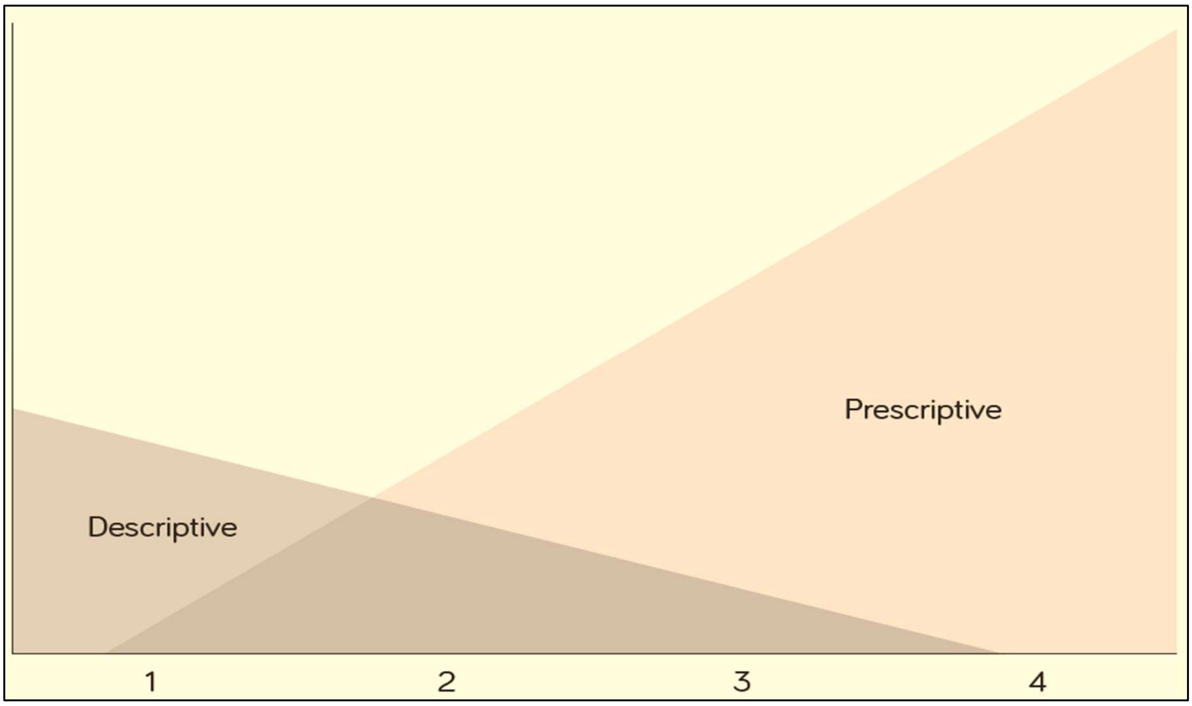


Figure 8 - The descriptive and prescriptive transition through the design stages (Source: Swaddle, P.)

3.4.2 Classifying specifications using Uniclass

Written specifications in the UK have used a number of classification systems to reference specific elements of the specifications, for over five decades (NBS, 2016). Initially CI/SfB was the primary classification type but was evolved to become the common arrangement of works sections or CAWS, as it is better known. CAWS is still used widely today to classify specifications and is what is often referred to, incorrectly, as an NBS specifications. In an industry slow to adopt change, it is likely that CAWS will remain current for some time. However, as a biproduct of the 2016 UK BIM mandate (HM Government, 2012), another classification type was defined to better facilitate the structured data and modelling requirements that the BIM process requires. Uniclass 2015, partially named due to the year it was conceived, is fast becoming the standard clause set for any project, particularly those that are BIM led. When the British Standards Institution annexed the ISO 19650 series of standards, they explicitly recommended through BS EN ISO 19650-2 that if a project is conducted using the BIM process, then the classification of all elements within that project should be defined using Uniclass 2015 (BSI, 2018).

Uniclass 2015 is maintained and operated by the NBS (National Building Specification) in the UK (NBS, 2020). It builds on previous standards of classification of building elements but offers a much more structured, hierarchical, tree set-up approach than previous methods such as CI/SfB or CAWS (Common Arrangement of Works Sections). As an example, something as simple as a wash basin would be classified as N13-335 in CAWS. What this classification code doesn't depict though, is any specific criteria. For example, what is the basin mounting type, inset, pedestal mounted, wall-hung and so on? This lack of clarity can have big impacts on decision making, particularly if applied to something more complex. On the other hand, using the example of a wash basin, a Uniclass 2015 code Pr_40_20_96_96 clearly identifies that the basin is a 'Wall-hung washbasin', specifically from its final 2 digits. Prior to the introduction of Uniclass 2015, any lack of clarity would have to be resolved by interrogating the relevant sections of the written specification against the clause to identify performance criteria.

Uniclass 2015 covers the specification of all aspects of building design, from complexes (i.e., an airport), to entities (i.e., the departure lounge), to locations (i.e., the washrooms), to elements (i.e., MEP fit out) then to systems (i.e., a wall) and finally the products (i.e., plasterboard). Products can be stand alone, such as a chair or a sub-set of a system such as metal stud in a wall system. Uniclass hierarchical structure offers clear and accessible methodology to classification. This is perfectly suited to digital data capture.

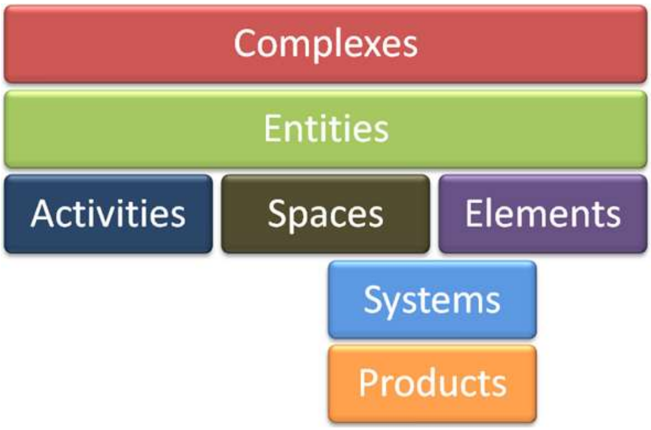


Figure 9 - Hierarchical structure of Uniclass classifications (Source: NBS)

Uniclass 2015 could be used in this research in line with standards and testing processes to identify performance and recommendations from material level through to fully assembled entities. By applying Uniclass 2015 to products that require fire testing, we would be able to provide a notification that clearly identifies how materials were tested, either in a single item form or as part of a system. This would bring benefits to providing a robust and easy to follow structure for evaluation, when selecting 'appropriate' materials for construction at the specification stage.

3.4.3 How fire safety is considered through the specification process

The specification is a fundamental aspect of achieving fire safety in any building design. The specifier must consider and implement many inputs in respect to fire safety; primarily how building regulations, legislation and associated technical documents may define their overall project outcome. Compliance is vital when considering any prescriptive or descriptive specification for both the elements that go into a built asset but also how they may be manufactured and installed. For most decisions, testing and compliance of materials and workmanship are covered by industry standards, however these are in abundance and often each element of the building will have various specific standards to be complied with. These standards will in many cases be impacted when products are fabricated to become part of a system. The specifier, be that an architect or architectural technologist, or engineer, must therefore ensure that the components they are selecting, not only meet their given standards for fire safety, but contribute and do not negatively impact the built-up system of which they will be combined to produce. The specifier must take all of this into account when designing and producing a written specification and it is therefore common for specialists within specific fields to work in silo on their individual design portion.

Construction Design and Management (CDM) Regulations 2015 assist with ensuring that consideration is given to how the building can be safely constructed and how all products and systems may be installed, however this is another layer of complexity in the production of the written specification (UK Government, 2015). The as built project must be verified and certified against the specified requirements and only by doing this can the building assessor ensure that what has been procured and constructed aligns with the design intent. With forthcoming regulatory changes, Stage gate 2 will require approval of the design and written specification prior to moving into the construction stage, whilst Stage gate 3 will require an as built specification and the physical building to be approved prior to moving to handover and the in-use phase. Both the design and as-built specification information will form part of the golden thread of information and be used for maintenance, repair, replacement, or removal of assets during the building's life.

3.4.4 Use of Fire Safety Standards in Specification

The below points summarise some of the main fire safety standards that are considered when designing buildings within the United Kingdom.

General building standards:

- BS 9991:2015 Fire safety in the design, management and use of residential buildings.
- BS 9999:2017 Fire safety in the design, management and use of (other) buildings.
- BS 7974:2019 and PD 7974:2019 Application of fire safety engineering principles to the design of buildings.
- BS EN 1993-1-2 Eurocode 3 Design of steel structures. Structural fire design
- BS EN 15725:2010 Extended application reports on the fire performance of construction products and building elements.

Education specific buildings:

- Department of education and health England (DoE DoH):
- Building Bulletin 100 (BB100) Design for fire safety in schools (2015)

Healthcare specific buildings:

- Technical Memorandum 05-02 Fire code, fire safety in the design of healthcare premised (2015)
- Technical Memorandum 05-03 Operational provisions Healthcare (2015)
- Health facilities Scotland (HFS)
- Scottish Health Technical Memorandum 81 Fire engineering of healthcare premises (2009)
- Scottish Health Technical Memorandum 83 Fire safety in healthcare premises (2004)

The prior standards are to be considered in relation to the building regulations compliance, being a legal requirement, but also a myriad of other legislation, guidance and standards exist. In particular, for external cladding on high rise buildings the below must be considered as a minimum:

- BS 8414-1 and BS 8414-2 Fire performance of external cladding systems
- BS 9414 Fire performance of external cladding systems - the application of results from BS 8414-1 and BS 8414-2 tests
- BR 135 Classified external cladding systems

The complexity of the task at hand is obvious, in that the key information required to ensure full compliance is dispersed between numerous complex documents. It is on this basis why the industry would benefit from an expert system that would assist in checking compliance of design and specifications.

3.4.5 The RIBA Plan of Work and Specification

The Royal Institute of British Architects (RIBA) Plan of Work 2020 is a document which depicts through a tabular structure the evolving stages in relation to any construction project (RIBA, 2021). Developed for use by Architects initially, it has since become the most common reference point for all construction professionals in the UK and many other regions, for defining the stages of a given project. The plan itself is made up of eight stages, with the building specification which evolves throughout those stages alongside the design process. Though certain stages are weighted more towards completing the written specification, there is not a singular stage at which the specification is written. The below summarises the evolution of the specification across the project timeline, aligned to the RIBA Plan of Work 2020.

Stage 0 – Strategic Definition: Though the specification may not officially be written here, how the project to be is defined can have a significant impact upon how the specification is approached.

Stage 1 – Preparation and brief: Similarly, to Stage 0, outline requirements for the project will be determined here. For example, if sustainable outcomes or specific fire safety requirements are to be met, this may result in a prescriptive specification instead of a more descriptive specification.

Stage 2 – Concept design: At stage 2, the building design starts to form and so does an ‘outline’ specification. This will fundamentally begin to include for items such as the building fabric and energy provision. Also, preliminary sections will be written for the specification to outline the contractual and construction requirements. These preliminary sections can be used for tender.

Stage 3 – Spatial co-ordination: Through Stage 3, the design starts to develop and focusses on how the building will function for its use. The outline specification will be built upon and updated throughout this stage.

Stage 4 – Technical Design: Stage 4 is where the final written specification must be completed and is the last stage before construction. This will now become a fully tailored document encompassing all requirements that define how the building is to be constructed and what materials, products or systems are to be used in its construction. The specification becomes a part of tender documentation.

Stage 5 – Manufacturing and Construction: During the construction phase, the specification is used as a reference to complete the works, however changes may occur during construction for varying reasons from client design changes or more likely to overcome obstacles during the build. These obstacles could be practical issues where building something as intended may not be possible, or there has been an oversight. A common issue is when certain materials that may have been specified are unavailable in a timely manner to allow works to be completed in line with the project plan. When alternatives must be substituted, the specification should be amended in line with those changes and documentation attached showing why.

Stage 6 – Handover: The specification is used to assist in compliance checking and sign off, of the finished build.

Stage 7 – Use: Historically the specification has not been a focus here, however, following the recent tragedies highlighted in Chapter 1, it has become pertinent to retain a digital copy of the specification for future reference. This can aid maintenance (i.e., to ensure replacement doors later down the line meet the required fire safety standards) plus in the event of any failure, offer clear insight into what exactly is a make-up of the built asset, to allow best approach to fire safety.

3.5 Chapter reflective summary

This chapter provides in-depth details and outcomes of the literature review relating to the status and complexity of construction fire safety design and specification compliance. The findings of which provide critical background and rationale for the proposal.

Regulatory compliance is a complex challenge. All buildings in England and Wales must meet the Building Regulations, of which the approved documents provide guidance to compliance. However, there are other routes to compliance, including fire safety engineering. Additionally, there are numerous facets including product safety standards, minimum testing and certification considerations, alongside continual updates and improvements to each facet. Those responsible for compliance in design, specification and construction are placed with a difficult scenario. The implications of these scenarios upon the research, identifies the potential benefit a technological aid may have upon each professional stakeholder.

Guiding each professional through the myriad of requirements in an automated manner, could prove beneficial in mitigating risk of failure due to any non-conformity. The literary review of existing standards and guidance in this chapter, define the requirement to provide a more user friendly approach to checking of designs and specifications to the applicable compliance areas. Notably, cross referencing what has been specified as a product of a subsystem and what the system requirements were, is an area also identified in this chapter. A system that could interact directly with the specification and provide a means to align 'as specified' data vs 'as built' data may aid compliance and checking of such information. The process could be applicable to various design elements, with the data captured being made available to the building assessor to validate the installation and general workmanship of the physical asset to that designed and specified. As building specifications provide the list of information of what materials should be procured, installed and how they should be installed in any given project. When considering regulatory compliance, the specification process is further identified in this chapter as a critical consideration for incorporation into the fire safety expert system development.

CHAPTER 4: TECHNOLOGY AND PROCESSES IN CONSTRUCTION

4.1 Adapting to change

The construction industry has evolved over the centuries; however, the fundamental principles remain largely the same. For the vast majority of projects built on site, they utilise the same skill sets such as masonry, mechanical and electrical work, that they have done for the past century, and in some cases, such as joinery, for thousands of years. A mix of skilled and semi-skilled labour has been common throughout the industry for as long as buildings have been constructed. Following the second world war, advancement in materials began to alter the design of buildings, providing them with higher levels of insulation, improved fire performance and sound absorption. There was even an attempt at offsite construction through the pre-fabrication of concrete and asbestos houses designed to assist the challenge of rebuilding war-stricken cities and provisional requirements needed (Science and Media museum, 2021). Modern methods of construction have seen an uplift in recent years, though the stigma associated with prefabrication of the post war era may be preventing a more rapid rise (JSTOR, 2015). The past two decades has seen an exponential shift in digital adoption in most industrial sectors, however construction is very low on uptake within that group. McKinsey reported on a sector-by-sector digitisation index in 2016, which showed construction to be the second slowest industry to adopt digital practice, only slightly in front of agriculture (Argawal, et al., 2016). Possibly the largest barrier to change is in the ways in which projects are carried out and financed. The following sections discuss three key areas where obstacles are documented to occur.

4.1.1 Financial barriers

Published the year before the Grenfell Tower Tragedy, Mark Farmer's report 'Modernise or Die' identified a number of the shortcomings of the construction sector (Farmer, 2016). Whilst the perspective of Farmer's review was one of the business model of the sector, many of the failings identified can be apportioned to the same failings which have seen substandard construction result in failures.

From the shortcomings identified in Farmer's report, low profitability is at the pinnacle and is the reason for many of the derived issues that cascade from it. This is a defining contributor to a lack of investment in research and development, technology deployment and possibly more importantly training of construction workers. Whilst a lack of training can be apportioned to low profitability, in that the overall pot does not stretch to sufficient spend elsewhere down the value chain, it is not solely to blame. The report also details how the industry is fragmented, with almost half of the work force being self-employed. This poses the issue to employers in that when they invest in training of staff, the risk presents itself in that if a person is up-skilled too much, then they are more likely to shift to self-employment. Having gained the necessary skills and experience at the employer's cost, this is clearly a motive towards limiting training provided by employers to their employees. The larger picture, though portraits a lower skilled industry than is required to deliver safe buildings of the highest standard.

Worryingly, Farmer's report also highlighted that clients and the professionals alike within the sector accept and expect that failure will occur on projects. So much so, that even today, almost all projects will have a margin apportioned to the overall budget to account for errors. Using the ratio of 1:10:100 which depicts the costs typically associated to correcting errors during the design, construction, and in-use phases of built assets (Sowards, 2013). Failures which occur in construction will likely incur higher costs further upstream during the assets in-use phases and be more costly to resolve. No cost can be deemed higher than that of human life, therefore the industry must change. It cannot be acceptable to continually repeat the mistakes of the past.

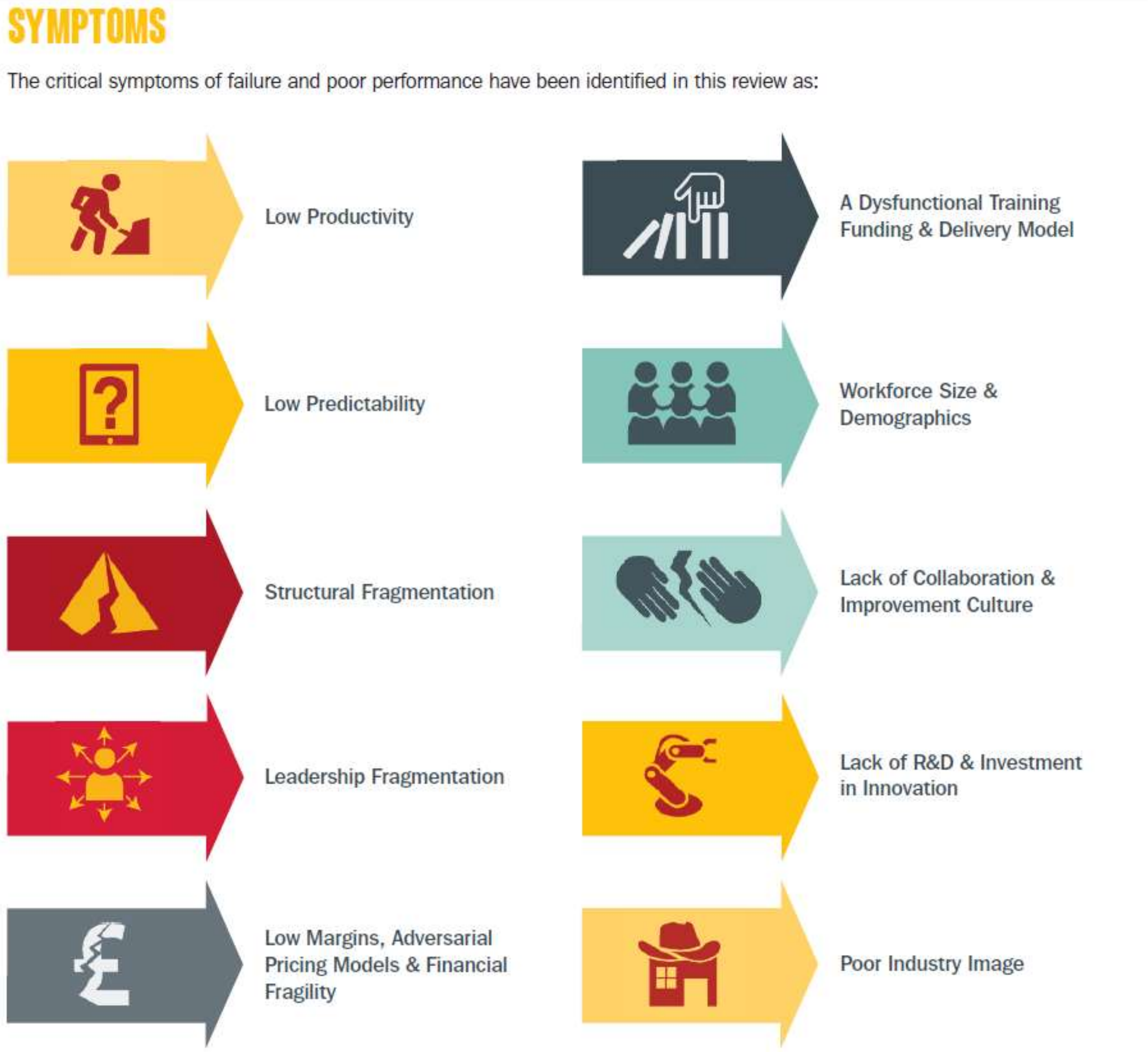


Figure 10 - The contributing symptoms of failure in construction (Source: Farmer, M. 2016)

4.1.2 Cultural barriers

We have just discussed that failure is an expectation in the industry. This is rooted deep into a culture that when viewed from outside, appears to be resilient to accepting change. The view that 'if it's not broken, then don't fix it' maybe perceived by many construction professionals. However, to the more experienced and researched individual, the issues are clear and in abundance. Only when the mind set of all industry stakeholder’s change, will we likely see genuine improvement. In most sectors, improvement is driven by client demand (Lee, 2022). The demand for better service, improved products and so forth. In the construction sector, the complexities of designing a building a project, where in most cases it will be bespoke each time, are often passed down to third parties, such as consultants, principal designers, and contractors. This removes the demand from the client in this sector to improve and manifests the buffer for expected failure. Other than the client, the second most influential push to promote change is regulation. The government is in a perfect situation to make changes to the construction sector that would influence cultural shift. Not only is the Government the largest single client to the sector, but it also has the obvious ability to impose the laws and regulations which govern it (Richardson & Gardener, 2014).

4.1.3 Technological barriers

A report in 2019 from McKinsey and company, depicted construction to be one of the lowest adopters of digitalisation (Abraham, et al., 2019). Numerous articles and journals published demonstrate how digitalisation can improve not only productivity and profitability, but also improve upon safety in design. Today, almost every aspect of our daily lives is assisted by digital technology, from ordering groceries to booking healthcare appointments and everything else in between. Digital has become an expectation. For the construction sector, there are many processes evolving, however there is a lot more ground to cover, should the sector become on par with other industries, such as automotive and finance. Furthermore, the adoption of digital technology in boosting productivity could compensate for the reduction in skilled labour which the industry is experiencing whilst attracting a younger generation to the sector (FCP, 2021).

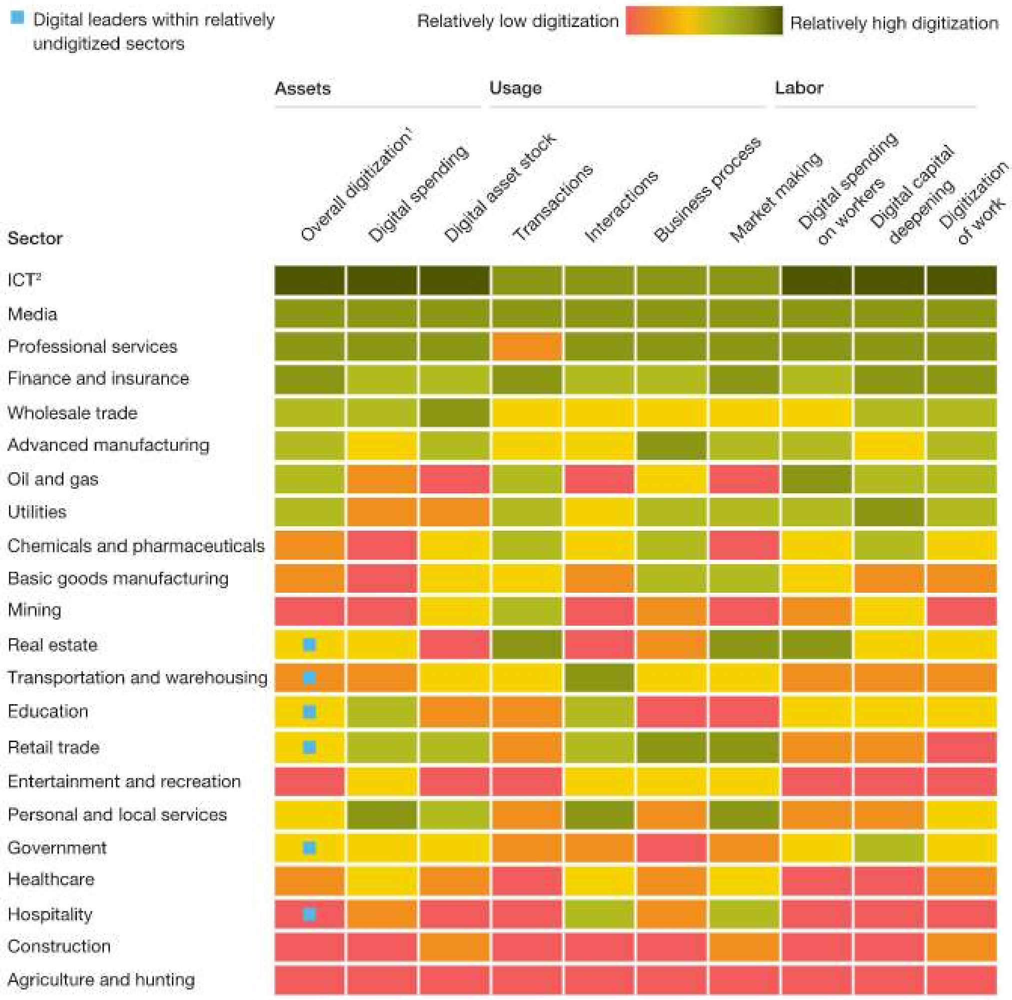


Figure 11 - Digitization index of commercial sectors (Source: McKinsey. 2015)

Examples of digitalisation that are improving safety in other sectors can be found across the board. Failure modes effect analysis and consequence modelling are common to sectors such as oil and gas for example (Amir-Heidari et al, 2017) (Dadashzadeh et al, 2013) (Shaba et al, 2017) (Singh et al, 2017). The oil and gas sector carries similarities to construction in that most of the plants are built assets. However, for oil and gas, the handling of extremely flammable and volatile substances drives adoption of robust methodologies to prevent failure. Clear requirements to prevent hazards to human life and the environment will be approached with extreme care. Financially, insurance in those sectors is also high because of the substances handled. The ability to model through digital means the potential spread of fire in the refineries and plants can aid the design from the outset. This could replicate in construction. However, as the result of death or serious injury occurring through the use phase of a typical building is relatively low when compared to end product use in other sectors, uptake is low.

A typical example of legislation mandate, forcing the uptake in digital adoption in the construction sector can be found in the UK Governments BIM mandate of 2016. Having advised that in 2016 all publicly funded construction projects must be BIM Level 2 compliant has resulted in a big drive for many stakeholders to become BIM ready. Designers, information managers, consultancies, contractors and building product manufacturers alike all scrambled to get to grips with adopting new technologies to assist BIM project delivery and to avoid dismissal from government contracts.

4.2 BIM (Building Information Modelling)

In 1974 Charles 'Chuck' Eastman and fellow researchers from Carnegie-Mellon University, published a paper entitled 'An outline of the building description system – Report No.50' (Eastman, 1974). Deemed as a ground-breaking novel proposal then, their building description system (BDS) set out what would later become an industry phenomenon. Today BIM is a widely adopted process with much of the principals and enabling software platforms that align to Eastman's vision. The term BIM is thought to have first been used by another industry giant, Phil Bernstein at an Autodesk conference around the turn of the millennium (Kubba, 2012). Irrespective of the responsibility for the naming, what is clear from these two historical facts is that it can take a very long time for the construction industry to adopt new technology. Whilst supporting infrastructure would not have facilitated a viable network for digital adoption back in 1974, computers have been commonplace in the workplace in many industries for four decades. According to NBS' digital construction report 2021, around 70% of the industry has since adopted BIM today (Bain, 2020). This percentage will cover those with low adoption and those at the higher end of the scale utilising cutting edge technology, and all others in between. The percentage will likely also be higher than what is the actual status of the sector, simply due to the types of individuals who respond to the surveys that facilitated the report. Five decades have passed since Chuck Eastman's conceptual proposal and two decades have passed since Phil Bernstein may have coined the term BIM. Yet today, a large proportion of the sector still operates in analogue siloed methods.

Arguably, one of the largest drivers towards BIM adoption in the UK was the Government BIM mandate in 2016. Announced in 2011 by Sir Francis Maude in his speech to Parliament, the UK government saw BIM as a means of reducing risk through construction and reduced in-use costs of built assets through improved digital asset management data provided via the BIM process. COBie was the basis of what outlined the 'BIM Level 2' mandate that came into force in April 2016 (Hamil, 2018). COBie in its most simple definition is a spreadsheet containing asset information for a building. The principal is that every material, product or system that makes up the building would have an associated COBie data template. The template itself is truly digital in that it is machine readable, has set properties and attributes that can be federated to suit each component. Particularly in the case of facilities management, the COBie spreadsheet will provide a reference point for maintenance scheduling and replacement that would have previously been unattainable or updated throughout the project life cycle. The capabilities of BIM far exceed the potential for cost saving, however. The power of data federated into a detailed arrangement of objects can be extracted and used for a variety of purposes.

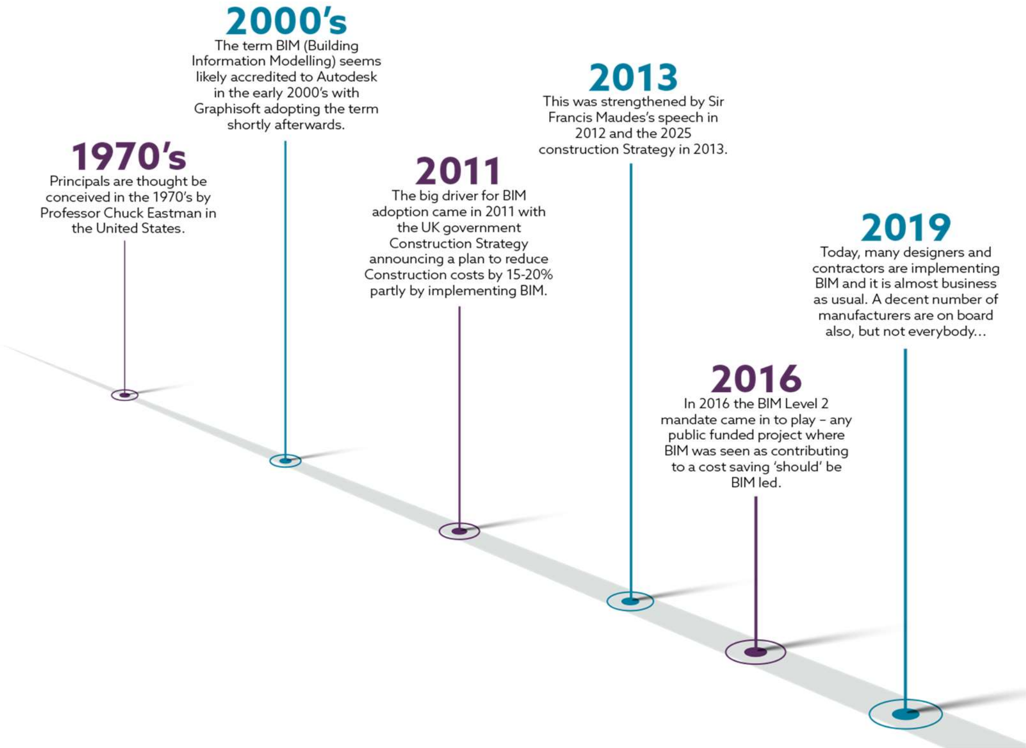


Figure 12 - Key points of BIM development through history (Source: NBS)

Figure 12 was created by the author and published by NBS, it details the history of BIM from its original concept through to the age in which it became 'business as usual' in industry. It demonstrates clearly, how slowly technology adoption has taken within the construction sector historically. For the earlier decades, computational power and affordability would no doubt have been blockers, yet the research findings discussed in chapters 4.1 and 4.1.1 show that this is still an issue today. Complexity, understanding and willingness to change potentially being continual barriers. In a reactive industry, technology that can aid compliance and avoid any reprimand should be met openly, but caution must be taken, so as not to be overly complex if its adoption is to be at a fast pace.

4.3 The 'Internet of Things' (IoT)

IoT is a name given to the process of enabling elements of a system (things) to connect and operate interactively without the need for human to human or human to machine input. The connection is facilitated via the internet and relies upon globally unique identifiers (GUIDs) associated to the 'things' to provide recognition and the ability to communicate accurately.

IoT is already widely used in many sectors outside of construction. Automotive is a perfect example where IoT is now commonplace. Modern cars have multiple sensors that can provide telemetry to manufacturers to enable fault diagnosis and performance monitoring. Even less safety critical aspects are visible through technology that can wirelessly connect mobile phones to the cars infotainment system to enable hands free communication, entertainment, and navigation to name but a few typical operations (Krasniqi & Hajrizi, 2016). This is all possible through IoT and is dependent upon the interface applications, viable internet connection and the unique identifiers.

For the Construction sector, IoT provides many opportunities, but the difficulties in encouraging a shift to the use of modern technology remain the same for IoT as all other technological implementations, as discussed earlier in this Chapter.

For any sector embracing IoT, all digital disrupters of significance have commonalities. Efficiency is the main success criteria to the likes of Netflix, Uber, Microsoft Teams, and many others. A means of conducting a task that previously existed but in a much easier way will always be attractive, especially to younger generations who will openly embrace digital technology and therefore will increase success rate of any emerging technology. Outside of efficiency, improving the function or delivery quality of an existing task is also a driver to success (Woodhead, et al., 2018). For construction, there are two very clear challenges that are widely covered in the media, industry papers and wider discussions in the need to urgent improvement, namely safety and sustainability outcomes, on all building projects.

IoT offers numerous methodologies to mitigate building safety risks. Bridges for example have utilised IoT for the past two decades. Sensors placed within bridges, typically wire vibration sensors, can feed back telemetry to remote computers in real time to allow increased monitoring of corrosion and stress within the bridge structure and supports. These systems also utilise sensors to monitor the vibration sensors, as a failsafe to ensure that all telemetry reported is accurate (Yehia, et al., 2007). In respect to buildings, sensors can also be used to monitor various functionality from thermal performance of appliances, security breaches and many other factors, feeding data back to the user’s mobile phone via apps. These apps also go one step further by allowing two-way functionality, being able to turn the heating down in your home or communicating with the delivery person through your doorbell app are just two commonalities facilitated by IoT.

Looking further to the construction stage of projects, new technologies such as BSi Identify (BSI, 2021), are aiming to place GUID’s within building materials, allowing full assessment of what has been installed with a building and cross referenced to the specification. Moving further forward into the in-use phase, it is intended that these same GUID’s can be used to assess data in relation to maintenance, replacement, and end of life requirements of products. The ‘as-built’ assessment will reap rewards through the use of identifiers within materials, particularly in the scenario where an identifier may be able to be scanned through a concealing material. A built up internal dividing wall system for example may typically be made up of steel stud, insulation, layers of plasterboard, skim and topcoats of paint. For the building regulator signing off the project before hand-over the ability to genuinely know what the wall is made up of, down to its non-visible internals and being able to then cross reference this with the specification will remove the potential for lesser fire rated or thermally efficient materials being used than those specified.

4.4 AI (Artificial Intelligence)

Artificial Intelligence or AI as its acronym most often referred to, is the demonstration of intelligence by a computer assisted machine. In many academic research papers and even science fiction movies, AI is often referenced as machine learning, though AI has varied levels of complexity and the majority of applied AI technology used in industry today is not the advanced machine learning type of AI. In many cases it is a basic AI that can make mundane or complex data processing tasks more efficient.
In 2016 Arend Hintze, an AI expert and professor at Michigan State University, published an article which classified four types of AI, as per Fig 13 below: 1) Reactive, 2) Limited Memory 3) Theory of Mind AI and 4) Self-aware AI (Hintze, 2016). However, the fourth and most advanced 'self-aware' type of AI does not exist yet.

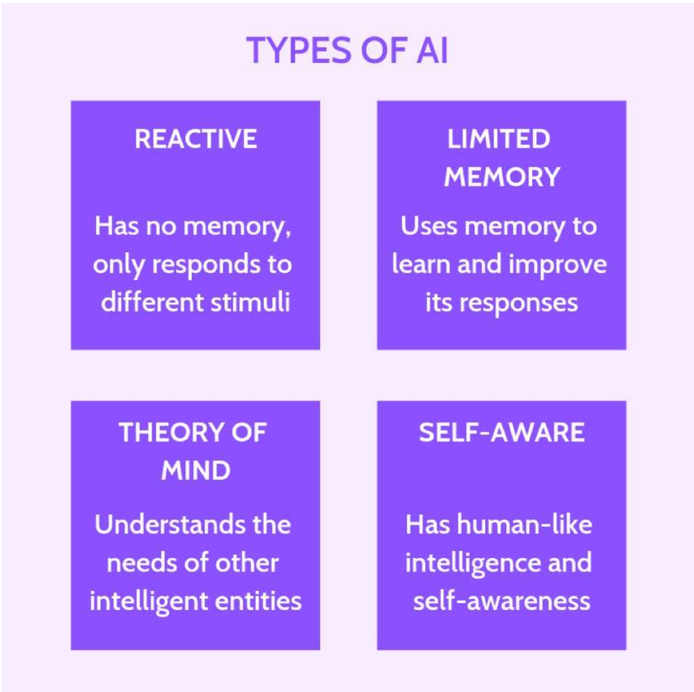


Figure 13 - The 4 Types of Artificial Intelligence (Source: Forbes)

Limited memory AI applications can include safety detection systems on sites, where sensors connected to software federated with knowledge from a domain expert, can not only raise an alarm when detecting anomalies in telemetry but can then process this data through memory knowledge bases to provide insights and predict maintenance or failures that may occur before they do. Theory of mind, branches into what is more commonly referred to as machine learning AI. The machine learning route is highly complex and expensive but can provide efficiency and monetary reward by creating more efficient project plans or scheduling. Delays on construction projects can easily create thousands to millions of pounds in fines, attributable to late handover of projects. It is in these types of scenarios where investment in machine learning algorithms may beneficially outweigh the risk of not being applied. If a machine can learn and predict patterns in project delivery, it could ultimately produce more efficient completion management plans (Walch, 2020).

4.4.1 Expert Knowledge Base Systems

An Expert knowledge base system, or expert system as they are often referred, is a type of system that draws upon a knowledge base created via input of human expertise. Expert knowledge based systems provide a tried and tested solution in many other industries, solving problems in an efficient manner whilst empowering lesser skilled staff to call upon expert knowledge and make informed decisions (Moore, 2018). They are a form of artificial intelligence and offer the potential to mitigate risk when there is high demand on subject knowledge and compliance (Akerkar & Sajja, 2009). The expert knowledge base system works by feeding a database with facts and rules from a domain expert, which is then visualised through a user interface via an inference engine by the system.

Fig 14 depicts the flow of information and processes for a typical expert knowledge base system.

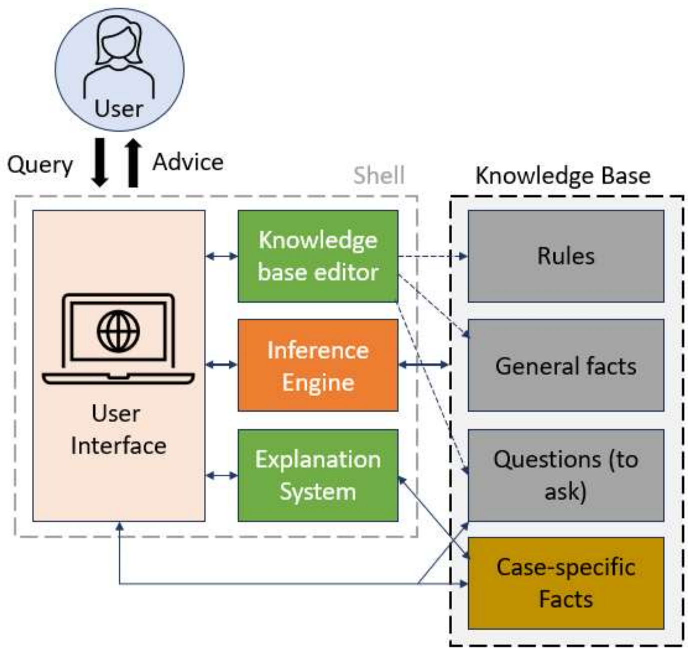


Figure 14 - Expert knowledge base system typical set up and operating flow diagram. (Source: Urbanowicz, R.J 2011)

An expert system is typically made up of four key components:

1. Knowledge base – Data input from experts.
2. Rules – How data relates to each other.
3. Algorithms/Interference engine
4. User interface – Commercial application interface to allow users to interrogate the knowledge base.

Advantages of expert systems include knowledge consistency, availability of expert knowledge, increased efficiency and reduced costs long term due to less requirement for specialist input to make decisions. Disadvantages of expert systems are that they can be inflexible and are not intuitive as a human can be. When diagnosing, the answers can never be 100% accurate, though offer high probability rates. Finally, expert systems can be restrictive as the knowledge base requires significant amounts of data input, so they tend to be limited to specific areas.

Examples of expert systems include the NHS direct 111 service where less trained call centre staff ask set questions fed by the knowledge base input from specialists, in this case doctors and other health care professionals. An expert system uses questions and responses to navigate to further questions and then decisions, based on IF and THEN methodology. For example, if the answer is this, then this is the next step, etc. Other examples include credit decision making applications which are used widely by the finance industry daily. The finance industry example can provide results for credit applications based on data returned from the applicant and their credit report. The data used can show the likelihood of potential defaults by the applicant and their ability to repay over set terms etc. Certain responses also calculate APR based on risk level diagnosis. Expert systems can help automate or ease decision making in many situations where diagnosis, prediction or instruction are required (Akerkar & Sajja, 2009) (El-Ghalayini & Kharbat, 2008) (Moore, 2018).

4.4.2 Expert systems in previous construction sector research

Through the literature review, a number of historical research projects have been documented as proposals for use of expert systems in construction (Burggräfa, et al., 2021) (Soh & Miles, 1995) (Rehak & Howard, 1985; Maher, 1985). Some of these have also been directly apportioned to fire safety design, mostly looking at specific aspects of design such as visual zoning for means of escape being considered (Donegan, et al., 1991) (Tofiłoa, et al., 2013). Perhaps the closest study to this research was undertaken by Frye, M.J. et al (1992). Their paper on the *Development of an Expert System for the Fire Protection Requirements of the National Building Code of Canada*, has some similar resemblance to parts of this research, notably the decision to use a forward chaining expert system to guide fire safety compliance to a regulatory framework. Their research appeared to focus predominantly on increasing the users ability of using the fire building code in Canada at that time and does not appear to be intent on assessing accompanying specification or design documentation (Frye, et al., 1992), nor provide an auditable trail of information. Other than a singular journal paper, no other research could be found by the author in relation to that project. What seems apparent across all construction based expert system research projects reviews is that none of them attempted to integrate BIM with the fire safety design specification into one singular expert system, which can assess the building design and specification for regulatory compliance and provide a golden thread of information.

4.5 Future developments in AI for fire safety compliance

AI is a fast emerging technology that will bring about automation within many disciplines, including that of fire safety design. Notable research can be found in relation to AI applications within the use of consequence modelling, where machine learning is utilised to critique and provide options for performance based spatial design (Yanfu, et al., 2022) (Huang, et al., 2022). In the previous section of this chapter previous research was also covered in relation to expert systems to aid fire safety design compliance, yet the majority of those reviewed by the author were found to focus again on spatial design. When considering the building specification and its critical role in providing a prescriptive itinerary of compliant building materials and its potential future use for maintenance and reference in the face of any failures associated with fire. Future research within the realm of AI and how it can assist the achievement of compliant and robust specifications, would no doubt be a positive approach. In this research a novel knowledge base expert system is discussed. The research proposal utilises mild AI and focusses on aiding issues that may arise via human input. Advancements in machine learning could be considered, with a view to understanding if and how AI could further reduce human input.

A role of the BIM workflow has always aimed to provide a single source of truth for the construction project (Rodrigues, 2022). However, many projects today still incur detached documentation (Rhumbix, 2023). For example, separate 3D models (structural, MEP, architectural) owned and controlled by separate actors, all with potentially detached written specifications. The silo impact in operating this way, will provide scope for error through misaligned documentation. It may be possible for limited memory AI to be modelled and taught to generate connected graphical and non-graphical documentation from a single model. For example, if a parent BIM model were to exist, the concatenation of associated documentation could be auto generated from that model. In tandem with a enhanced development of the research conducted in this project, it could also generate a report of compliance. This would still require human intervention, notably in the assessment of what the AI has generated. However, in bringing together construction documents into one linked source, efficiency and compliance could be improved. Additional considerations for future research are identified at the end of the thesis.

4.6 Chapter reflective summary

The focus within chapter 4 was technology in construction. The research discussed the various technologies advancing both in the sector and within other sectors. For construction specifically, barriers to digital adoption were presented. These barriers were defined across various attributes, including culture, siloed operations of different trades, availability of training and resulting competency, and financial barriers. An apparent aspect that would impact the viability of this research was understood to be, that any digital application designed to improve efficiency and or safety, must be cost effective to deploy and importantly accessible to the user. BIM was also discussed and provides a case study example of how slow to adopt change the construction sector can take. Originally conceived in the 1970's it is only today that this is beginning to become an everyday workflow. The benefits of BIM were also discussed and relating to this research, alongside accessibility and connection to the specification, benefits may be found through integration of a fire safety expert system with the BIM model.

This project proposes the use of an expert system to improve fire safety design and specification compliance. Expert systems form part of the AI group of technologies and are found in the literature review to be highly beneficial and widely adopted in other sectors. The research within this chapter set out to understand what prior research had been undertaken in relation to applying an expert system to fire safety design in construction. A number of past projects were discovered and reviewed, however the majority linked directly to spatial planning or fluid dynamics. One project from Canada in 1992 explored the connection between Canadian fire safety standards and the potential assistance of expert systems, however the research was limited and linked directly to the norms of its time.

Technological solutions exist to solve problems or improve efficiencies. When striving for an improved cultural outlook, technology will go hand in hand with continual improvement. Currently, AI provides arguably the biggest scope for advancement within all industries, construction included. From the discussions within this chapter, the author identified that a novel approach to aiding fire safety design and specification compliance may be found via the implementation of an expert system that connected to the building specification and 3D BIM model. Utilising the data within each of the existing available graphical and non-graphical project details, an expert system could potentially automate checking of the design and spec whilst ensuring alignment of both data sources.

CHAPTER 5: DEVELOPMENT OF A FIRE SAFETY EXPERT SYSTEM (FSES)

5.1 High Level Framework

The fire safety expert system (FSES) proposed in this research has been developed with the aim of providing a set of knowledge based rules for guidance and support in the fire safety design specification compliance in buildings. Its main benefit is at the design stage where the working design of a built asset can be assessed to comply with the fire safety regulations more easily than is currently possible, providing a systematic approach to the specification and data capture relating to relevant building products, components, and systems. Two approaches will be considered, one in which follows the RIBA Plan of Works 2020 aligned to Approved Document B, and the second approach that follows a qualitative design review aligned to BS 7974.

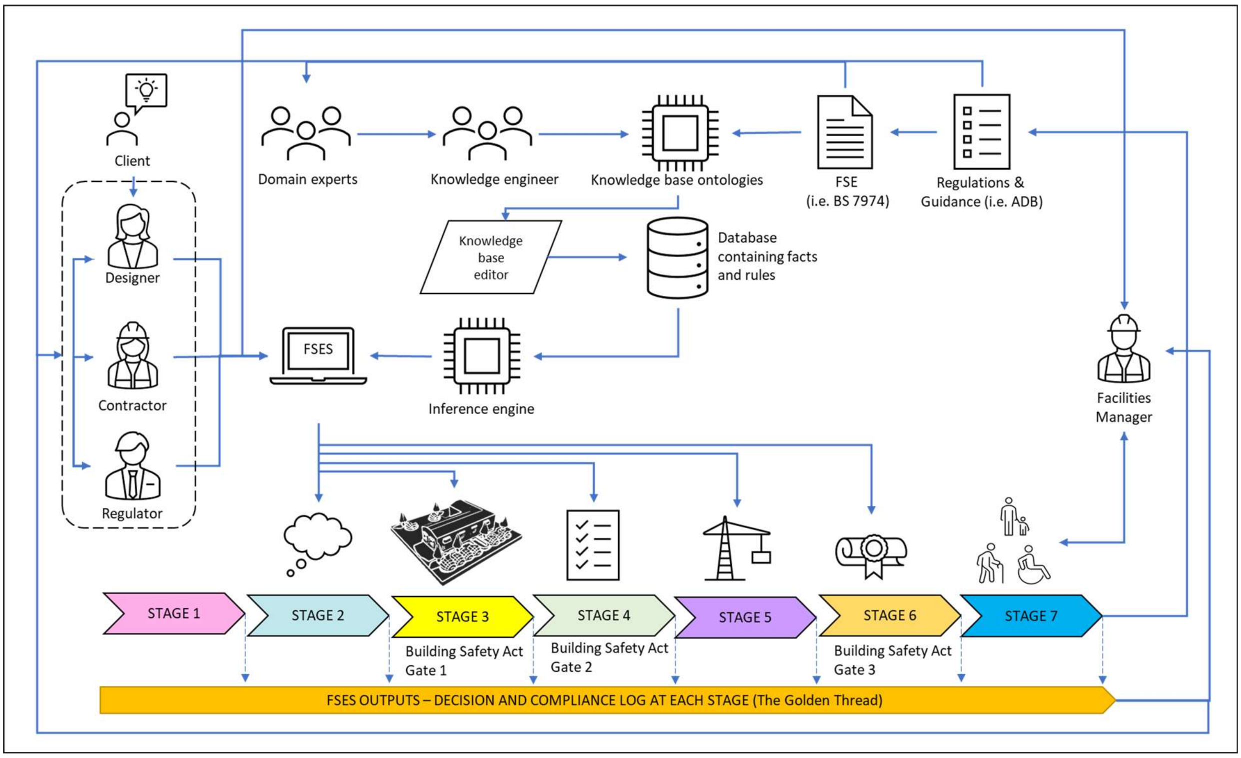


Figure 15 - High level structure of proposed FSES (Source: Author)

Fig.15 shows the high level framework, developed in this research to align the proposed expert knowledge system with the relevant stages of the RIBA Plan of Work (RIBA PoW 2020), which is widely recognised as the industry benchmark standard for planning of building works. It is also aligned to the new legislation, specifically the Building Safety Act 2022, and its Stage Gates. This alignment is proposed to ensure more robust project control, with the building regulatory reform proposing new 'stage gates' that must be passed before the current project stages can proceed to the next stage (Mohammed, et al., 2020). Notably, a Compliance Stage gate for buildings of high risk is proposed at the end of the design stage prior to allowing construction to commence. A Final Stage gate is then proposed at the construction completion phase, prior to allowing the built asset to be handed over to the client for the in-use phase of the project. The expert knowledge based system serves as a reference point to allow clear decisions to be made on progression in these situations.

5.2 Fire Safety Expert System Development

The Fig.16 depicts the decisional flow of the proposed FSES system. The approach to fire safety engineering is decided upon, either prescriptive, as aligned to Approved Document B, or a performance based, as aligned to BS7974:2019. The user navigates through the system based upon the route taken, with the new planning stage gates shown in their respective time frames, within the assessment journey.

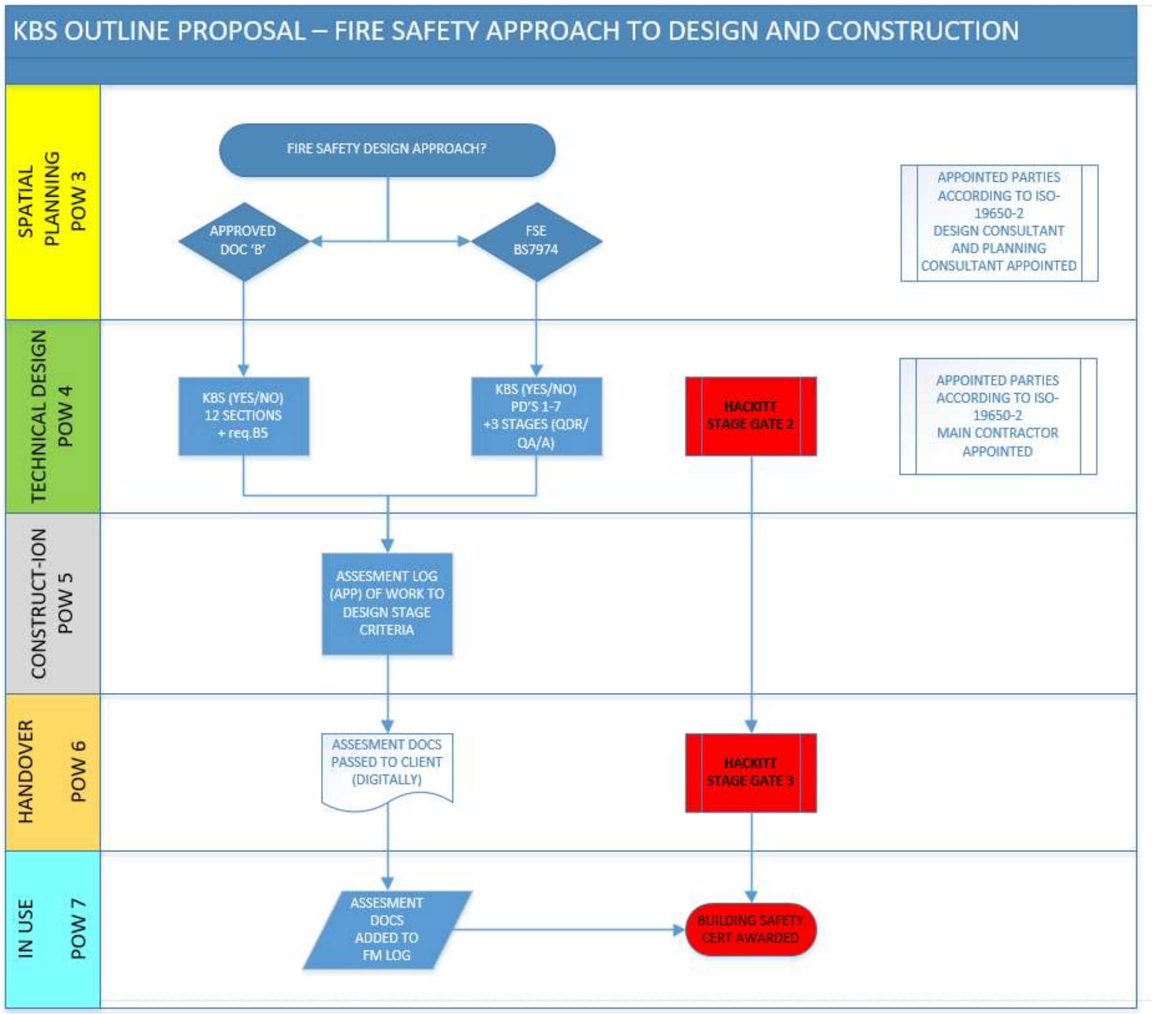


Figure 16 - Proposed expert knowledge base system flow through the project stages, aligning to the RIBA plan of work and proposed building safety act project stage gates.(Source: Author)

Whilst the choice of a prescriptive route leads to a clearly defined path of compliance via Approved Document B, the choice of a fire safety engineering route requires a more complex decision making path. Fig 17 shows how the proposed expert knowledge base system would align to an FSE approach and the qualitative design review (QDR) strategy. The chart shows the key decision points when following a QDR process. The columns indicate the stages of the QDR process, and the decision points are indicated within them. The final process in the flow chart is the data capture logged by the FSES generated at all review points, providing a logged history of all designs and decisions.

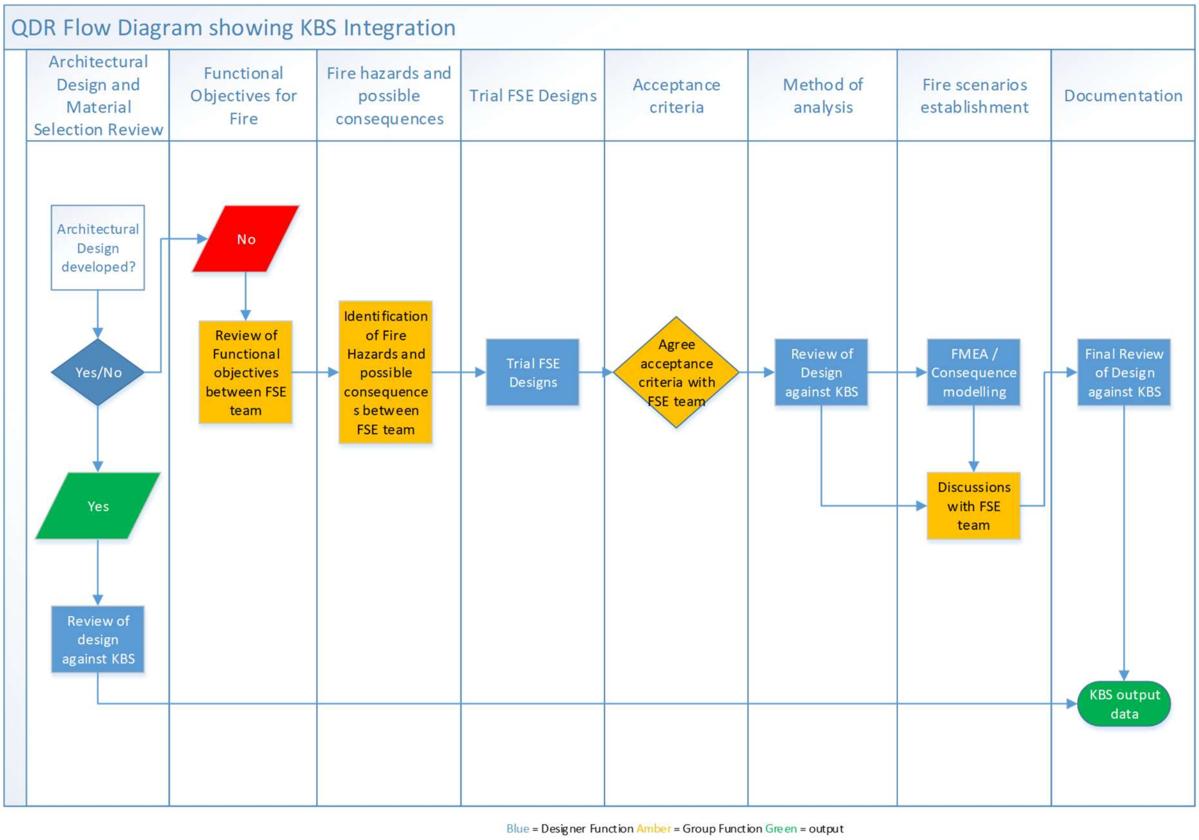


Figure 17 - Proposed expert knowledge base system flow through the project stages, aligning to an FSE approach and qualitative design review strategy (Source: Author).

To address a golden thread of the information and data capture during the lifecycle of a project, the FSES is integrated with the BIM model and the building specification system. Through direct connectivity with the BIM model, tagging assets and compliant details will ensure that the model and compliance document are coordinated in respect to the specification. The proposal utilises the hierarchical specification structure of Uniclass 2015 to allow additional syncing of the specification to the expert knowledge base system. This gives a layer of robustness, providing an application that not only allows compliance checking against the appropriate regulatory requirements but also ensures that the model and specification are fully coordinated. The resulting data is finally captured in a common data environment (CDE) to provide a 'golden thread of information' relating to the fire safety design. Figure 18 shows the basic flow of information and connectivity through the proposed system.

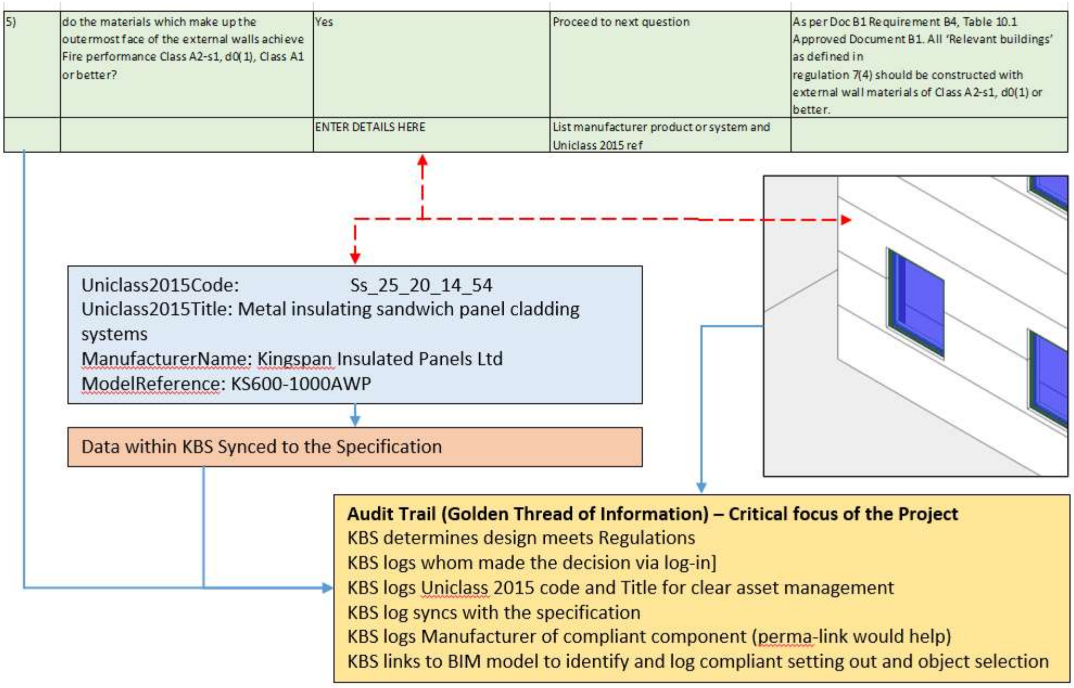


Figure 18 - Graphical diagram of the proposed expert knowledge base system data capture process.(Source: Author)

5.2.1 Functionality

The intention of the proposed fire safety expert system is as follows:

1) The expert system guides the user through the design and specification of constructed assets in relation to fire safety. A logic and knowledge base are developed that pose questions to the user via an inference engine.

2) The responses that the user gives to the expert system questions, determine the decision tree navigation within the expert system. Utilising a forward chaining IF/THEN model.

3) Based upon certain questions and the design/material use within the project, the expert system would also request that the user provide a log of certain key aspects within the design. Notably, materials, products or systems which must comply with the building regulations and associated standards applicable to those components. The log would be formulated via the user entering the associated Uniclass 2015 code and title to identify the material, product, or system type along with the manufacturer and product reference details. This would allow any validation by others to be easily conducted but also provide the clear log during the in-use phase to aid the golden thread of information.

4) The expert system is integrated with the BIM model and the building specification platform to provide a golden tread of information. This would allow the tagging of responses within the expert system to be applied to relevant geometry within the model and potentially retrieving or communicating data from the model to the expert system or vice versa. As BIM models can be federated with data relating to the materials, products, and systems, this could be a link that would function similarly to the intention with the specification. It was also intended that the expert system may also have a reverse ability where it could allow correction of data within the BIM model, should any errors be discovered during the assessment. For example, if the model contained information relating to a fire door which stated it had 30 minutes fire resistance, but the expert system identified that in that particular instance it should be 60 minutes fire resistance, then the model could be updated automatically.

5) The expert system is linked to the building specification platform either independently or via the BIM model, allowing the information contained within the specification to be sourced directly into the associated areas within the expert system. This is only feasible however with a cloud-based specification tool, as the expert system would be reliant upon machine readable data in the form of properties and attributes.

5.3 Aligning the fire safety expert system to current industry processes

The fire safety expert system is anticipated to be used throughout the project timeline, notably during the design specification process but also at the handover stage and post construction. There is also potential for this to be used during procurement and refurbishment, however this proposal will focus on ‘as designed’ and ‘as built’ data assessments. Whilst a Fire Safety Engineering approach would differ from a traditional route to compliance against ADB, when overlapped the processes which would utilise the fire safety expert system are comparable.

5.4 Development of High-Level Ontology

The proposed FSES application is a novel approach to fire safety regulatory compliance in that it builds upon a knowledge base from experts, in this case fire safety engineers, architects or other construction professionals with elevated experience in the fire safety design regulations. This knowledge is then processed and applied to a set of ontologies, which are devised primarily from the Building Regulations Approved Document B, factoring in fire safety engineering principles, as per BS7974:2019. The structured ontologies form the main aspect of the expert system in respect to the flow of questions. Dependencies in relation to scenarios where certain sections of the building regulations may not be applicable to the individual design being assessed are built in to ease the user experience and provide a more efficient process.

Using Urbanowicz's expert system diagram, Fig 19 and Fig 20 depict how the knowledge base design is intended, and how the user interface utilises this knowledge base to infer status, provide guidance and capture outcomes (Urbanowicz, 2011). Note that the user interface, knowledge base editor, and inference engine are grouped together within a shell, separate from the knowledge base. This allows the knowledge base to be updated should updates to regulations occur, or new knowledge be deemed necessary, without the need for manual update of the user interfacing functions.

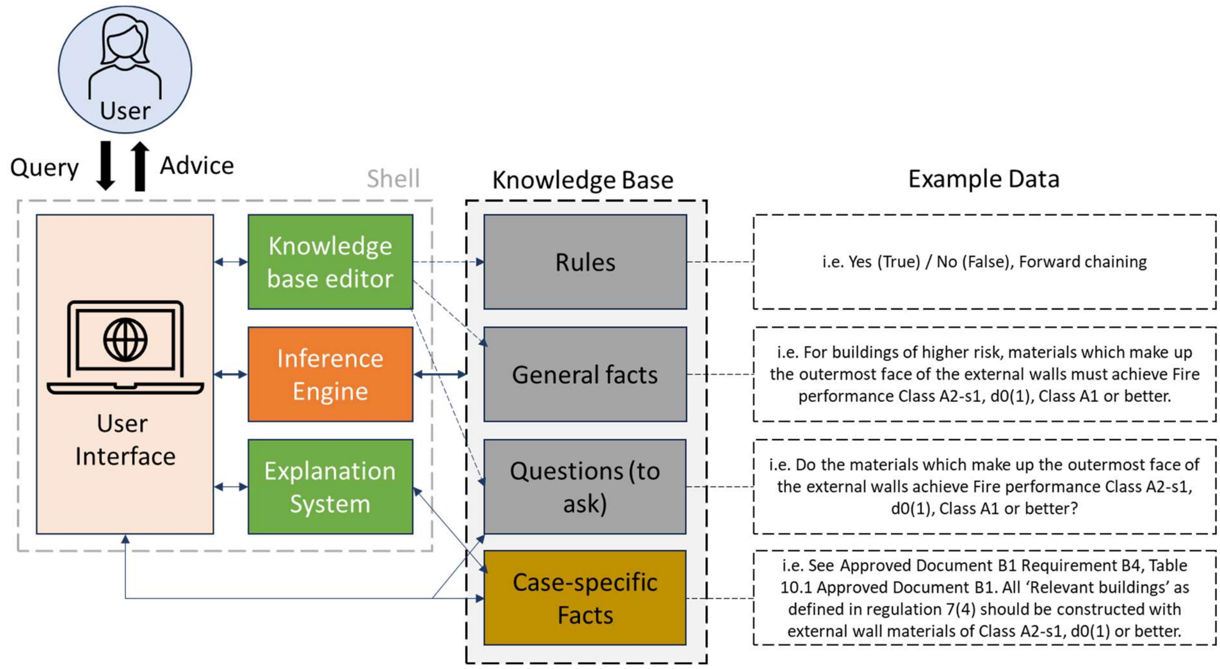


Figure 19 - Intended 'forward chaining' knowledge base example. (Source: Author)

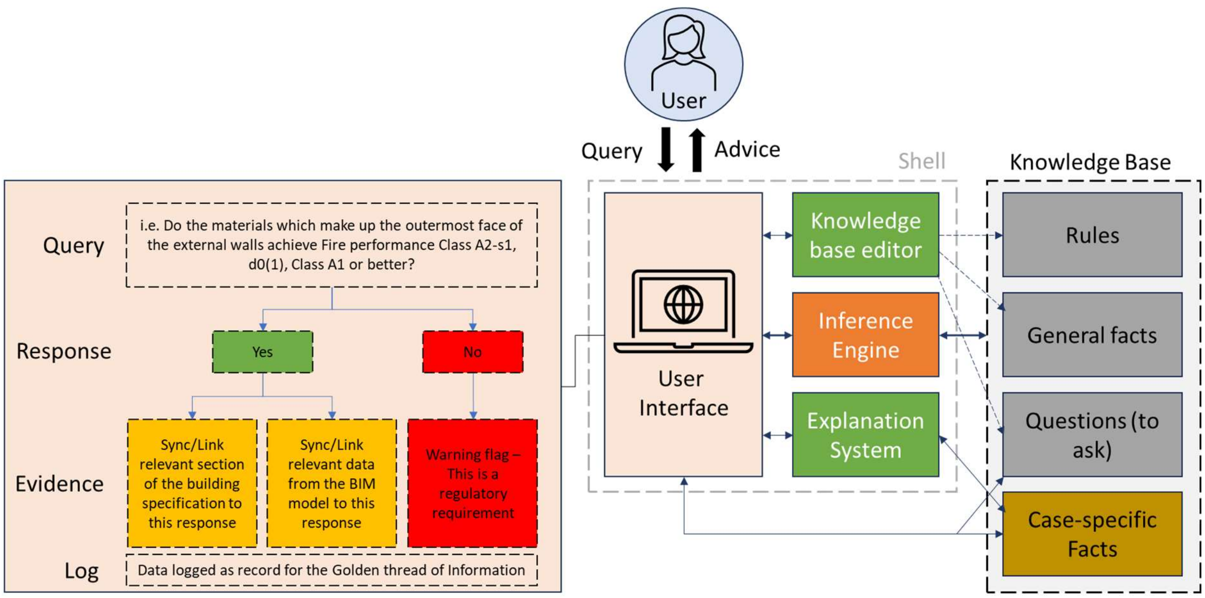


Figure 20 - High level overview of the user interface and inference engine support. (Source: Author)

Fig 21 on the following page shows an example of decision tree that supports the proposed expert knowledge base, for the section relating to resisting fire spread over external walls. Note that a parent and child relationship occur for many questions, as their dependency upon the result is a critical decision factor. The warning triangles represent a warning message to be communicated to the user, should the input response to that question be deemed non-compliant to the building regulations.

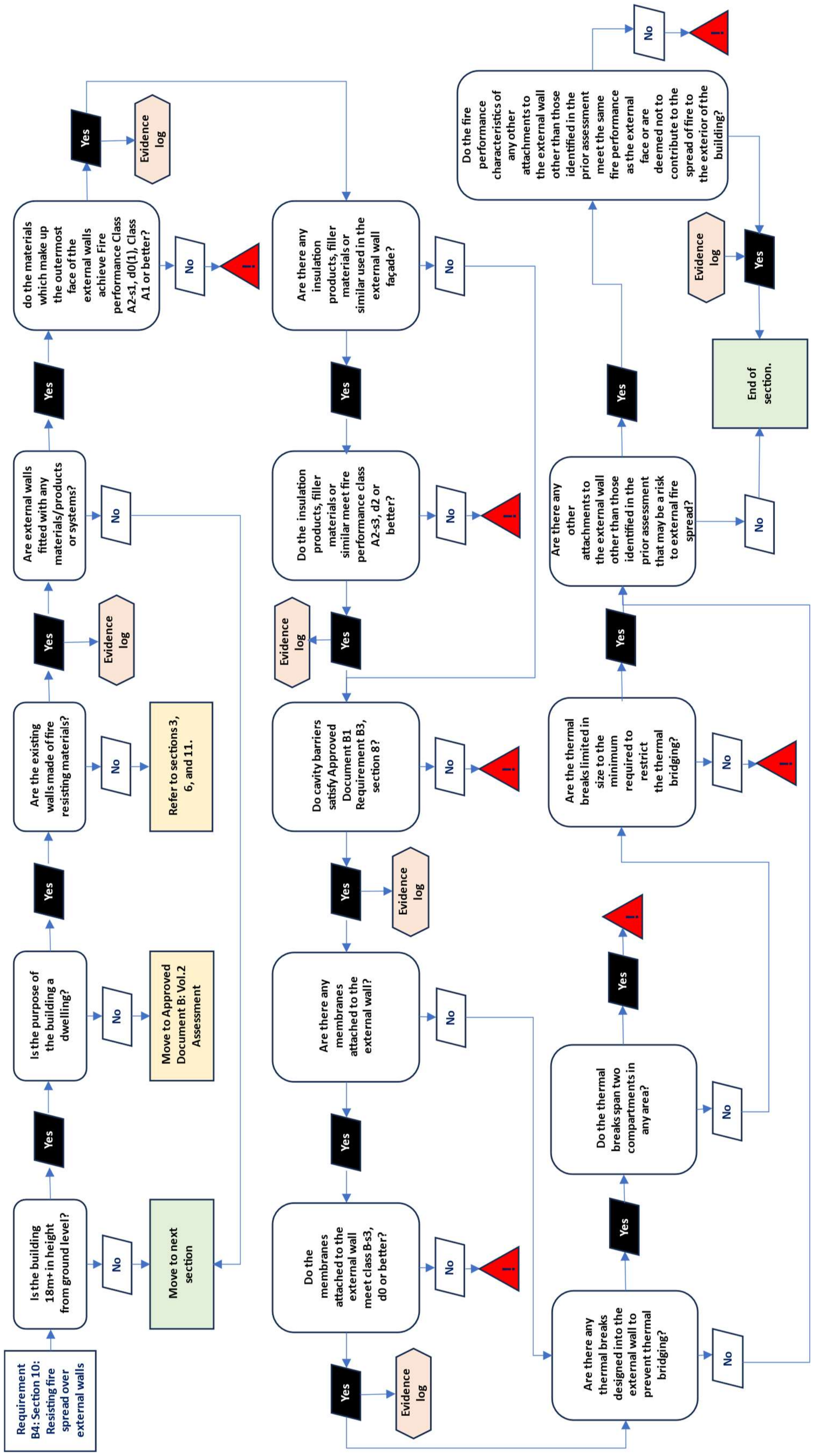


Figure 21 - FSES decision tree for section relating to assessment of fire spread over external walls.(Source: Author)

The system creates the structured ontologies and a data log dependent on the interaction with a sequence of questions, leading to the request that the user records the details of the materials, products, or systems, including the manufacturer, specific product reference and the Uniclass code, with the title for coordination with the specification and model.

The log provides two benefits, firstly it requires the user to check the specification of the components and that they meet the regulatory requirements. Secondly, it captures that information against the relevant section of the building regulations, which can be used to generate a record of decisions made in relation the built asset. This log can be passed to the principal designer, building assessor and client, aiding the golden thread of information.

5.5 Review of Visual Programming Applications

To develop the proposed fire safety expert system into a prototype required the development of a digital application using visual programming and API (application programming interface) functionality.

Expert systems are niche applications and by default the availability of dedicated software packages with visual programming functionality were limited. Research was conducted online, with the below summarising the candidates suitability for the prototype development:

1. Visirule. Visirule is a dedicated expert system building application using visual programming functionality (Visirule, 2021). The marketing of this software was clearly aimed at financial and legal applications to allow users to automate billing and contract documentation in a bespoke manner. Visirule offer a free 90-day trial, but purchase of the software is then required to continue use. Furthermore, Visirule has API functionality, which allows connection of the developed expert system logic to the user interface via programming to the other applications. As the intention of this research was to also investigate the potential for connectivity of the fire safety expert system to proprietary BIM software, this was deemed a strong candidate.

2. Drools DMN (Decision Model and Notation). Information was limited online for Drools DMN, however it does appear based upon minimal information provided to be an expert system builder using visual programming methods (Drools, 2021). Drools DMN also appeared to be free to use.

3. D3Web. Details for D3Web were very limited when conducting the online research (D3Web, 2021). The D3Web website at the time of the research was quite basic and lacked any information that would allow a potential client to assess suitability. D3Web appears to be a knowledge base development solution and is open source, however it was not feasible to assess potential suitability.

4. DTRules. DTRules is a decision table solution for Java. Immediately the lack of visual programming available ruled out the potential to use this software. In addition, it was also only available through the purchase of a commercial licence (DT Rules, 2021).

5. OpenExpert. OpenExpert is a dedicated expert system builder predominantly for law use (Open Expert, 2021). It operates in an Open Source manner but has clear conditions on community sharing of all developments. Due to the sharing potential and the sensitivity of this research and its novel approach, this software was deemed not suitable.

6. DEX. DEX is an Expert System Shell for Multi-Attribute Decision Making programming. Whilst this at first glance indicate potential compatibility to the requirements for the proof of concept. The DEX website was not secure, and the software was deemed not suitable based upon the potential for data security breaches.

7. Pyke. Pyke is a python based expert system builder application (Pyke, 2021). The software is Open source but offers no visual programming functionality. On this basis, this software was deemed not suitable.

8. Jess. Jess is a Java based expert system builder application and through the online research, appears to be popular with developers (Jess, 2021). However as with other software noted above, Jess does not have a visual programming function and was dismissed on this reason. Furthermore, Jess requires the purchase of a commercial license to enable use.

Following the research into visual programming applications and discussions with some of the providers as to the requirements of this research, Visirule was the chosen application to build the prototype. This was for a few reasons. The Visirule application resembles Dynamo quite closely, which is the system intended to be used throughout this research for BIM connectivity and integration. In the construction sector, the use of Dynamo is increasingly encountered, which uses the same key principals of visual programming applications and allows users to interact with the design applications such as Autodesk's Revit (Autodesk, 2021). In addition, the Visirule case studies and applications, mostly tailored to financial and law expert systems, provided a satisfactory account to allow a reasonable level of expectation that the software would perform adequately.

For commercial development the expert system would likely require expert knowledge of application programming languages such as C#, Python or JavaScript. However, this was deemed outside of the scope of the research, as its primary aim was to develop a proof of concept prototype to determine its feasibility. Hence, it was deemed that use of the existing programmes that allow visual development of the expert system applications would suffice.

5.6 Prototype development

The expert knowledge base system outline, sequences and mapping were based on several regulatory framework requirements and standards. Approved Document B guidance was utilised as the primary basis, ensuring that all outcomes were aligned to the Building Regulations approval requirements. However, other standards influenced the development, including (but not limited to) British standard BS 7974 and BS9991, ongoing development of regulatory guidance and discussions with industry professionals. A visual programming tool was used to develop a prototype system, as it can be seen in an example snapshot in Fig 22.

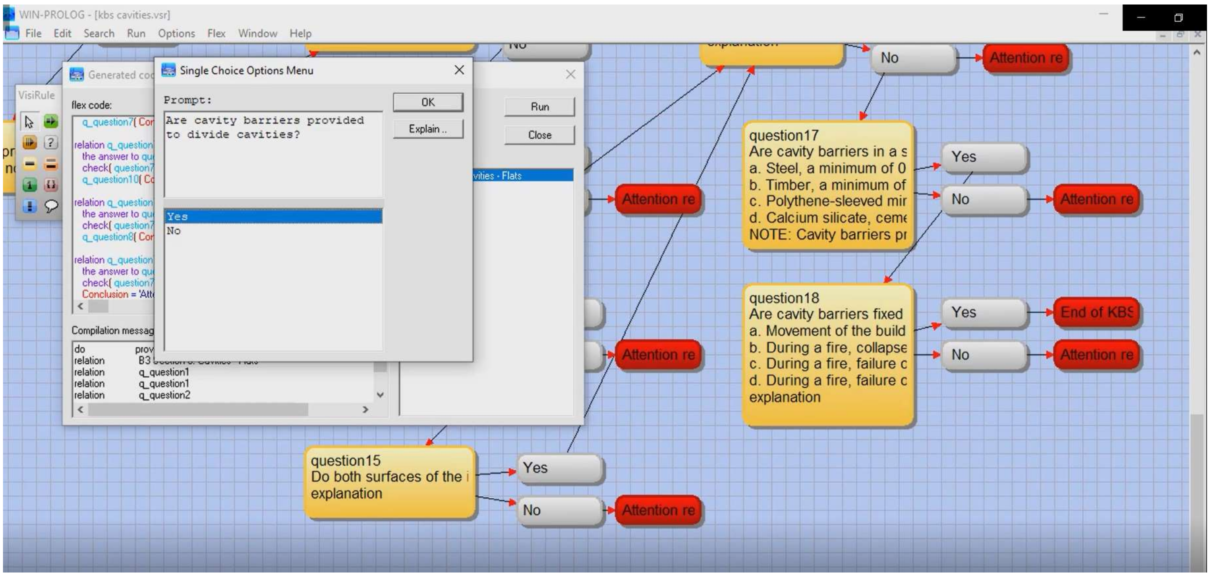


Figure 22 - An example of FSES visual programming development (Source: Author)

The programming for the system itself is based on the decision tree making model, which allows the functionality of the system to progress from question to question. In instances where the user's response resulted in the next sequential question becoming inappropriate, the code was developed to provide mapping to the next appropriate question, or section of compliance. A script was then generated from the visual programming, which is then used to generate a prototype of expert knowledge base system for testing purposes.

5.6.1 Applying the expert knowledge logic rules

Figure 23 shows a typical example of the logic applied within the visual programming software, in this particular instance illustrating logic rules that would evaluate cavity design within a building. This particular example was chosen as it clearly shows the interdependent relationship mapping between various questions. The functions within the visual programming software utilised to upload the draft logic are as follows:

1) Yellow text boxes = FSES questions
2) White text boxes = Allowed user responses
3) Red text boxes = Non-compliance warning flag
4) Arrows = Connecting nodes between questions/responses

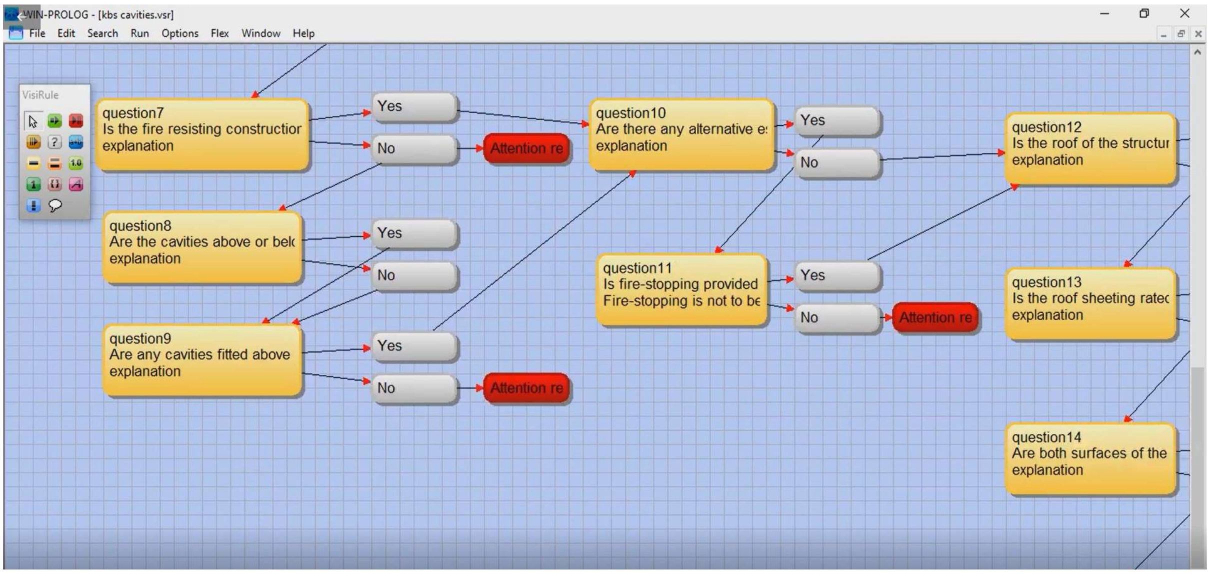


Figure 23 - Typical example of the draft logic applied within the visual programming software (Source: Author).

Note that the process flow, from question 10 onwards, gives a clear example of the interdependencies of the FSES expert knowledge base system logic. If the next sequential question becomes inappropriate, the code is developed to provide mapping to the next appropriate question, or section of compliance. For example, if the answer to question 10 is ‘No’, then the expert system logic recognises the question 11 as irrelevant and the FSES process moves the user onto the next appropriate question, which in this example would be question 12.

5.6.2 FSES Code Generation and Review

Once the draft logic has been authored and mapped out within the visual programming software, an inbuilt functionality allows the user to generate a written executable code. This is what can be taken by a software developer and utilised within a more commercially development version (see Fig 24).

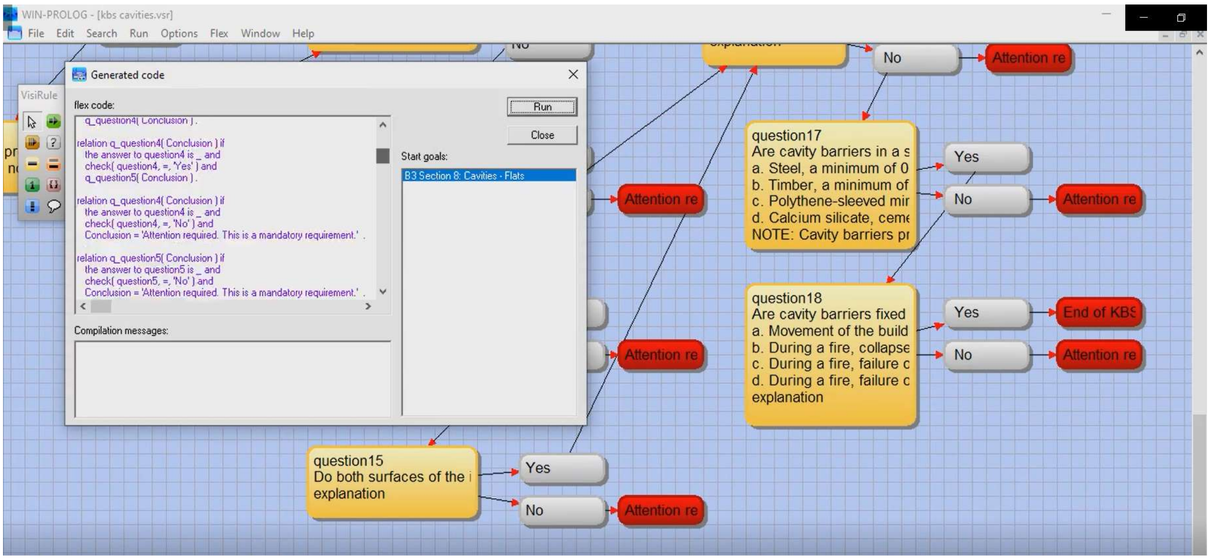


Figure 24 - Generated text-based code from the visual code (source: Author)

5.6.3 Knowledge base logic testing

The visual programming software utilised for this prototype was Visirule, which is specifically designed to develop expert knowledge base systems, and provides a means of testing the created expert system logic. Note in Fig 25, that in this instance for the question in relation to cavity barrier provision the decision tree logic progresses as the user selects a 'Yes' or 'No' answer. From the button that is titled 'Explain', access to an authored guidance is set out within the system and can be viewed by the user. Once the user has selected their answer, and in order to progress, the system will move onto the next question or section of compliance, depending on where the user is within the process.

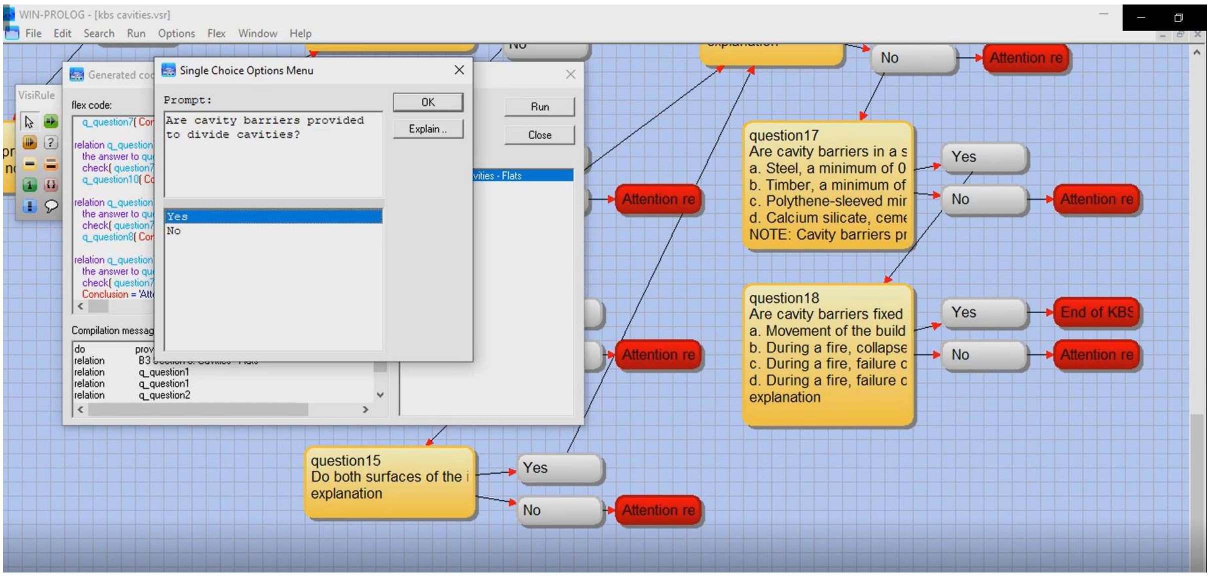


Figure 25 - Testing the FSES system within the visual programming software (source: Author)

Should the question be responded to with an incorrect selection, then the system would flag an error warning, instructing the user to re-evaluate and correct their response (see Fig 26).

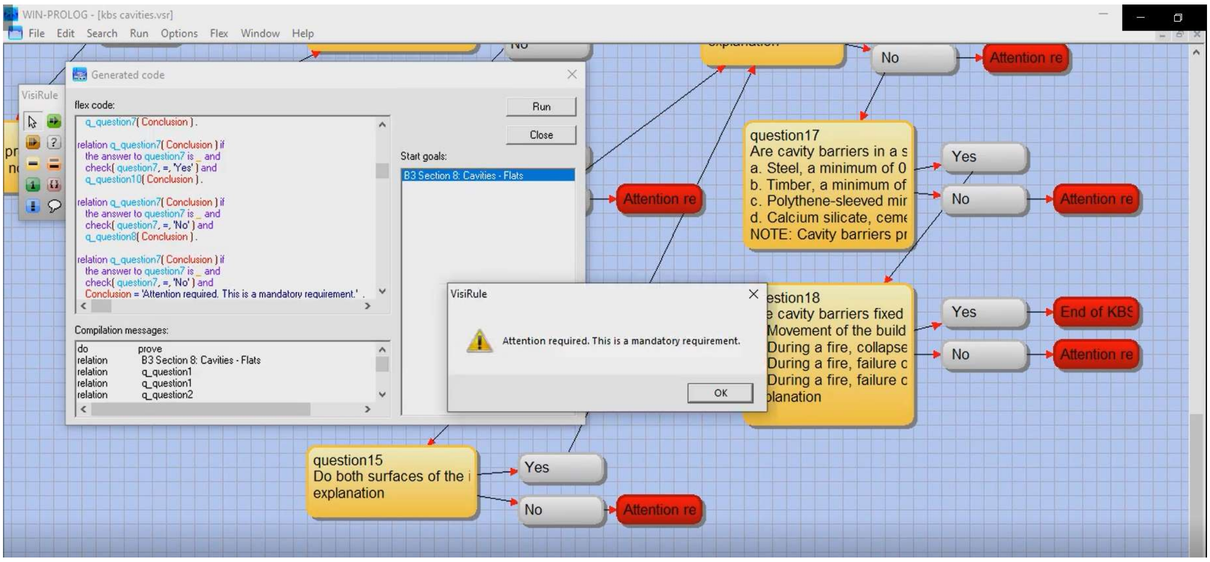
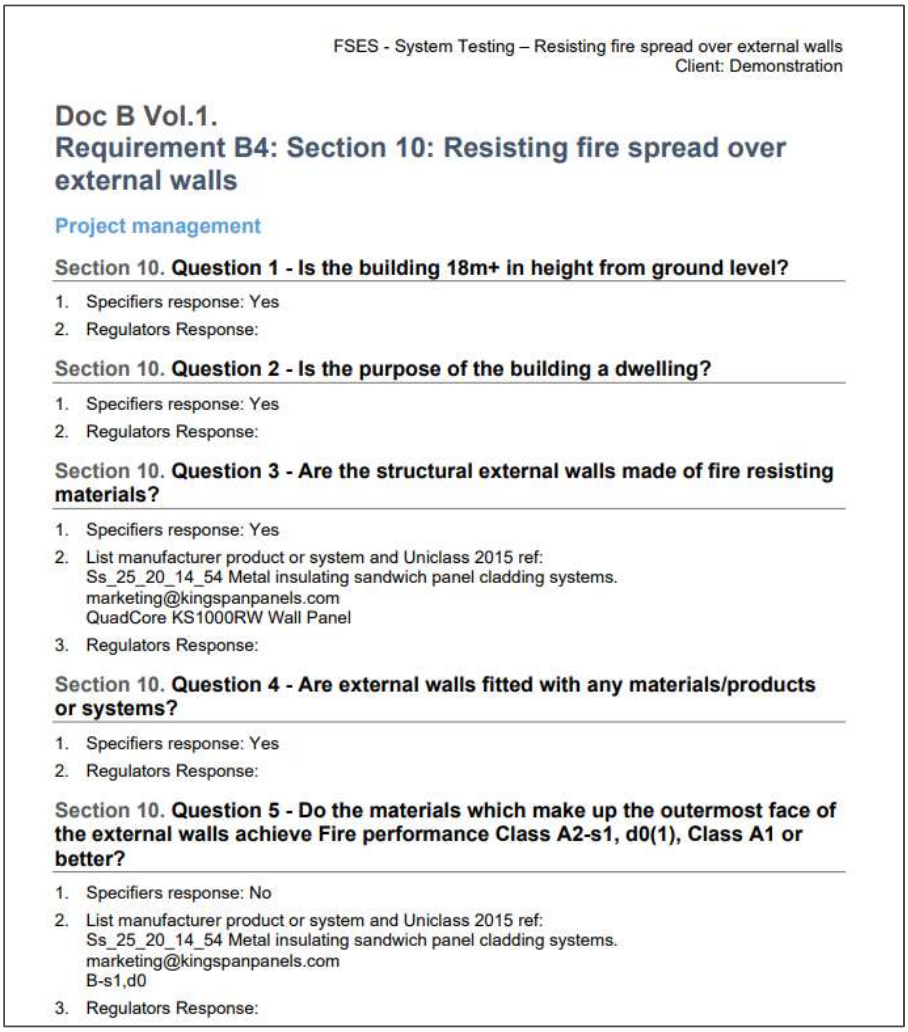


Figure 26 - Error warning surfaced in the FSES test due to incorrect selection (source: Author)

5.6.4 Reporting

The principal aim of the proposed FSES system is to mitigate the risk of failure in respect to fire safety which could occur through the design, specification, and construction processes within a project. A key outcome of this is the need to support the golden thread of information and provide an auditable log of the assessments, the data applied within them, including both material choices and supporting comments which refer to why certain decisions were made. By default, the FSES system would require the functionality to produce a report of the assessment outcomes, which could in turn be accessed by all stakeholders on a project without the need for access to the FSES software. The report would ideally be outputted in .pdf format in order to facilitate this or held within an accessible yet secure online application, to provide an evidential document which cannot be easily edited after output.

An example of how a summary report of assessments has been developed within the industry standard specification software NBS Chorus. NBS Chorus can produce written specification documents in Pdf format and through the adaptation of this software it is possible to incorporate the same functionality within the FSES system. A bespoke output template has been produced using NBS Chorus to demonstrate this, as shown in Fig 27. A bespoke summary schedule has also been developed within Chorus as per Fig 28, which is designed to act as a quick reference without the need to interrogate the full assessment record. These outputted published documents can be shared and uploaded into the common data environment which will facilitate the golden thread.



FSES - System Testing – Resisting fire spread over external walls
Client: Demonstration

Doc B Vol.1.
Requirement B4: Section 10: Resisting fire spread over external walls

Project management

Section 10. Question 1 - Is the building 18m+ in height from ground level?

1. Specifiers response: Yes
2. Regulators Response:

Section 10. Question 2 - Is the purpose of the building a dwelling?

1. Specifiers response: Yes
2. Regulators Response:

Section 10. Question 3 - Are the structural external walls made of fire resisting materials?

1. Specifiers response: Yes
2. List manufacturer product or system and Uniclass 2015 ref:
Ss_25_20_14_54 Metal insulating sandwich panel cladding systems.
marketing@kingspanpanels.com
QuadCore KS1000RW Wall Panel
3. Regulators Response:

Section 10. Question 4 - Are external walls fitted with any materials/products or systems?

1. Specifiers response: Yes
2. Regulators Response:

Section 10. Question 5 - Do the materials which make up the outermost face of the external walls achieve Fire performance Class A2-s1, d0(1), Class A1 or better?

1. Specifiers response: No
2. List manufacturer product or system and Uniclass 2015 ref:
Ss_25_20_14_54 Metal insulating sandwich panel cladding systems.
marketing@kingspanpanels.com
B-s1,d0
3. Regulators Response:

Figure 27 - Sample published assessment report from the FSES system (source: Author)

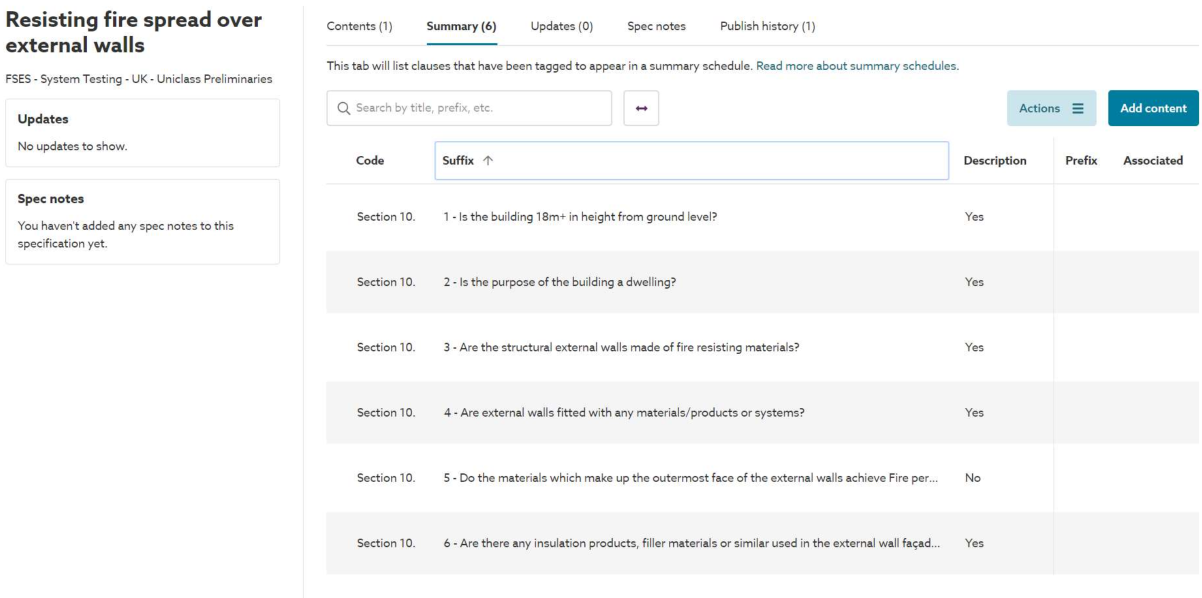


Figure 28 - Summary schedule output from FSES within the specification software (source: Author)

5.6.5 Wire Frame Designs

In any user application software development, consideration to the user interface or UI is paramount in producing a system which not only facilitates the needs of the user, but also provides a means for them to navigate the system without difficulty.

For the FSES, navigating the assessment for compliance to the building regulations, requires a systematic approach to the screens in which the user will interact with. Each question will also be supported by guidance documentation, which has the potential to take up significant space on the application screen. Figure 29 shows a wire diagram for the user interface. At the top of the page, the section is always clearly highlighted, so that the user is completely sure which section of the FSES analysis they are working in. The interface would then surface each question individually. Keeping the response functionality minimal, should ensure ease of understanding and provide efficiency in workflow.

Guidance is also reasonably lengthy for this question. The intention is to have the guidance viewable via an information icon (as illustrated) or if on a standalone desk top application, this could be provided in a separate window within the application that would be viewable alongside the question.

Once a response has been selected, the user could simply move onto the next question by clicking the next button. A view ‘previous’ button is also included, to allow the user to toggle back in case they need to refer to previous responses. It is intended that a summary page would also be available, showing completeness of the survey, with links to each section (Fig 30).

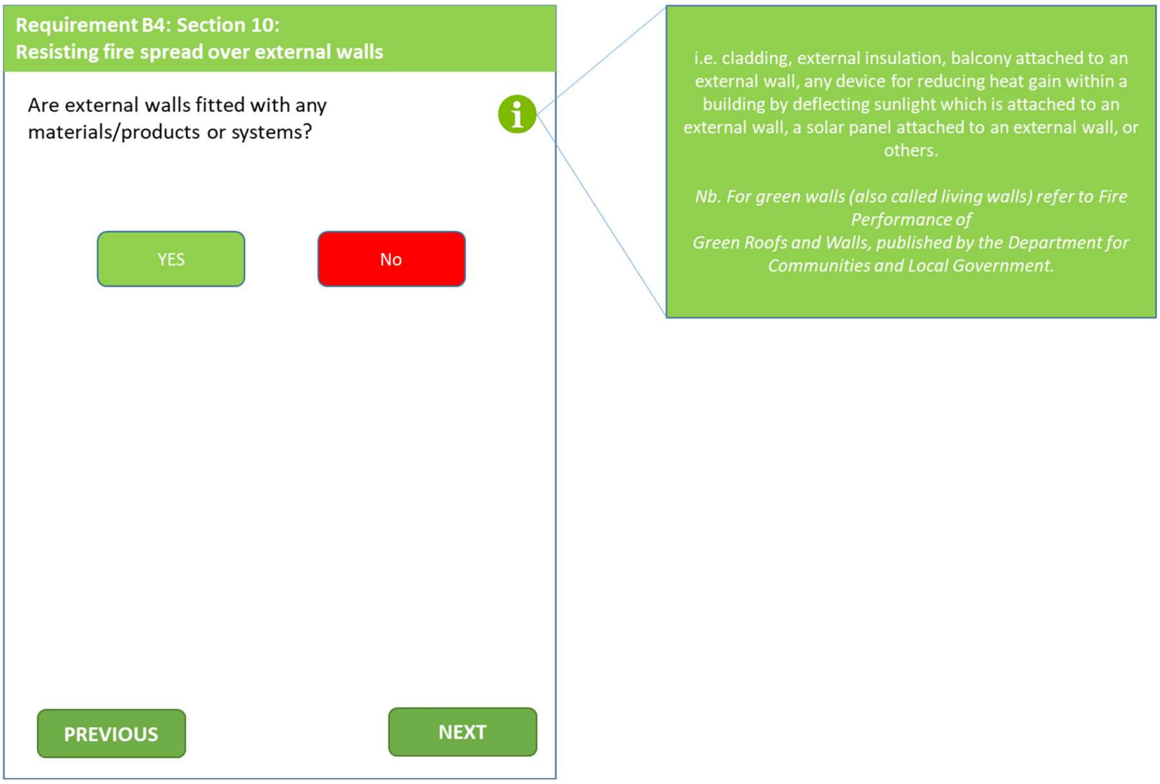


Figure 29 - FSES wireframe design, showing guidance function. (Source: Author)

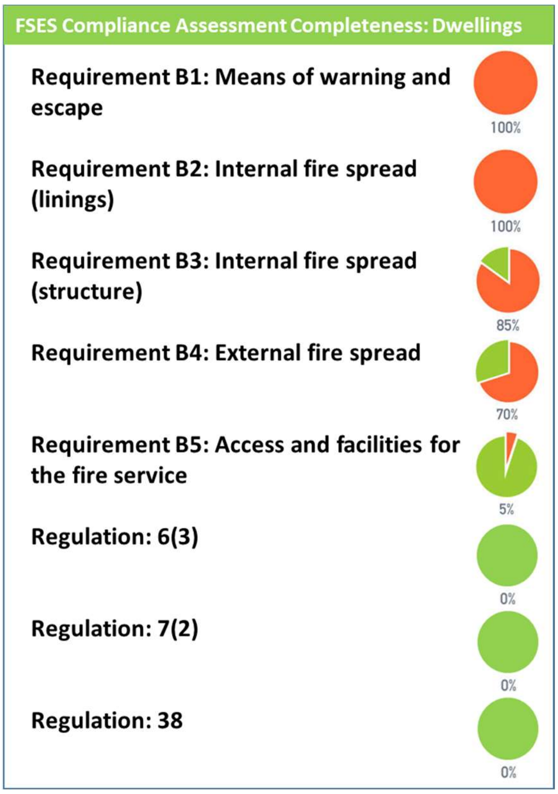


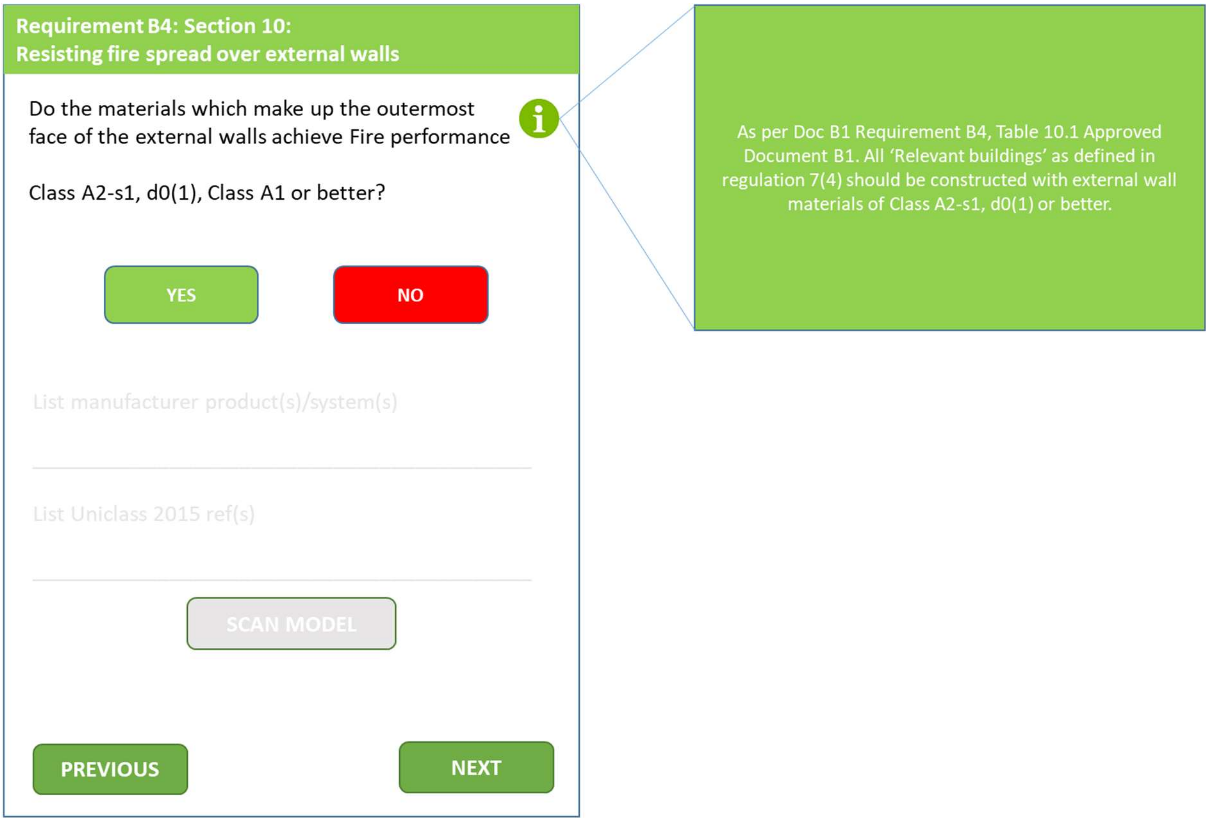
Figure 30 - FSES wireframe design showing section menu and completeness pies. (Source: Author)

The next image Fig 31 shows a question which requires evidence to be provided in relation to the material choices specified, should the response require this. Once the answer is selected which requires the evidence to be submitted, then the greyed-out sections become active, and the user has two options:

1) Manually enter the information

2) Scan the BIM model and pull in the data from the associated objects.

In respect to potentially connecting to the specification, the material properties are taken directly from the associated specification clause.



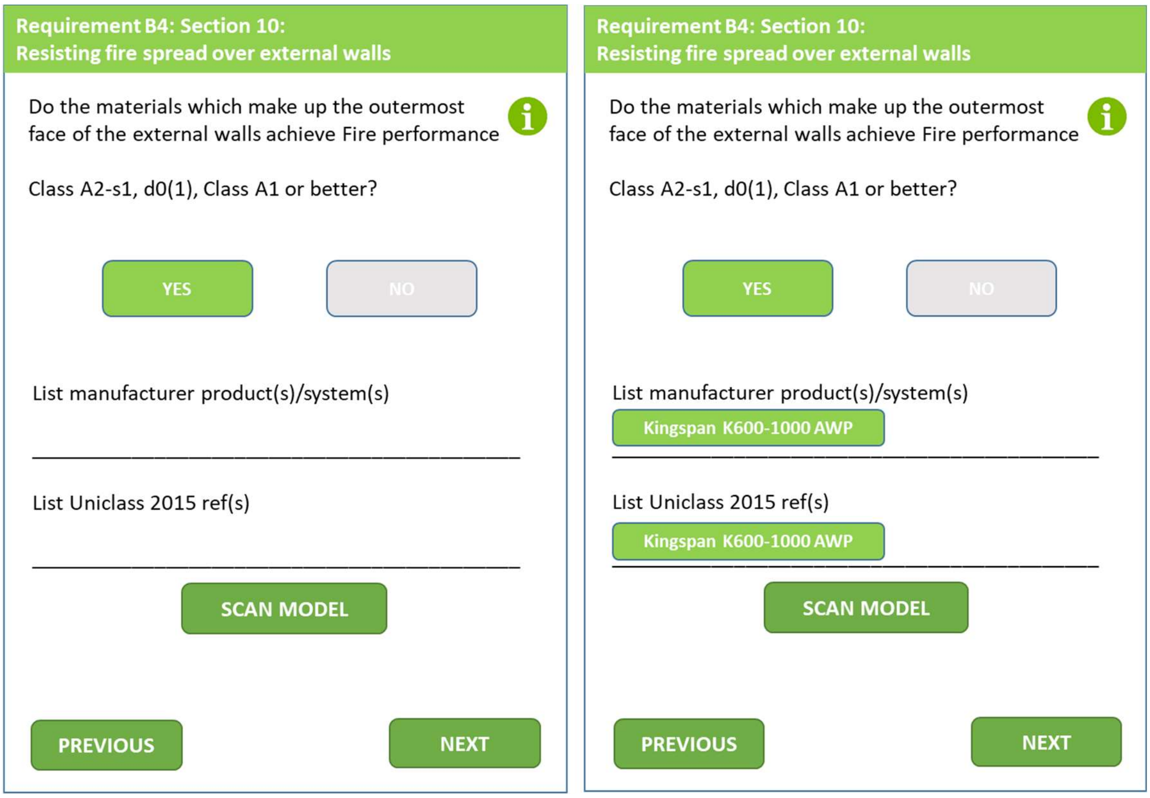


Figure 31 - FSES wireframe design showing Product information log routes. (Source: Author)

A critical requirement of the FSES system is to notify users when a response does not comply with the building regulations. Compliance is a critical factor, and the warning message must be clear and understood.

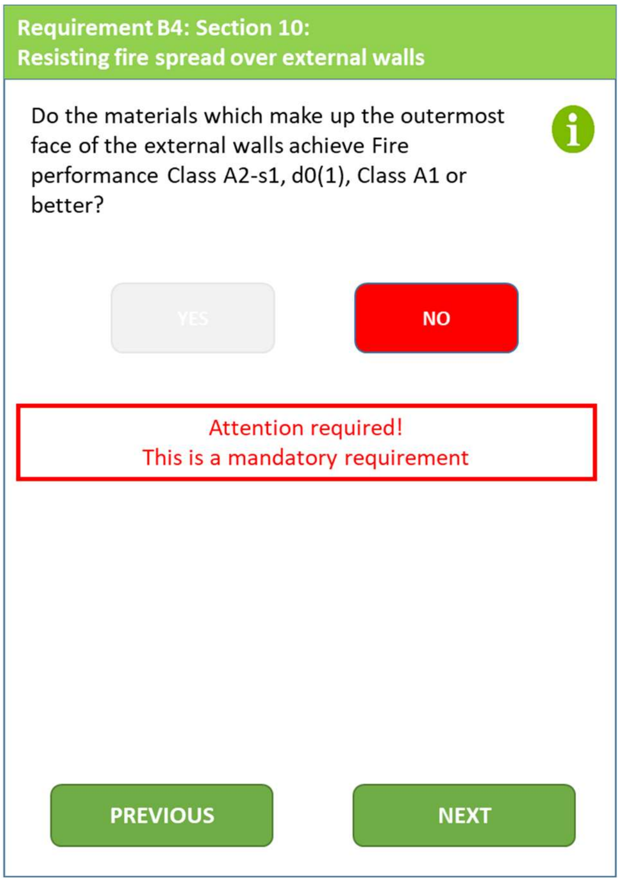


Figure 32 - FSES wireframe design showing non-compliance warning message. (Source: Author)

The wireframe designs depicted above are intended to allow the interface to be applied to both a standalone desk top software, but also be viewable in a plug-in window within BIM design software or accessed from a smart phone or tablet on site.

5.7 BIM Framework and Specification Integration and Implementation

Creating a 'golden thread of information' over the lifecycle of the project and capturing data that provides clear specification of fire safety products, components, and systems, and how each was tested, is a very important part of the FSES system. The need for this is highlighted by the key Government report titled *Building a Safer Future*, which provides an independent review of Building Regulations and fire safety, (Hackitt, 2018). The expert knowledge based system has been linked to a proprietary BIM system to capture data within a common data environment (CDE), aligned to the UK BIM framework. This enables the proposed FSES system to align design decisions with the specification whilst ensuring regulatory compliance.

The script shown in Fig 33 allows the data from the BIM 3D model to be extracted and added to the relevant fields within the expert knowledge base system that require the specific data i.e., Manufacturer Product Name, Uniclass Reference or Fire Performance Ratings. This was initially tested to extract the relevant properties for the fire door sets within a project. Note that within the code, the door sets have all been uniquely identified within the ‘watch list’ identifier in the code (highlighted in green).

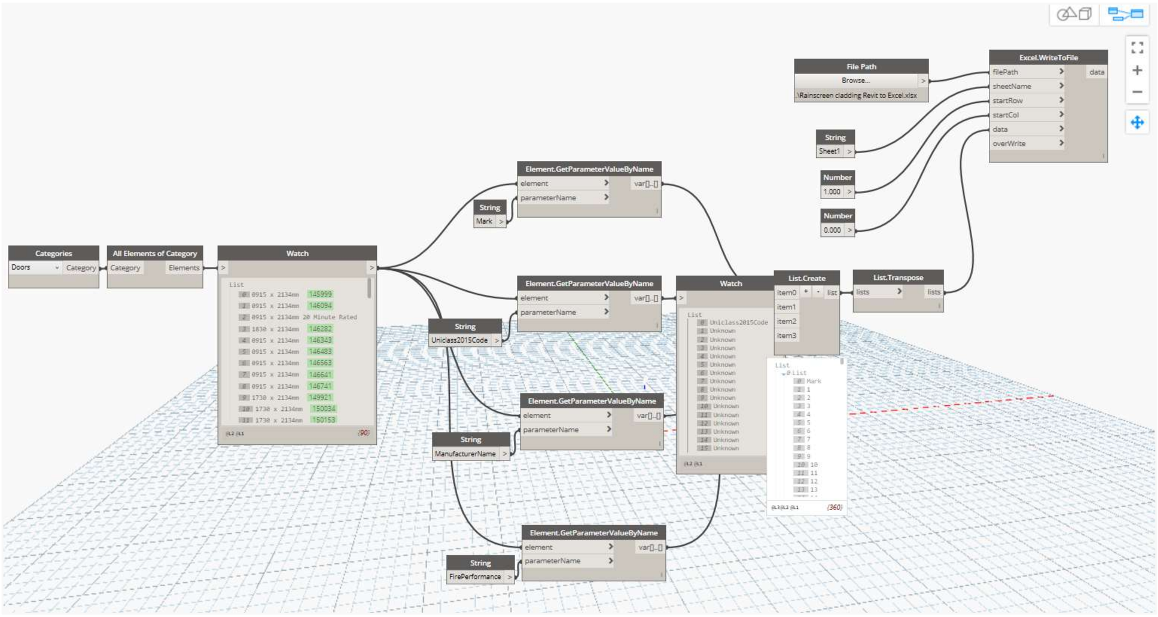


Figure 33 - Visual coding application generated code to export data federated within the BIM design software to the expert knowledge base system. (Source: Author)

This code was then further developed to allow the extracted data to be edited within the expert knowledge base system and then transferred back to the BIM software to automatically update the 3D building model information. This would allow the correction of specification in a situation where the expert knowledge base system may find that the current specification does not meet regulations i.e., changing the product and fire performance rating. Importantly, the two-way connectivity would ensure that when either the model or expert knowledge base system are edited, the data aligns within both, thus protecting the golden thread of information.

The building specification is a written document that dictates how a building should be built, including things such as preliminary clauses on workmanship, specific requirements and more (Swaddle, 2021). Importantly however, the building specification also provides an itinerary of the intended materials, products and systems to be used and their performance characteristics. The specification is a live document during the design and construction stages which develops as the project progresses. During early stages of the project when the building is a concept, the specification, in terms of materials, will typically set out key performance requirements for elements which will impact the overall building performance. This is what is referred to as a prescriptive specification. As the project moves on through RIBA works stage 3 - spatial planning, and crucially into Stage 4 - technical design, the specification becomes much more detailed and is developed into a concise prescriptive document, which now identifies not only the performance characteristics of key elements, but also includes an increased list of components with specific manufacturer product references associated to the relevant clauses (RIBA, 2020). As the project moves to construction, the specification should be updated to reflect the ‘as-built’ details, particularly should any design changes have occurred during procurement and build. The new regulations for buildings of high risk, now demand this as a mandatory requirement.

In terms of this project and the development of the FSES, it is crucial that the building specification is considered within this development. The developed, prescriptive specification is after all, a single source of all material references and will be a key reference point for the analysis conducted by the system. In the UK, NBS (National Building Specification) is the de facto specification platform used by the construction sector (Day, 2018). Having been developed over fifty years of building specification expertise by the NBS, its latest cloud-based iteration of the platform, NBS Chorus, already connects the top four most widely used BIM software's in the UK. This BIM connectivity allows the written specification to be linked to the design model, ensuring that the design and specifications are aligned. It is therefore highly beneficial for the proposed expert knowledge base system to also be able to link to the specification system connected to the BIM model so that the data captured within each platform is all aligned.

Fig 34 shows the concept of the proposed expert knowledge base system sitting within the NBS specification platform. The example shown relates specifically to the assessment of an external cladding specification. Note that as well as providing data capture for the design team, the system can also capture the data log for the building regulator/assessor, ensuring both the design and 'as built' meet requirements and importantly are documented accurately. The guidance in the right-hand window lists the relevant references for compliance or provides advice as to why this aspect of compliance is important.

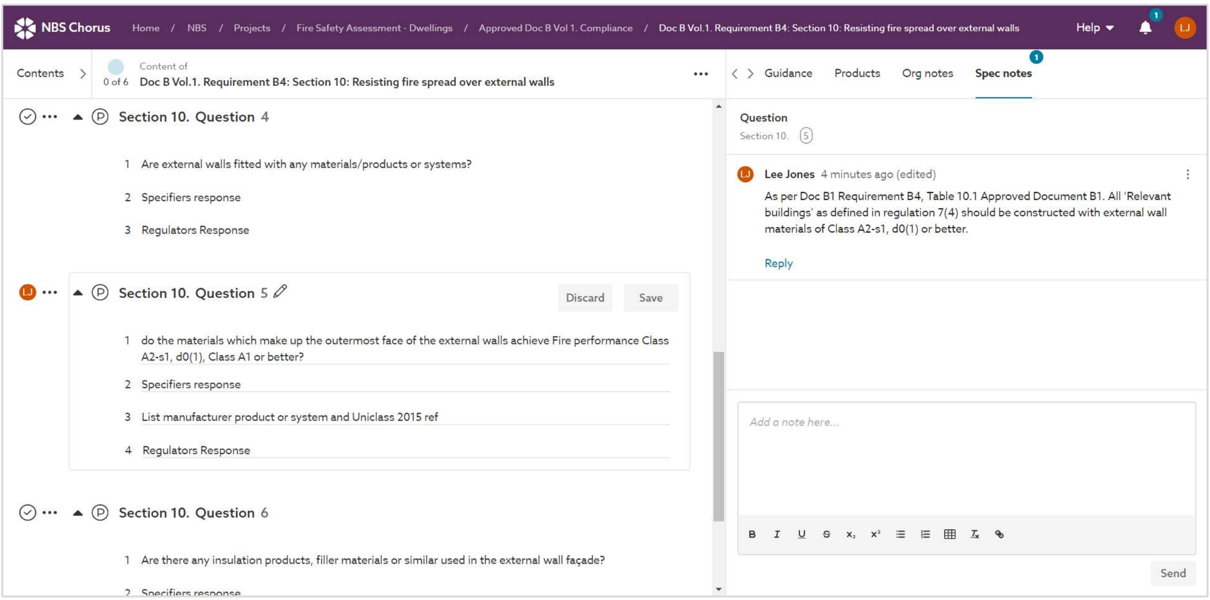


Figure 34 - Initial Concept showing expert knowledge base system questions built into NBS Chorus.(Source: Author)

Construction specifications are dependent on two information factors, non-graphical information such as the specification and contract documents etc. plus the graphical information such as detailed drawings of how the built asset is arranged and the co-ordinated details of how it should be constructed and assembled. Today BIM forms the process of the building design and construction framework. Notably, the ISO 19650 series of standards and in the UK the BS annexes of those standards depict that framework and provide guidance on how a project should be approached through a BIM methodology.

In the context of the proposed FSES, aligning the validation process to the BIM model is deemed important. The expert knowledge base system should, therefore, have the ability to interrogate both the specification and model. Having a functionality where not only can the expert knowledge base system interrogate the specification and model but, can also aid automating correcting them may be an area where risk can be mitigated through ensuring that any rectification highlighted by the expert knowledge base system is found, a two-way connectivity between this and the model could allow automated or aligned correction.

5.7.1 Developing a secondary code to read structural element data

Following successful development of the code to extract and populate object data, a secondary code was developed to understand how and if the same principal could be applied to structural elements within the building model.

Walls in particular, have strict regulatory requirements in respect to fire safety, depending upon the type and location of the wall in question. As a system, potentially made up of various components from multiple sources, a wall has the potential to be an area of high risk if specification or installation do not meet regulation. Furthermore, as many parts of a wall are hidden behind the face surface, it can be impossible to understand what the makeup of the system is without correct documentation of installation, and without disassembly. The secondary code was therefore trialled using a wall system.

Fig 35 shows a code developed using the visual programming software that would extract the data from a structural wall element within the BIM model. In this example, the section of the expert knowledge base system that covers cavity barrier design and specification is referenced. For cavity barriers, particularly those which are specified with intumescent strips that expand when subjected to heat, an air gap within the wall cavity must be within manufacturers recommended tolerances. The impact of an air gap which is too large would mean that in the scenario where a fire may occur at the wall, the cavity barrier intumescent strip would expand but not fill the cavity. Leaving a void in which heat, smoke and flames may spread. During interviews with panel experts, this was one of the greatest areas of concern in ensuring designers and specifiers understand and execute correct specification.

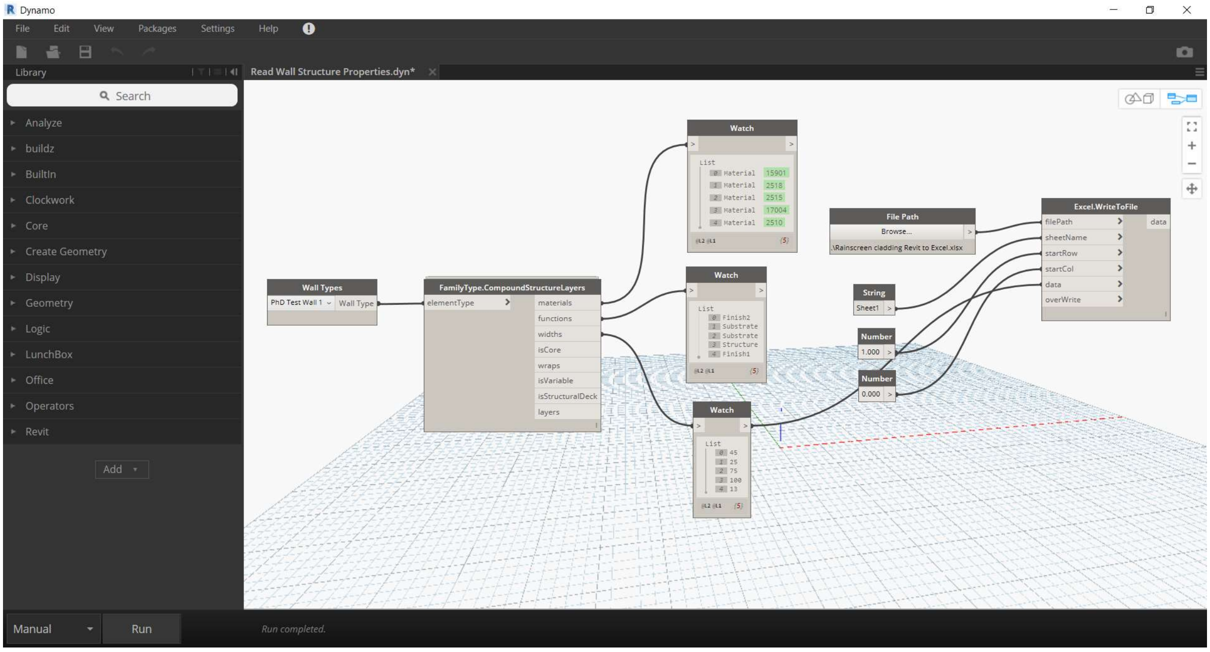


Figure 35 - Secondary developed code to extract structural wall element data. (Source: Author)

	A	B	C	D
1				
2	45	Cladding thickness		
3	25	Air gap		
4	75	Insulation thickness		
5	100	Steel frame thickness		
6	13	internal Plasterboard thickness		
7				

Table 1 - extracted wall properties. (Source: Author)

The extraction of data from the wall parameters was successful by implementing a read functionality within the code. The code was developed further to include write functionality, which allowed the data to be amended within the fire safety expert system and pushed back into the BIM model. However, whilst the updates to the structural wall were successful, the concatenating effect on dependent elements within the wall, such as doors, windows and hidden MEP fixtures was detrimental.

Whilst aspects such as ensuring the air gap is specified correctly to allow the correct function of intumescent cavity barriers is paramount, the further potential for risk through displacing connected elements was felt a higher risk. Windows for example may be specified as set sizes. Increasing the cavity depth of a wall without adjusting the window design to suit would potentially cause further non-compliance, particularly if the windows form part of the cavity barrier design. Additional lesser risk issues could also occur, such as clashing of pre-set MEP fixtures with a re-sized wall. Whilst not a risk to safety as such, clashes will prove highly costly to resolve if not picked up at the design stage.

Automating the update of structural elements would not be progressed as a result of this test. Recommendations would be that the expert knowledge base system will be able to retrieve data as part of the checking process, but no write functionality would be included for structural object types to avoid causing errors within the model.

5.7.2 Developing a code to aid visual identification of compliant features

Although the editing of structural elements from within the fire safety expert system has been deemed a high risk. Other aspects were researched to aid compliance and checking. A potential area of risk can exist when a system such as a wall or door set does not meet the required fire rating for its location or function. When inspecting details with multiple elements that look visually similar in the model or within outputted drawings, the potential exists for aspects to be overlooked. Therefore, in addition to examining the non-graphical data, the ability to examine the graphical data was explored.

A further code was developed that would select all walls that had a defined fire rating as set within the structural element properties (Fig 36). The code would then apply a solid fill colour to the section detail in the models 2D plan views, allowing easy identification of which walls had the set fire rating (Fig 37). This would allow a quick reference during inspection by both designers and compliance professionals alike. Whilst the fire safety expert system is intended to aid regulatory compliance, the execution and responsibility for compliance still remains with the individual professional tasked with the role. This functionality is therefore intended as an aid through providing clarification in visual checking and improving efficiency through the FSES assessment process.

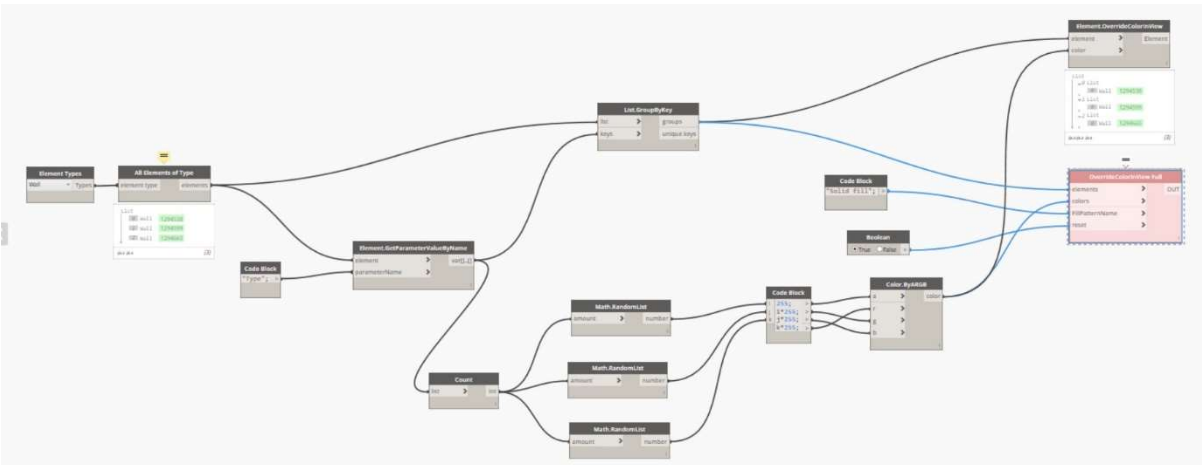


Figure 36 - Visual code developed to colour code fire rated walls upon request. (Source: Author)

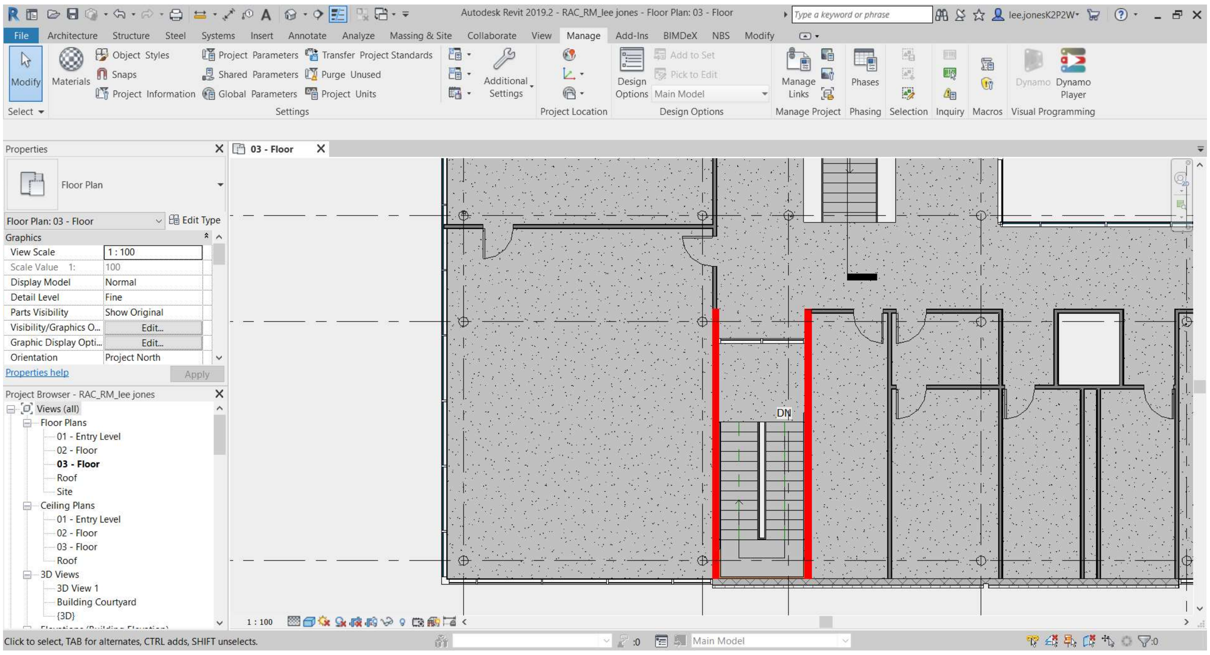


Figure 37 - Fire rated walls highlighted in BIM model. (Source: Author)

The result successfully identifies all walls with the specified fire rating. In Figure 37, the whole enclosure surrounding the stairwell has to meet fire resistance criteria as this is a fire escape zone. The code in this instance has highlighted the internal walls only, as per the checking request. The fire doors and the external clad walls could also be queried in the same manner. This will provide a straightforward visual reference for the user when assessing the design via the FSES.

5.8 BIM Integration Conclusion

The series of developed codes have proven that connectivity between the FSES and the BIM model is possible. A two-way connectivity that allows data to be extracted from the model into the FSES, and then data within the FSES to be edited and fed back into the model to synchronise has been achieved. However, through the various design elements explored, the write functionality from the FSES to the BIM model should be limited to data sets only and not aspects which could change the physical shape or size of the model. Due to design dependent fixtures with elements such as walls, the risk of creating further issues through parametric adjustment is not recommended. In terms of amending data, it can be common for written specifications to not reflect what is illustrated in drawings or displayed in a 3D model. The edit data functionality in the FSES development will allow synchronisation of the specification and model, with a supporting compliance checking document that can be uploaded into the common data environment as part of the golden thread of information.

5.9 Chapter reflective summary

Following on from the previous chapter, which discussed past research relating to expert systems within construction fire safety and the potential future uses for AI development within that remit. Chapter 5 discusses in depth, the development of the proof of concept FSES system. The workflow of the development is fully detailed from the initial concept, drafting the ontologies and knowledge base, developing a code for a proof of concept application, interconnectivity with the BIM model and specification tools and output design. Whilst expert systems have previously been researched to aid fire safety design, the approach in which the FSES development was undertaken including the technical development is to the best of the authors knowledge, an original concept. Whilst it is acknowledged that to facilitate a commercial product, advanced programming would be required to create a fully functioning software, the proof of concept detailed within this chapter has shown that the FSES proposal is effective against the research aims.

Clear advances discussed in the development of the FSES through chapter 5 include structuring the regulatory framework as a hierarchical tree structure, with forward chaining parent and child relationships. It is this element that provides the initial easing of navigation of the regulatory framework for the user. Secondly, through the developed connection with the BIM model and specification tools, the FSES provides a means to amend any non-compliant details that may be discovered via one source. This strengthens the strive for BIM workflows to become a single source of truth. Additionally, as the research identified within the introduction of this thesis, under the new building safety regulatory regime, providing record points at the newly introduced project stage gates, the FSES was perceived as a solution to generating the relevant data sets to achieve the golden thread of information.

Through providing a systematic tool, the developed FSES proof of concept would enable users of various abilities to robustly critique and where necessary, correct any fire safety related issues prior to construction or handover, depending upon which project stage the assessment would be conducted. In providing a means to identify and correct any failure points, the potential to save lives is deemed a positive development. Further advancement and analysis of this proof of concept will be discussed in the following chapters of the thesis through system testing and analysis.

CHAPTER 6: SYSTEM ANALYSIS AND VALIDATION

6.1 System evaluation

To evaluate the FSES protype a series of trials of compliance against standards were undertaken, simulating how the system would perform in a ‘real world’ case scenario of the assessment of various design aspects that impact fire safety specification within a typical project. The trials of compliance against standards have been triangulated and validated by the interviews with experts.

Gaining access to sensitive real life building failure design plans, specification and other information was not feasible, and arguably not needed, as the key aspects of those failures and their remedies have already been built into the prototype expert knowledge base, based on the relevant regulations, standards and guidance, including the literature review of expert opinion. This is particularly evident in the Trial 1 - Resisting fire spread over external walls - Requirement B4: Section 10.

The trials were conducted to understand how the FSES application would guide through the process of fire safety design and specification, in particular: 1) how effectively potential errors have been flagged in the system, 2) production of an appropriate technical specification for both the components and the system as a whole and 3) how the data was captured in line with the golden thread of information.

Additionally, the trials were undertaken to determine how effective was the system in navigating through a myriad of design decisions, thus removing unnecessary complexity from the process. As noted earlier in this research, where certain compliance requirements were derived from the building regulations and may not be applicable to the proposed design elements, these would be controlled through a defined parent and child relationship and logic within the ontologies, with only relevant questions following, depending upon the choice of the answers to the preceding questions.

The scope of the trials highlighted in this research included the assessment of an external, pressure-equalised rainscreen cladding system including the fire cavity barriers, and the BIM integration of the building specification, in the light of the golden thread of information.

6.2 Trial 1 - Resisting fire spread over external walls - Requirement B4: Section 10

With some of the more recent fire tragedies in the multistorey residential design being apportioned in many aspects to the make-up and installation of external cladding systems, it was felt that this was an important aspect to capture and mitigate through the implementation of proposed FSES system.

Note in Fig 36 the proposed FSES application has automatically scanned the BIM model and populated the response with the high-level details of the cladding system specified, and the result in this case is the cladding system does not meet the regulatory requirements. The system within the BIM model has a fire rating of B-s1, d0 and the regulations require a higher classification of either A1 or A2-s1, d0. As it can be seen in Fig 38, this is automatically flagged by the FSES application via a non-compliance warning to the user, prompting them to change their specification.

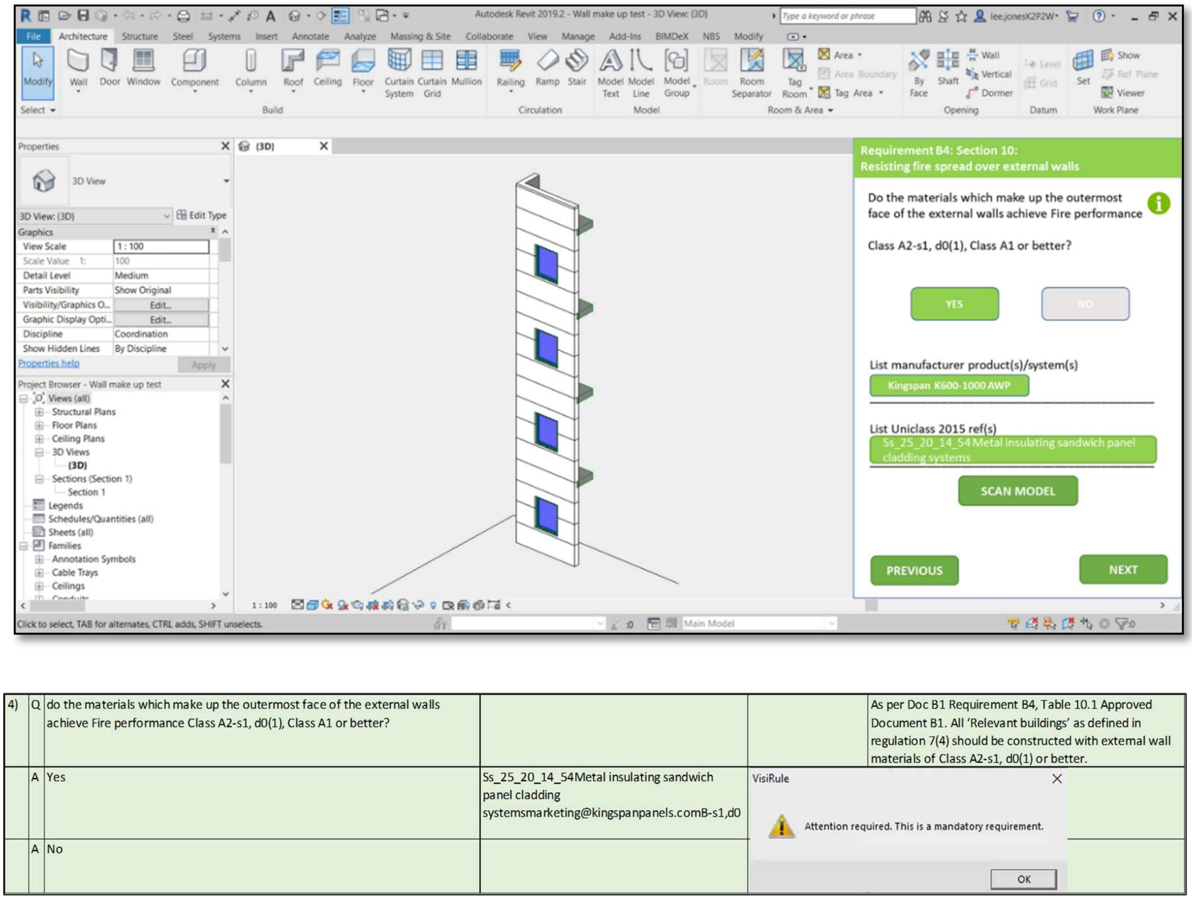


Figure 38 - Auto-population of FSES application with error warning, demonstrating that fire performance is inadequate. (Source:Author)

6.2.1 Sample Rainscreen cladding model

The decision was taken to model an example of pressurised rainscreen cladding system. This entails the model being a solid form wall element which would comprise geometry and data for tangible aspects of the system. For items such as permeable membranes, fixings and such, these would not be visible in a 3D model or associated sectional details, so are typically omitted. The reference to these is carried through the specification which is associated with the model. A further omission in the 3D geometry would potentially fall with the supporting steel work. These again would be referenced throughout the specification and typically be left to 2D detail drawings or models generated by the specialist manufacturer, contractor, or structural engineer to ensure that the supporting structure is safe and fit for purpose.

In respect to the federated data within the model, critical aspects that would require assessment through the fire safety expert system include the façade panels (cladding panels), insulation and cavity barriers. The federated data applied to the model was sourced from the National BIM Library and is actual manufacturer data captured at the time of design. The details of this data are outlined within Appendix C of this thesis.

6.2.2 Sample Rainscreen cladding specification

To simulate a 'real world' scenario it was necessary to produce a written specification for the external rainscreen cladding system to accompany the graphical model. With the Golden Thread of Information promoting the control of built asset data at component level, the specification was written with over-arching system clauses and connected sub product clauses. NBS Chorus was used to write the specification and as this analysis was testing the basis of a project which would be BIM integrated, the classification type for the written specification was chosen as Uniclass 2015, aligned with the requirements of the UK BIM Framework, as identified within BS EN ISO 19650 Part 2.

The below specification details the components that would be required to be interrogated by the proposed FSES system when assessing fire spread over external walls, in a real world scenario.

Pressure equalized rainscreen cladding system specification

Ss_25_20_70_65   Pressure equalized rainscreen cladding systems

1. Description: PhD Project Cladding Example
2. System manufacturer: Varies.
3. Thermal insulation: Pr_25_57_06_56 Mineral wool slab insulation
4. Breather membrane
    4.1. Material: Pr_25_57_10_94 Vapor permeable sheets
    4.2. Fasteners: Pr_20_29_56_12 Carbon steel wire nails
5. Secondary support structure: Pr_20_85_07_10 Carbon steel carrier rails
6. Cavity fire barriers: Pr_25_80_80_79 Sleeved mineral wool cavity barriers Vertical barriers; Pr_25_80_80_79 Sleeved mineral wool cavity barriers Horizontal barriers
7. Cladding panels
    7.1. Material: Ss_25_20_70/320 Custom-made carbon steel panels
    7.2. Panel joints: Labyrinth joints.
8. Execution: Ss_25_20_70/625 Assembly and erection: components; Ss_25_20_70/615 Assembly and erection: quality; Ss_25_20_70/620 Assembly and erection: tolerances

The specification was written in a prescriptive manner. Actual manufacturer products and materials were selected to build the make-up of the pressurised rain screen cladding system. The full specification with product details can be viewed in appendix B of this Thesis and details of the design can be seen in the following image.

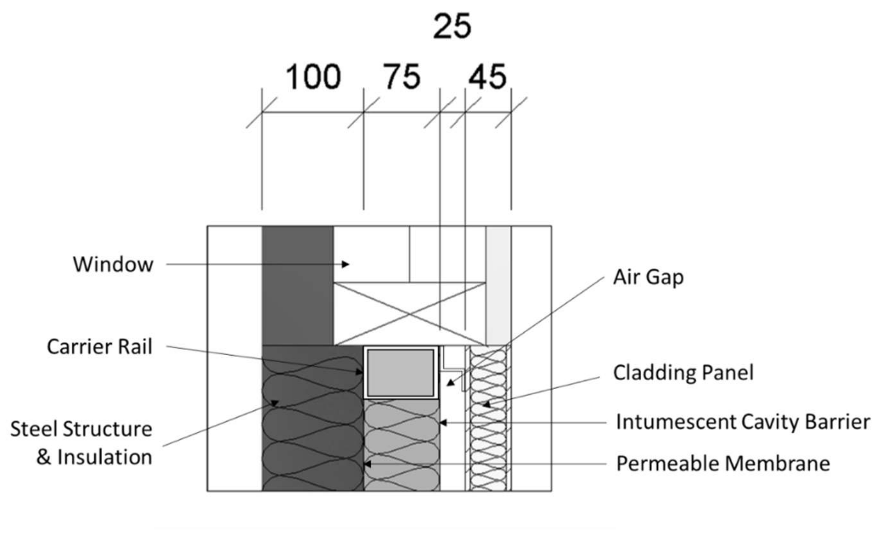


Figure 39 - Section through detail on proposed rainscreen cladding detail (Source: Author).

6.3 Testing the rainscreen cladding system

Sections 6.2.1 and 6.2.2 discuss the test case rain screen cladding system that was developed to provide a realistic system for the FSES to assess. In summary the system is made up from:

- Powder coated carbon steel insulated cladding panels, the main visible aesthetic cladding.
- Carbon steel carrier rails, the frame to support the cladding panels.
- Mineral wool slab insulation, to provide thermal requirements.
- Mineral wool cavity barriers, to enclose cavities and provide thermal requirements.
- Vapour permeable sheet membrane, to provide weather tightness.

The system itself was selected as a typical approach that cladding design may take and was curated as a hybrid system, where individual components could be sourced from various material manufacturers. The system identified within this test, was purposely selected with non-compliant cladding panels, to demonstrate that the FSES would highlight non-compliant specifications. The test scenario would use both the BIM model and the written specification as a simulated assessment that would occur during the design phase of a project.

To simulate the use of the BIM model and its inherent data, a macro was developed that auto-populates the relevant sections of the FSES from the BIM data exported from the model.

```
Sub KBSBIM1()
'
' KBSBIM1 Macro
' This Macro retreives BIM data from the Revit export wall schedule properties.
'

'
    ActiveCell.Formula2R1C1 = "=CONCATENATE(Sheet3!R[-8]C[-3]:R[-8]C[-1])"
    Range("D12").Select
    Application.CutCopyMode = False
    ActiveCell.FormulaR1C1 = _
        "=CONCATENATE(Sheet3!R[-8]C[-3],Sheet3!R[-8]C[-2],Sheet3!R[-8]C[-1])"
    Range("D16").Select
    ActiveCell.FormulaR1C1 = "Yes"
    Range("D20").Select
    ActiveCell.FormulaR1C1 = _
        "=CONCATENATE(Sheet3!R[-16]C[-3],Sheet3!R[-16]C[-2],Sheet3!R[-16]C[-1],Sheet3!R[-16]C)"
    Range("D24").Select
    ActiveCell.FormulaR1C1 = "=CONCATENATE(Sheet3!R[-20]C[-3],Sheet3!R[-20]C[-2])"
    Range("D25").Select
    ActiveWindow.ScrollRow = 17
    ActiveWindow.ScrollRow = 18
    ActiveWindow.ScrollRow = 19
    ActiveWindow.ScrollRow = 20
    ActiveWindow.ScrollRow = 21
    ActiveWindow.ScrollRow = 22
    Range("D28").Select
    ActiveCell.FormulaR1C1 = _
        "=CONCATENATE(Sheet3!R[-24]C[-3],Sheet3!R[-24]C[-2],Sheet3!R[-24]C[-1],Sheet3!R[-24]C)"
    Range("D32").Select
    ActiveCell.FormulaR1C1 = "Yes"
    Range("D36").Select
    ActiveCell.FormulaR1C1 = "Yes"
    Range("D40").Select
    ActiveCell.FormulaR1C1 = "Yes"
    Range("D44").Select
    ActiveCell.FormulaR1C1 = "Yes"
    Range("D45").Select
    ActiveWindow.ScrollRow = 33
    ActiveWindow.ScrollRow = 34
    ActiveWindow.ScrollRow = 35
    ActiveWindow.ScrollRow = 36
    ActiveWindow.ScrollRow = 37
    ActiveWindow.ScrollRow = 38
    ActiveWindow.ScrollRow = 39
    ActiveWindow.ScrollRow = 40
    Range("D49").Select
    ActiveCell.FormulaR1C1 = "No"
    Range("D52").Select
    ActiveCell.FormulaR1C1 = "Yes"
    Range("D56").Select
    ActiveCell.FormulaR1C1 = ""
    Range("D57").Select
    ActiveCell.FormulaR1C1 = "No"
    Range("D60").Select
    ActiveCell.FormulaR1C1 = "n/a"
    Range("D61").Select
End Sub
```

Figure 40 - Developed Macro to auto populate data within the FSES from the BIM model (Source: Author)..

Once the macro was run, the FSES would include any relevant data relating to the rainscreen cladding system, where the assessment required the input of product identification data to be uploaded. This includes details such as Uniclass reference for specified materials, along with the manufacturer's product name and any associated third party assessed fire rating codes.

As discussed in section 3.2, the fire classification of construction materials is given a code made up of 3 sections, Fire resistance, smoke emittance, and flaming droplets. The fire classification of the specified material is B-s1,d0, when it must be a minimum of A2-s1, d0 to be compliant. In this case, the fire resistance (the time it takes for the substrate to fail due to fire) is the non-compliant aspect. By splitting the code into its three components [B] + [s1] + [d0], the FSES through an additional developed code can check the inputted data. To comply, the FSES first checks that the material must meet A2 or A1, otherwise it is not compliant. Likewise for the following parts, they must be s0 or s1 as there is no higher smoke emittance code. The third section of the code must also be d0 as there is no higher classification for flaming droplets. By separating to its 3 component parts within the FSES the compliance check is automated, as shown in Table 2.

5	Q	do the materials which make up the outermost face of the external walls achieve Fire performance Class A2-s1, d0(1), Class A1 or better?			As per Doc B1 Requirement B4, Table 10.1 ADB1. All ‘Relevant buildings’ as defined in regulation 7(4) should be constructed with external wall materials of Class A2-s1, d0(1) or better.
	A	Yes		Proceed to next question.	
	A	No	Ss_25_20_14_54Metal insulating sandwich panel cladding systems marketing@kingspanpanels B | s1 | d0	**Attention required. This is a mandatory requirement.**	

Table 2 - Revised fire code capture within the FSES. (Source: Author)

The cavity barriers within the cladding system are also analysed for the compliance with the requirement B3 section 8, Approved Document B, as shown in Fig 41. The system highlights the details of the cavity barriers at component level, with direct connection to the full specification for fire performance requirements, classification, and correct installation and where possible hyperlinks to the relevant detail sections generated by the BIM model.

3	Are cavity barriers provided at the edges around openings?	i.e. windows, doors, exit/entry points for services		As per Approved Doc-BV1 B3 8.3
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	
4	Are cavity barriers provided at the junction between external wall cavities, every compartment floor and compartment wall?			As per Approved Doc-BV1 B3 8.3
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	
5	Are cavity barriers provided at the junction between an internal cavity wall, every compartment floor, every compartment wall and other wall or door assembly forming a fire resisting barrier?			As per Approved Doc-BV1 B3 8.3
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

Pr_25_80_80_79 Sleeved mineral wool cavity barriers Horizontal barriers

1. Description: Horizontal cavity barriers
2. Manufacturer: Siderise Group
3. Contact details
    3.1. Address: Forge Industrial Estate
    Maesteg
    Bridgend
    Mid Glamorgan
    CF34 0AH
    3.2. Telephone: +44 (0)1656 730833
    3.3. Web: www.siderise.com
    3.4. Email: sales@siderise.com
4. Product reference: SIDERISE RH Open State Horizontal Cavity Barriers (formerly Lamatherm CW-RS) (RH25-90/30)
5. Residual cavity width: 49–425 mm.
6. Fire performance: To EN 13501-1, Class A1; To EN 13501-1, Class E.

Figure 41 - Cavity barrier assessment aligned to requirement B3 section 8 and sample cavity barrier specification (Horizontal barriers). (Source: Author)

Approved Documents B provide clear guidance as to the location of cavity barriers. However, no guidance appears to be noted in respect to the dimensions of cavity depths vs min/max cavity barrier intumescent expansion. The depth of the void between cladding and the structure, the top of a wall and a soffit are critical in the function and selection of intumescent cavity barriers, this is something that was noted during expert peer review of the FSES application. Capturing this information could mitigate the risk of inappropriate specification of unsuitable cavity barriers or excessive gaps in the design where cavity barriers are placed. The gap between the design and the installation could create room for error with no dictated specification of void depth and cavity barrier types.

The proposed FSES application helps in addressing this gap. Through validation of installed materials and the data captured, the questions are used to validate the installation of the cavity barriers. Typically, the installation requirements for any material, product or system are highlighted and navigated within the execution clauses of the FSES application in conjunction with the user input, and a full written technical specification is produced as a result (see appendix).

6.4 Trial 2 - BIM integration of the building specification - Requirement B1: S3: Means of escape

For this trial the BIM model itself was purpose built, with certain elements that were known to be incorrect or missing to assess whether the FSES would identify those within the system trial. The errors which were built into the design were the incorrect fire rating properties of internal fire doors sets and the incorrect fire rating of internal walls which must provide resistance to fire in order to retain the integrity of a stairwell compartment and assist in successful fire escape routes.

Figure 42 shows the data the proposed FSES has automatically retrieved from the BIM model through the use of visual programming in respect to fire doors. In this case the fire door set should achieve a rating of FR60, however in the model and specification data this has not been defined at all.

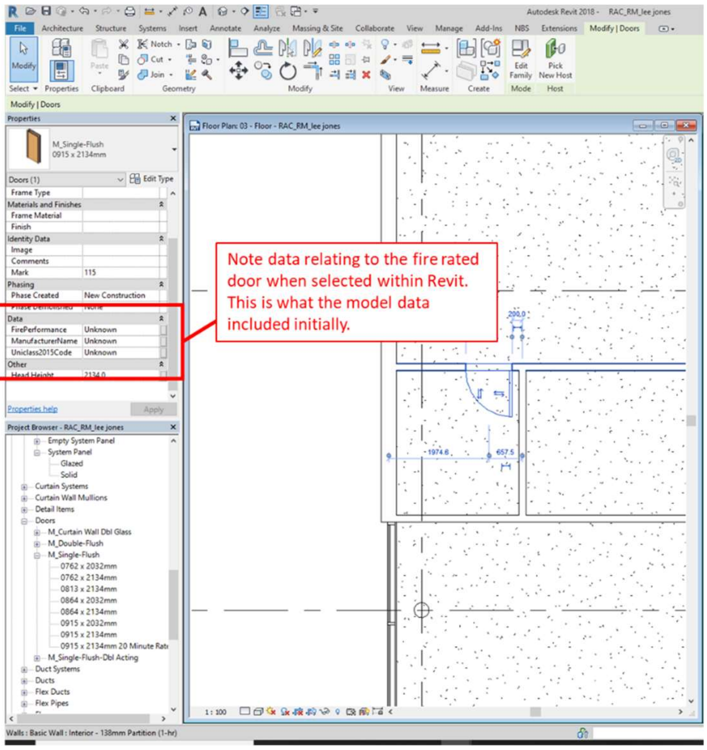


Figure 42 - BIM Model showing missing data in relation to fire door specification. (Source: Author)

The BIM integration component of FSES developed in this research was then run and the fire door data retrieved into the FSES application. This was then automatically amended to reflect the required fire rating and prescriptive manufacturer components and the update was then back propagated using the BIM visual programming script (see Fig 43), which in turn updated the model to now include the correct details within the design (see Fig 44).

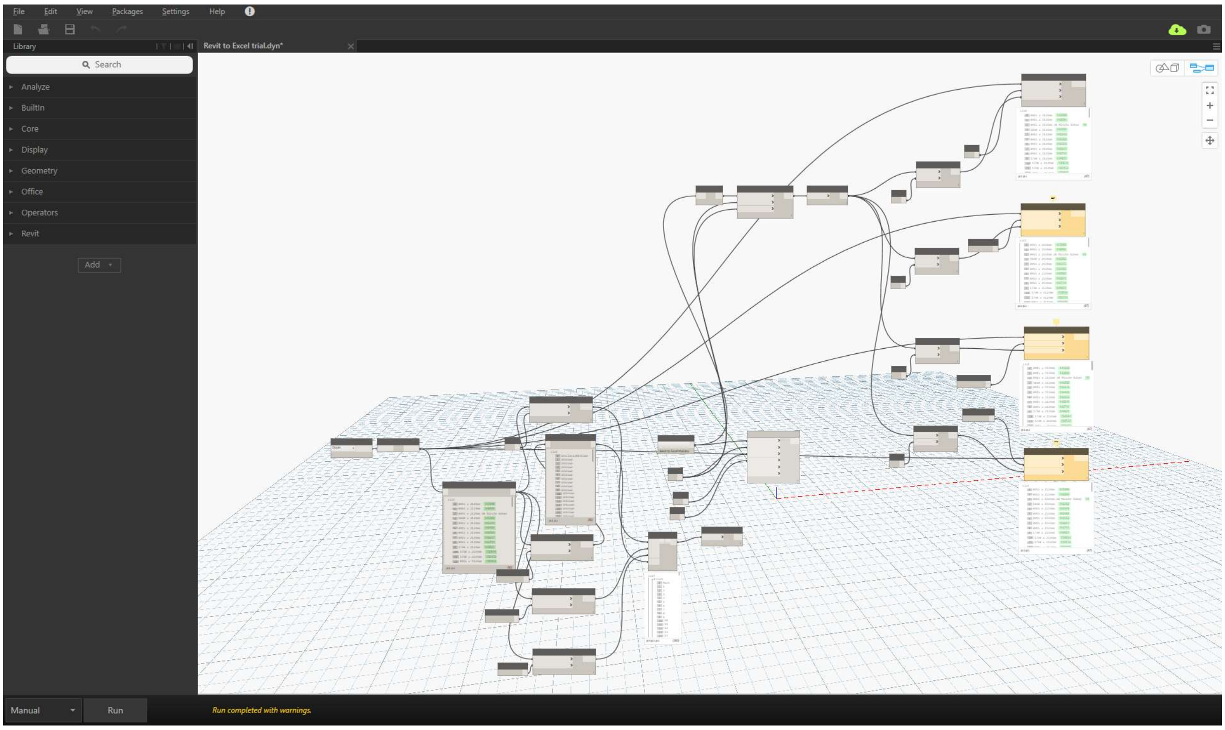


Figure 43 - BIM integration visual code running updates to the fire door data following correction in FSES application. (Source: Author)

Fig 44 shows the BIM integration update, with the door set now including correct performance requirements for fire rating of FR60. Additional properties are also included to further identify the suitability of the whole door set system, backed by the specification clauses under Uniclass 2015 code.

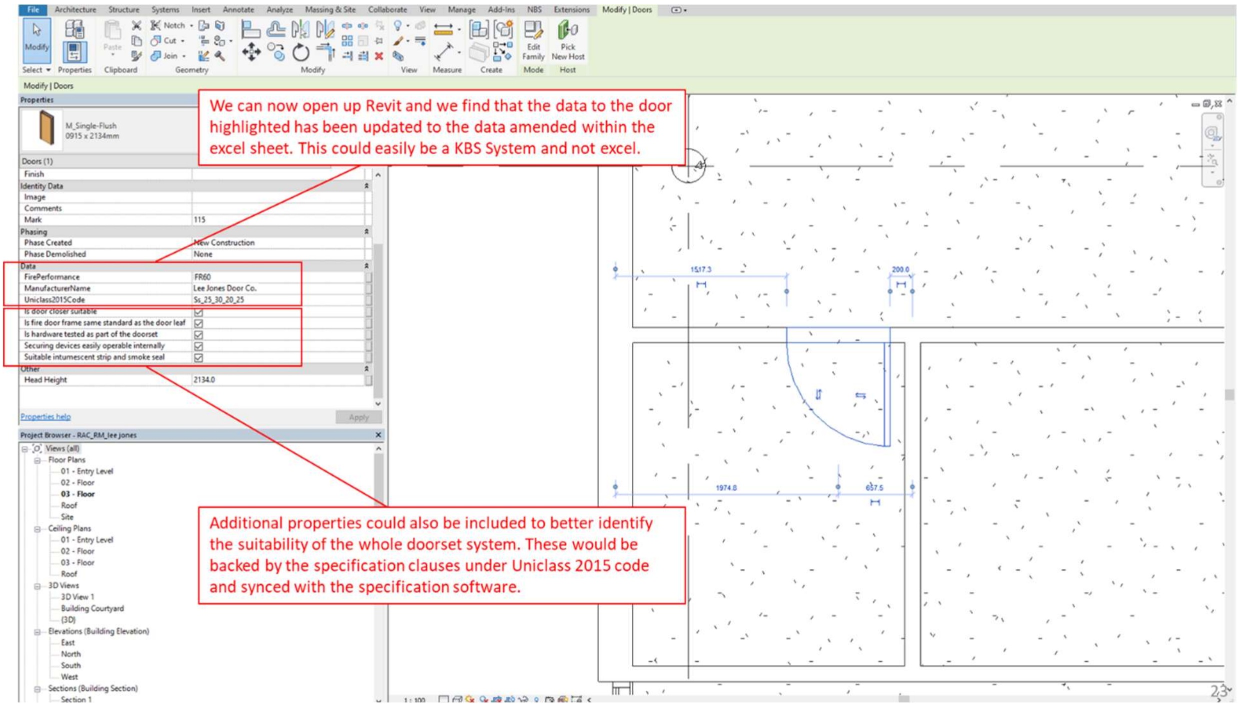


Figure 44 - BIM integration via the FSES application - The fire door data is now compliant. (Source: Author)

In the case of the internal walls, the FSES application has a developed visual programming code that provides a reference to the fire rating of internal walls. When the code is executed, it highlights all walls which have a fire rating of 60 minutes (see Fig 45). By highlighting these, when the FSES application asks if the relevant walls comply, the response can be compared to the floor layouts and any non-compliant walls can be easily identified.

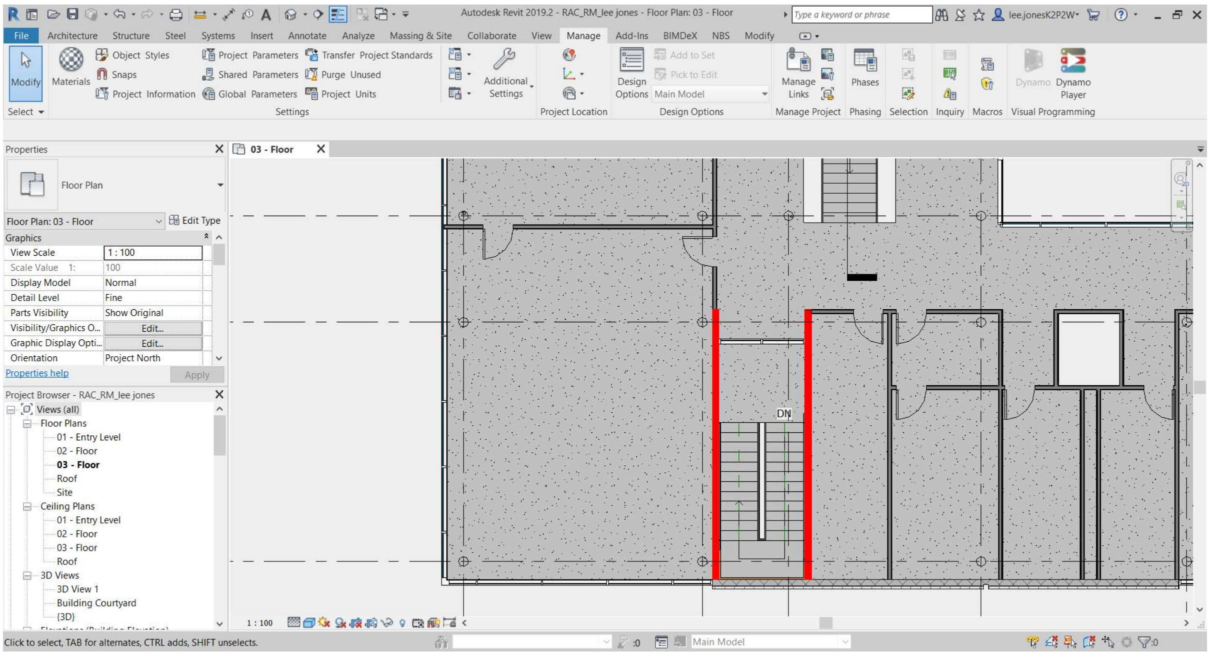


Figure 45 - Visual identification of assigned fire performance within internal walls via FSES BIM integration. (Source: Author)

Through use of the FSES application, it is clear that assessing fire safety design specification could be aided and corrected if found to be non-compliant. Importantly though, irrespective of the element being assessed, the FSES application would provide a clear and structured methodology for checking compliance of design specifications with the building regulations, with the information being captured and stored by the system to fully support the requirement for golden thread of information.

6.5 Discussion

It is imperative that records are kept in line with the golden thread of information, particularly as this now is a legal requirement for high-risk buildings under The Building Safety Act 2022. Through BIM integration within the proposed FSES, data is held centrally in a common data environment (CDE), which can be accessed by key stakeholders and retains a single source of truth about the built asset. Amongst the 'as-built' records, it is also important to log decisions and specifications that were made throughout the design and construction stages of a project. This is particularly important to provide a clear record of why decisions were made and by whom, should the event arise that this information is required to be assessed during the in-use or end of life stages of the project. The FSES application provides links to both the BIM model and digital specification for fire safety.

Through the means of a digital approach, the FSES application would be able to output a record of the assessment, each time this is conducted. Furthermore, each publication that includes changes would be assigned revision sequencing, with unique identifiers, allowing a full audit trail to be kept.

The Fig 46 shows the record of assessment, as generated by the FSES system.

Doc B Vol.1.
Requirement B4: Section 10: Resisting fire spread over external walls

Project management

Section 10. Question 1 - Is the building 18m+ in height from ground level?

1. Description: Yes
2. Specifiers response: Yes
3. Regulators Response: Building is classified as a HRRB and falls within the high risk building category.

Section 10. Question 2 - Is the purpose of the building a dwelling?

1. Description: Yes
2. Specifiers response: Yes
3. Regulators Response: See question 1 response.

Section 10. Question 3 - Are the structural external walls made of fire resisting materials?

1. Description: Yes
2. Specifiers response: Yes
3. List manufacturer product or system and Uniclass 2015 ref:
   Ss_25_20_14_54 Metal insulating sandwich panel cladding systems.
   marketing@kingspanpanels.com
   QuadCore KS1000RW Wall Panel
4. Regulators Response: Specification of external cladding to be submitted with assessment for validation.

Section 10. Question 4 - Are external walls fitted with any materials/products or systems?

1. Description: Yes
2. Specifiers response: Yes
3. Regulators Response: Specification of external cladding to be submitted with assessment for validation.

Section 10. Question 5 - Do the materials which make up the outermost face of the external walls achieve Fire performance Class A2-s1, d0(1), Class A1 or better?

1. Description: No
2. Specifiers response: No
3. List manufacturer product or system and Uniclass 2015 ref:
   Ss_25_20_14_54 Metal insulating sandwich panel cladding systems.
   marketing@kingspanpanels.com
   B-s1,d0
4. Regulators Response: External cladding must meet fire performance requirements. Contact manufacturer for alternative compliant materials or consider substitution for other compliant products/systems.

Figure 46 - Sample output publication from the FSES application showing data logs. (Source: Author)

In the case of the record of assessment above, it has clearly logged a non-compliant specification choice within the external wall cladding. Once corrected, the system will update and assign a latest revision to the BIM model but retain the previous versions for records. Utilising a unique identifier assigned to a URL, the system would also ensure that previous revisions from the current latest version would be clearly marked as such.

Further consideration following the trials and the associated output have highlighted that it may also be beneficial to include two further information captures within the system when referencing compliant materials, namely ‘explanation’ and ‘evidence’. The explanation section would be a text space where the user could note reasons for selecting certain materials or making certain decisions or changes. For example, if an initial specified product was withdrawn from market, the specification would need updating along with the relevant FSES assessment section and a note could be added to explain the change and its reasons. This would be invaluable for future referral, which could be many years after the building was completed. The evidence section would be intended to include for URL links, i.e., a web page containing information about the product, a .pdf technical data sheet, drawing or similar that supports the decision. What is clear is that the system prototype provides a means of assessing the design specification of a built asset, whilst the digital approach to the data capture will provide an increased means of providing an accessible log of all decisions made during the design and construction processes.

General workmanship could also be validated against the FSES if relevant questions and responses are recorded in respect to this detail or others. For any system specification, it is typical for the system outline specification to be created with general requirements of items such as fire performance of specific make-up components which form the system as a whole. The subsequent components are then typically specified under their own clause and template later in the specification. Cross referencing what has been specified as a product of the subsystem and what the system requirements were is an area where focus is needed. Interaction directly between the FSES application and the specification will automate this checking procedure.

6.5.1 How can more robust classification improve the situation?

Uniclass 2015 is maintained and operated by the NBS (National Building Specification) in the UK (NBS, 2020). It builds on previous standards of classification of building elements but offers a much more structured, hierarchical tree methodology than previous classification systems such as CI/SfB (Construction Index/ Samarbetskommitten for Byggnadsfragor) which originated in Scandinavia or the currently widely adopted CAWS (Common Arrangement of Works Sections). For example, take cavity barriers which are needed in the external rain screen cladding systems, as per requirements of Approved Documents B. Prior to the introduction of Uniclass 2015, it would be down to interrogating the relevant sections of the written specification against the clause to identify performance criteria (Hamil, 2019). With CAWS, which is still today one of the most widely used classification systems in the UK (NBS, 2021), a product classification example of these would be 'P12/360 Mineral wool rigid batts'. To an untrained eye, it is not clear that this is a cavity barrier, and it could also not be determined by a professional without further inspection of the specification data. Under Uniclass 2015, the product is clearly identified as 'Pr_25_80_80_79 Sleeved mineral wool cavity barriers'. Uniclass 2015 covers specification of all aspects of building design, from entities to products and systems, it also includes activities, and its hierarchical structure offers clear and accessible methodology to classification. This is perfectly suited to digital data capture. BS EN ISO 19650, the UK BIM Framework recognises this and has made Uniclass 2015 the recommended classification structure when designing via BIM in the UK (BSI, 2018). In respect to 'the golden thread of information,' when asset management data is passed to the client or building management at the handover stage, having the assets logged at component level and classified to Uniclass 2015 would ensure accessibility to all stakeholders that may need to understand the component make-up of the building.

Applying Uniclass 2015 as standard to all built asset data provides a robust and easy to follow structure for evaluation when selecting 'appropriate' materials for construction at the specification stage. This would be further strengthened by the introduction of an expert knowledge base system (Zwass, 2016), which could capture the developed fire safety stages in a novel and robust manor, whilst capturing the data from each selection in a structured format.

6.6 Expert Interviews

To critically assess the FSES development further, an expert peer review of the prototype was deemed necessary. To ensure that the provided responses offered a robust insight into the potential benefits or otherwise, each profession that plays a key role in fire safety was considered. The peer review process followed a set methodology, with the initial conceptualisation beginning by determining the peer group roles and then identifying specific individuals for interview selection. Whilst there is a broad range of actors within construction fire safety design and specification, five key roles were identified that were perceived to have the most influence over the potential use of the FSES. The identified roles included, Architect, Architectural technologist, construction product manufacturer, facilities manager, and software development engineer.

The second stage in the process was to develop the interview questions, which would be conveyed through face to face interviews. The initial assessments of the FSES development were critical in providing a basis for the questions, of which some would be agnostic to all interviewees, whilst some would be tailored to the specific expertise carried by each profession. Once the interview questions were drafted, a code of ethics and conduct assessment was carried out. Due to the nature of the research, it was expected that discussions surrounding fire safety, particularly whilst the Grenfell Tower enquiry was still ongoing, may be sensitive. For that reason, all questions were aimed to be specific to the FSES specifically and industry performance generally. No specific projects were questions during the interviews.

Each candidate was invited to interview, and all were provided with a consent form relating to their participation and use of data, and a participant information sheet.

The interviews were conducted, and a full list of questions and responses are contained within the annex of this thesis. To analyse the responses from the interviews, an open coding method analysis was performed. This involved grouping each role, parent topic, question, and response with a code. The results were then analysed individually and collectively.

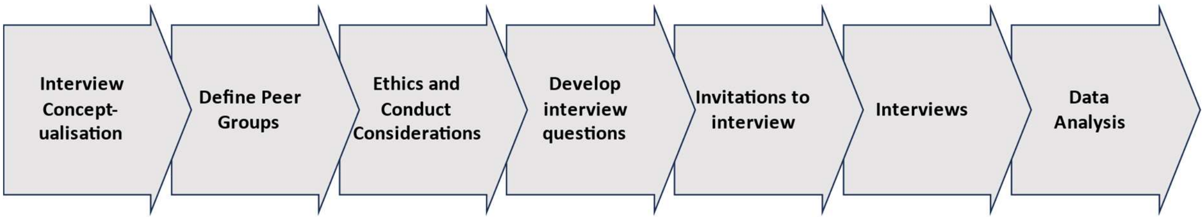


Figure 47 - Interview development process.

6.6.1 Summary of interview responses

All individuals identities have been omitted from this thesis to ensure fair and just practice, though the candidates roles and function within the sector are identified. It is also pertinent to document some of the additional ethical issues encountered that had some impact upon the interview process. Two respondents would not comment in any depth or at all on matters of fire safety due to close involvement with the building regulatory reform processes. It was felt by the author, that a general fear of publication of any provided comments was apparent and in once specific case this openly admitted and if conducted would contravene their company’s protocols. Concerns surrounded how any publication may suggest perceived liability or could be deemed as misinformation, if not fully explained or interpreted accurately. On that basis some responses were limited. Finally, it was initially intended to utilise an actual building design case study to test the FSES system in the final stages of the research. During interviews, the candidates were asked if they would be able to share any such details for use within the research testing cases. None of the interviewed respondents were prepared to share actual project data to analyse using the FSES system.

A full review of responses is listed below. The results of the interviews were analysed and further development suggestions where practical were integrated into FSES development;

Architect: The role of the Architect, particularly when considered the lead appointed designer under the new building regulatory regime is paramount in ensuring that fire safety is achieved within a given building design. The Architect selected for interview is Chartered professional, with day to day responsibilities for design and management of projects, but also BIM delivery and fire safety compliance for an established practice. It was within this interview that the broad scope of issues were established, relating to both fire safety design and technology. Notably when discussing the potential for the FSES to aid benchmarking of compliance across all projects, this was seen as a clear benefit. The Architect was very much of the opinion that technology has its role to play in addressing some of the issues experienced within the industry. Compliance tracking and data capture being crucial areas of focus.

"A systematic benchmarked assessments would be an improvement…"

***"The proposed FSES has great potential to develop into a commercial system**."*

Architect

When provided with a demonstration of the FSES, the Architect was in full agreement that the proposal would be a benefit to the industry. Notably producing a customised digital subset of the Approved Documents, thus enabling better compliance tracking was deemed the highest beneficial development. But, going further as the system could evaluate compliance with these requirements from user inputs or from parameters in a BIM model, the automation potential would no doubt bring efficiency and alignment of both the graphical and non-graphical data.

Final thoughts relayed on the interview were that the FSES could be expanded to cover other approved documents from the building regulations, and not just be limited to fire safety.

Architectural Technologist: The role of the technologist in the design process, whilst often not solely bearing the overall responsibility, is key to the design outcomes. The technologist makes the designs work. They take the overall proposal and create detailed working arrangements and specifications that meet the regulatory demands. It was for these reasons that the Architectural Technologist was chosen for interview. As with the Architect, the Architectural Technologist saw the benefits of the proposed FSES system from a design perspective.

I believe this form of automation is of real benefit and doesn't need to stop at fire safety!

Architectural Technologist

One particular note from the responses were in relation to the installation of the materials and how these play an equal role in compliance. If the materials are specified and designed correctly, flaws could fall with poor or incorrect installation on site.

"As with all systems, execution (installation) will have an impact on fire performance. You just need to read the press on quality of UK residential sector to understand there is an issue in UK."

Architectural Technologist

From this perspective, the connection of the FSES to the building specification will be crucial, as the specification should depict execution clauses to explain how the systems and products must be installed to meet quality and regulatory requirements. It is also noted that the FSES is intended to be utilised following construction at the pre-handover stage to ensure that 'as built' matches design intent, and if not, that any differences are compliant, and data logged in respect to those changes.

Manufacturer: The construction product manufacturer plays a pivotal role in the safety of our built environment. They are the responsible party for ensuring that materials, products and systems bought to market are fit for purpose and compliant. The role of the manufacturer also extends beyond this responsibility, particularly when considering complex systems, such as rainscreen cladding. The manufacturer is the specialist knowledge expert in these scenarios, and often assist the designer and/or contractors in defining a specification that is compliant, fit for purpose and within budget. A leading rainscreen cladding manufacturer was chosen for interview as the research narrows down focus within this design area, following the uncertainty surrounding cladding within the industry to date.

In respect to cladding itself, there were notable references from the manufacturer with regards to the impact the design of cavities can have on the fire safety outcomes of a project, and the installation of these against the design. From a design perspective the depth of cavity vs the barrier size was of note. However, critically, the responsibility for the installation position and type of cavity barriers was of the highest concern.

"Where responsibility lies for cavity barriers is a common pitfall on projects. Often the cladding installer gets left holding baby."

Manufacturer

Poor cavity design and installation can play a major role in fire failure modes in cladding scenarios, as explored in Chapter 3 of this thesis. Whilst the building regulations cover compartmentalisation and cavities, the FSES could pick up compliance data in either the design stage or the handover stage. Whilst this does not address the failure of contractual obligations definitions, it would certainly provide a safety net in situations where responsibility became a grey area.

When questioned about their thoughts on the proposed FSES, the manufacturers response was highly positive. Their view was that the logic could also be utilised for materials/system selection within their own company.

"The FSES system would be a great benefit, we would like to see how logic works for use within our own means."

Manufacturer

Facilities Manager: The role of the facilities manager is to ensure that when a building is in use, it is maintained to a safe and functional manner. It is for this primary reason that a facilities manager was selected for interview. More specifically however, it was a facilities manager for a large social housing group that was selected, as their day to day involvement with multiple occupancy and high risk buildings was deemed to be beneficial to the research.

Notably the facilities manager discussed that more often than not, simply obtaining relevant data in relation to their building could be difficult. If it is provided, then it will typically be fragmented. This provides a lot of requirement upon the facilities manager to join the dots when ensuring that maintenance and replacement is carried out. When demonstrating the FSES, the FM noted that simply having access to the data and the compliance output specifically, would be of real benefit. Firstly, for day to day management, but critically for insurance purposes. Insurance has become problematic following recent tragedies and the potential to provide a documented and live assessment to the insurers would no doubt help.

"Knowing that a building has been thoroughly reviewed at the design stage as well as the as built stage (in the form of a fire risk assessment) would help the **facilities manager** ***confidence knowing that the designs have been through a thorough assessment before the construction phase. Insurance, future proofing of the asset and lifecycle all play a part too."***

Facilities Manager

Software Developer: The software development expert was selected for interview, from a specialist construction technology company, in order to evaluate the FSES prototype and further enhance the system development. Note was given to how selection within the specification could ensure that only compliant products were selected initially, but that the FSES would provide the means to assess the whole specification holistically.

A particular suggestion to the operation of the FSES from the software development expert came in the ability to assess visual data, with a specific proposal surrounding highlighting compliant materials within the BIM model, through the FSES.

"Possibly update systems by colour for compliant parts and show it visually by switching off other types".

Software developer

This suggestion was adopted in the FSES and is covered within this chapter.

6.6.2 Analysis of the gathered data

The data was collated and analysed using an open coding methodology. This involved tabulating the responses by actor, parent topic, sub-topic, question, response, and then applying a code to each of those responses. The applied codes served as means of grouping relevant feedback, issues, and suggestions from each professional. This allowed the author to assess topics in a combined manner and identify any commonalities raised by each interviewee. The applied codes demonstrated that certain topics were more prevalent relating to industry concerns and provided a means to filter specifics such as feedback on the development or topics relating specifically to one actor.

Code	Data Points
Proof of concept	27
FS regulations	19
Cladding errors	17
Declined comment	13
Digital advances	10
FS Responsibility	8
Cladding benefits	4
Change adaption	4
Barriers to safety	3

Table 3 - Qualitative analysis of interview data code tally.

The commonality across the peer review was that regulations did not go far enough or cover specifics to a relevant degree in some areas. Complexity of the regulations were also noted, which links to the key literature findings within this research. Issues with cladding design and installation were discussed mainly by the specialist manufacturer and linked directly to compliance and competency related issues also noted within the initial research conducted by the author. In respect to the role digital technology has to play in resolving compliance issues and specifically in the case of this research, it was deemed that FSES expert system technology has a part to play in improving the safety of the construction sector and the built assets it delivers. Notably, it was the response from the manufacturer and the architect which were perhaps most compelling. Both saw the FSES system as a viable solution to help drive improved decision-making and regulatory compliance. From the Architect's perspective, the intelligent navigation of the building regulations provided by the FSES in tandem with the progress monitoring ability, would de-risk regulatory compliance through complex and involved designs. Whilst the manufacturer also saw the same potential in remediating design risk. From the manufacturer's perspective, it was felt that the FSES could also be dual developed as a manufacturer specific tool to allow correct selection of marketed components and system combinations for each individual circumstance. This provides the FSES with the opportunity to facilitate improvement in fire safety design and specification. Upstream, the selection of complex high-risk systems could be made more robust, via the FSES restricting non-compliant sub-product selection in system build ups within manufacturer websites. Downstream, the FSES could stand alone as an assessment tool for the compiled specification at each relevant stage of checking.

The Interview transcripts from each professional involved can be found within the Appendix A of this thesis.

6.7 Chapter reflective summary

Chapter 6 provides an evaluation and analysis of the proof of concept system. Initially the intention was to test the FSES proof of concept on a real-world project data set, to provide a means of simulating how the system would perform in the industry. From the various conversations with industry stakeholders during the evaluation process, it was not possible to obtain relevant ‘real life’ project data. This was an ethical consideration on the behalf of the expert interview panel, where risk of contractual conflicts of interest or liability may be incurred. To fully test the system, it was therefore necessary for the author to create a series of mock up projects for testing. This generated a lot of work within the research, including the creation of federated BIM models, detailed written specifications, and associated other documentation. All of which was aligned to the regulatory framework applicable to the design details in question. Whilst the work was now fabricated through the research, this did provide a means for the author to purposely build in a series of errors within the design and specification data, which were placed to provide a means of validating if the FSES would highlight those and allow correction.

Analysis was further conducted through quantitative assessment of the results obtained by running the FSES application as a simulation, and through qualitative assessment via expert peer reviews. The outcome of the analysis provided relevant feedback as to what was successful, what any limitations identified were, and where improvements could be made to the system. Any improvements identified were then actioned and tested accordingly.

Overall, the project was felt to be a success. Whilst it is acknowledged that technology, such as the proposed FSES, cannot provide a silver bullet. De-risking fire safety by any potential percentage would make the implementation worthwhile. Financially, the research found that the average construction dispute value within the UK was circa £8M in 2020, with the building safety act and associated stage gates expected to increase both the number of disputes and the time taken to potentially resolve them into the future (Arcadis, 2022). Whilst technological applications, such as the FSES, have a role to play in protecting the financial longevity of professional organisations, more crucially, if an application could save one life, then the research efforts will have been invaluable.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

The current regulatory system demonstrates conflict and complexity in achieving high fire safety standards. Multiple ways of achieving compliance also brings the potential for error. Whilst the Building Safety Act 2022 has bought positive updates to the sector, the complexity around compliance with the building regulations and the varying ability of stakeholders within the sector remains. The introduction of systems such as the proposed FSES application would help to ensure that any steps taken in fire safety design specification of buildings were robust and clearly aligned to the regulations.

In respect to the proposed FSES application itself, which draws ontologies based on the knowledge and experience from industry experts, relevant standards, and extraction from the Building Regulations, would make compliance checking much more simplified, especially in the case of high-rise residential buildings. With clear depiction of choices and an audit trail made against each design and specification decision, it would also clearly support an enhanced golden thread of information throughout the life cycle of the project.

The FSES application is intended not only as a single point of compliance check at the end of the design stage but also to work as a companion through all stages, assisting users and potentially bridging knowledge gaps to improve overall compliance and design decisions. Its integration with the BIM and its visual methodology that highlights certain design requirements is of clear benefit.

Where errors may potentially be discovered by the FSES application, these are flagged up throughout the design process and provide a clear structure of remedial action required to obtain compliance. All data is captured and held in a machine-readable format within the application. With accessibility and interoperability as the key rationale for this, the output documents are then stored within the built assets common data environment (CDE) to enable the golden thread of information and provide an easy-to-follow accessible documents for future reference.

7.1.1 Overview

In this concluding chapter, an evaluation of the research objectives and the methodologies utilised to achieve them are discussed. The chapter also provides a review and summary of the original contribution within the research, its limitations and how the project application can benefit the construction sector. To conclude, considerations in respect to potential further linked research are outlined.

The research began by conducting a review of the current regulatory landscape, which governs fire safety in construction. As part of the literature review an in-depth analysis of both the current building regulations, particularly ADB Vol 1 & 2 plus relevant industry standards such as BS 7974 was carried out. This was supported by further research into the building specification process, and procurement routes, particularly how the two are connected and impact any project decisions in relation to fire mitigation. Additionally, numerous academic journals were reviewed relating to implementation of safety-based technologies within both construction and comparable sectors.

Chapter 3 progressed to understanding the reasoning behind fire failure modes in buildings and the current methodologies applied in mitigating the risk of fire. Extensive consideration was given to the role external wall cladding has played in high profile fires around the globe. Active and passive fire protection was also discussed. What became apparent through the research conducted is the sheer complexity surrounding existing fire safety design, which is amplified further by the number of contributing actors in the process. The closing section of this chapter begins to consider how technology can or does play a role in current fire safety design.

Technology in construction generally was the focus of Chapter 4, however we began discussion by questioning the adaption to change within the industry generally. Change is a complex matter in any sector, and within construction the research has demonstrated that other factors alongside technology are at play, in particular cultural and financial barriers. An in-depth review of current technology used in the sector was provided and notably building information modelling was discussed. The adoption of BIM within the industry is still ongoing, though the research has shown that it has become more widespread throughout the industry in recent years. Whilst this is a positive step, digitisation in construction is deemed to be very low, especially in comparison to other sectors. The research referenced the McKinsey digitisation index, where construction was shown to be the second slowest industrial sector to adopt digital ways of working. From this, the research moved to explore how technology influenced by other sectors could be utilised to bring efficiency gains to the industry but importantly, aid mitigating the risk of failure due to fire. Cloud based technology and artificial intelligence were discussed as a pre-cursor to the topic of expert knowledge base systems, which have been proven to aid other sectors such as finance and health care in providing a means of upskilling and risk mitigation in assessments. Chapter 1 also reviewed the difficulties faced in achieving compliance, a section of which was also dedicated to professional competency.

The research has found that knowledge base expert systems are proven technologies used in a number of sectors, but very little in the fire safety domain of construction industry. On this basis, the proposal of implementing an expert knowledge base system to assist compliance with fire safety design and specification were proposed and is deemed a novel research topic. Chapter 5 set out the rationale and justification behind the project, providing full detail of the development of the FSES (Fire Safety Expert System) prototype. An outline set of ontologies and knowledge base were defined and a FSES was produced. Consideration was given to how specification could integrate with the FSES.

The final development of the prototype explored how the FSES and specification could be integrated with the BIM framework. Proprietary BIM software was used to simulate the performance and integration of the FSES with BIM. A number of visual programming macros were developed, initially to allow the FSES to retrieve data from the BIM model during the assessment of the specified design. Once refined, the connectivity was then progressed to provide a bi-directional functionality which allowed the FSES to retrieve data from the BIM model, but then also push data into it, providing a seamless link to correct errors flagged by the FSES within the model. The bi-directional connectivity was found to have limitations, however. BIM models are a series of complex and co-ordinated geometries, with further complexity added due to the way in which any individual designer will have differing modelling techniques. The ability to push data into the BIM model from the FSES was deemed a potential area of risk, and through careful assessment was restricted to allowing data only updates. Geometrical updates were found to cause conflicting parametric interfaces between numerous components within the model.

Chapter 6 set out the results of trial testing with respect to compliance with standards, regulations, and guidance, as used in the professional practice This was followed by a critical appraisal in the form of an expert review of the FSES by various industry professionals.

7.2 Research Methodology, Objectives and Achievement

7.2.1 Methodology

Whilst an analytical epistemology is closely aligned through focus on knowledge, the failures and potential risks within the built environment were perceived to only be learned through enquiry into both historical failures and the current status of legislation and professional practice. This pragmatic approach brings together two historically established research approaches, positivism and interpretivism.

From the perspective of positivism, insight was gained through observing accounts of failure modes within buildings due to fire. Chapter 3 discusses in depth those observations and the applicability of the research. Combined with this, the interpretivist approach obtained data from various sources including the expert interviews, research papers and regulatory framework. The validation of the prototype within this study and the collection of accounts surrounding fire failure modes, support the view that consequences are necessary to test the validity of a proposition (Dewey, 1938). It is this final consideration, which deems the research methodology as appropriate for this study.

7.2.2 Achievement of Research Objectives

Chapter 1 discusses the research objectives for this project. To provide an overview of the achieved outcomes relating to those objectives, the Table 3 below identifies both the objective and the methods which indicate the achievement. The table also provides reference to the relevant chapters of this thesis which cover the specific objectives and methods.

	Objective	Methods of Achievement	Chapter(s)
1	Carry out an in depth and detailed study of subject specific literature in order to assess, interrogate and inform an innovative approach to a development of integrated BIM framework for fire safety design. Focus to be given towards consequence modelling, failure mode effect analysis and existing approaches surrounding construction product fire testing, record keeping and change control processes.	Literature review	1, 2
2	Investigate and critically evaluate current design techniques, protocols and strategies in construction design and specification in relation to fire safety design, and through the use of consequence modelling techniques highlight the potential issues for failure within designed and constructed entities.	Extensive review of current implications of fire safety design protocols, state of industry and technological developments.	1, 3, 4
3	Develop an original Expert Knowledge Based System and accompanying guidance to support proposed BIM framework, from which an effective fire safety design digital workflow and accurate asset information capturing can be simulated and tested, either retrospectively or progressively.	Development of the FSES and BIM integration.	5
4	Critically evaluate the findings and potential of the proposed expert system, and as a result initiate creation of new guidance for robust design strategy in fire safety, models and or frameworks. Define fully coordinated information control process for assembly of fire rated construction products, when manipulated to form part of a system, element or entity.	System development analysis and validation.	6

5	Indicate how the developed processes can form part of the UK BIM framework, including integration with proposed stage gates of the Golden Thread of information.	BIM framework integration and analysis	5, 6

Table 4 - Achievement of research objectives

7.3 Research findings

This research has investigated in depth the variables which contribute to fire safety within construction, and how the link between digital technology and regulatory compliance could provide a solution to improvement. The summary of findings is categorised in two sections below: industry findings and the novel research findings. Industry findings denote the issues identified during the literature and peer reviews. The novel research findings outline the potential benefits in adopting a fire safety design specification expert system.

7.3.1 Research findings – Industry

This research has provided a means to appreciate the current regulatory landscape and evolving requirements in construction. The adaptation of technology both in the construction sector but also outside of the sector is also discussed in depth. The below points highlight a summary of the key research findings.

- The current regulatory landscape for construction is complex. The way most buildings are designed is bespoke, which places great emphasis on the knowledge and professional competency of all relevant stakeholders involved with the design, specification, and construction decisions on each project. Several high-profile tragedies apportioned to fire in high rise residential buildings have been found to be apportioned in part if not entirely, to design and construction errors. ADB provide the regulatory framework for fire safety in building design; however, these approved documents do not discuss consequences. BS 7974 is a British standard that outlines fire safety engineering approaches to building design and does discuss consequences, however, the decision to use this standard is optional, where the approved documents provide mandatory compliance guidance.

- As the demand for improved fire safety and use of appropriate building materials escalates, the need to technologically innovate is vital. However, the complexity of meeting regulations is stifling innovation. Other reasons, such as potentially uninsurable assets and professional competency is at the fore of concern too. The complexity of meeting regulations already creates risk, particularly if one is not fully conversant with specifics relating to standards and regulations of the vast methods of achieving design outcomes.

- Construction product testing is flawed. In the case of building fabric and other elements within a building, most products work or are installed as part of a system. The assembly of those individual components to form part of a system can result in loss of performance against laboratory tested manufacturer claims. Specifiers need to understand and be aware of the impact that can result in combining individual products and materials to form a system. Whole system performance is critical to the overall safety outcomes of the design.

- The procurement route for any given project can vary and critically, can influence the safety outcomes on any project. New regulatory regime introduced during this research is placing higher responsibility upon the principal designer and principal contractor in any procurement route, to ensure that safety measures are met, with accountability now enforced by increased judicial penalties. For high-risk category buildings, including high rise residential buildings, a golden thread of information will be required by law from 2023, which will contain details of all project information, relating to the design and as-built specifications, and the decision processes behind those specifications. This will place increased reliance upon both the design and construction team, to provide a full digital log of the compliance documentation for buildings of this type.

- The construction industry is notoriously slow to adopt change. In particular, digital adoption within the construction industry ranking second lowest adopting sectors in the world, only slightly ahead of agriculture and fishing. When compared to other manufacturing sectors that contribute widely to the gross domestic product of any region, there is substantial opportunity for development and implementation of new technologies within construction. BIM is arguably the greatest advancement in technology in the sector in the past two decades. However, its adoption has been hindered by perception of complexity and/or higher cost. Successful implementation of any technology within the construction sector, will likely depend on the cost vs benefit summation. Technology such as failure modes effect analysis and consequence modelling are proven to mitigate risk in the oil and gas sector for example, however whilst the implementation of this technology in construction would provide a benefit, the uptake by its nature would be restricted to a limited number of large scale projects.

- Knowledge base expert systems provide a viable means in many sectors including finance and healthcare, to automate or assist lower skilled individuals to make informed decisions. Knowledge base expert systems lean on a knowledge base, generated by domain experts and then surfaced through a digital interface to allow decisions or suggestions to be made based on the data input from a user. Whilst complex to develop, the ease of use of knowledge base expert systems, the efficiency they bring and importantly the risk that they can mitigate are key to their success.

7.3.2 Research findings – Novel contribution

The original contribution which this research possesses is in a novel method of assessing building design specification against compliance with fire safety regulations, whilst providing a BIM integrated digital audit trail, aiding the golden thread of information. By developing an expert knowledge base system for fire safety design specification mapped to the latest UK standards and regulations, the proposal offers a solution to the fire safety design problems which, to the best of the authors knowledge, have not been wholly resolved. The approach offers simplicity to the checking of the specification through different design approval stages and alleviates risks that may occur from the complexity of regulatory framework and varying competency between different professionals. In addition, an integration of fire safety expert system with BIM environment provides a means of capturing and editing specifications which align to fire safety design standards, but take full account of other performance requirements, such as thermal, resistance to moisture, acoustic and aesthetic requirements. The principal contributions from the research can be summarised as follows:

1) The review of the current regulatory framework provided a sound basis for the development of a logic that allows the regulations to be broken down into parent and child relationships and decision making trees. Whilst the building regulations provide a framework for the compliance, ensuring that the relevant sections are applied correctly to each bespoke design is complex. Through the generation of the parent and child logic, users can easily navigate the relevant sections of the regulatory framework for their specific design issues. With domain knowledge varying between all professionals and design practices, a means of assisting compliance checking and digitising audit trail was perceived to be beneficial. This provided the basis for the development of the FSES, a fire safety design specification regulation compliance tool.

2) Further development of the FSES focussed on BIM framework integration. The research developed a link between proprietary BIM software and the FSES, with the connectivity that provides a bi-directional functionality. This provides the means to allow data to be extracted into the FSES for interrogation from the BIM model, providing a means of aligning the written specification. Through bi-directional functionality, the FSES also allows both the specification and the BIM model to be corrected via the FSES, should details be found to be non-compliant.

7.4 Applicability of the Research Framework

The research within this study focusses on the UK building fire safety regulatory framework. Whist globally the building regulations vary in every country, the proposed research framework provides a basis that could be adapted to the regulatory framework of any country. Whilst the research framework focussed specifically the use of digital technology to aid regulatory compliance for fire safety design, the fundamental principles of the framework could be adopted to other areas of complex regulation, particularly those that have an impact upon each other. Remaining with building compliance for example, sustainability is arguably the most complex challenge all industries face. In the UK alone, recent updates to approved documents Part L – Conservation of fuel and power, have been implemented, placing greater emphasis on the reduction of energy demand within buildings.

Similarly approved document Part F – Ventilation, has also been updated and is indirectly connected to both Parts B and L. In respect to fire safety for example, ventilation of smoke is a key passive measure, whilst for modern air-tight sustainable buildings, ventilation is a critical performance requirement. These interrelations provide further regulatory compliance requirements burden upon industry professionals. The research framework could be adapted to aid these areas.

7.5 Limitations of this Research

Whilst the research aim and objectives have been fulfilled, there were certain limitations, primarily due to the complexity and layers of all aspects of fire mitigation regulations and guidance. For research illustration purposes, the knowledge base focussed mainly upon external spread of flame in buildings. Whilst this topic is pertinent given the clear focus on external cladding following the high-level tragedies outlined in this thesis, the intentions of the proposed FSES would be to provide a holistic assessment required for fire safety design specification. This would require the development of ontologies for all aspects of fire mitigation, and therefore excessive amount of time and expertise to populate the knowledge base domain. Secondly, as the research explored the potential for risk mitigation via technology and through the creation of the FSES prototype, further software development would be required for a commercial solution. Software development is a highly skilled profession and learning the programming languages such as JavaScript, Python or C# were deemed outside the scope of this research. The prototype was therefore developed using visual programming, which allowed both the delivery of a functional proof of concept and facilitated the connectivity between the FSES and the proprietary BIM software. The limitations whilst notable, did not restrict the achievement of the research aim and objectives.

7.6 Recommendations for Future Research

From this research, several potential avenues of further research to explore have become apparent. This concluding section provides a summary of the researchers view into viable research topics, as follows:

Consequence modelling and failure modes analysis

During the intense literature survey at the beginning of the research, a number of academic journals and other literature were reviewed, focussed on consequence modelling and failure modes effect analysis. The two topics are very similar in that they both simulate through graphical and non-graphical data the potential for fire ignition, spread and ultimately failure within projects. Consequence modelling and failure modes effects analysis could be utilised in tandem with the FSES to design out risk from early conceptual building designs. This would form an interesting and relevant direction for further research.

Systems testing

Approach to the testing of building systems is a clear area for development. The research has shown that the majority of construction materials and products are tested as single entities. Their performance, when forming part of a system as a whole, how they interact with connecting components, and the impact installation or fabrication may have upon tested materials requires increased study. Following the review of the current regulatory processes following the Grenfell Tower fire, the connection between products and systems has been highlighted. However, to date, no additional regulation has been positioned to effectively tackle this.

Artificial intelligence
This is another area of potential research. A knowledge base expert system is a mild form of artificial intelligence and machine learning could be utilised to provide further intelligence to the system, including predictive failures analysis and system optimisation.

Other applications
Finally, the FSES system is designed to assist fire regulatory compliance. Whilst fire safety is a crucial subject to resolve, the FSES could easily be adapted to aid in the compliance of all building regulatory compliance including those which focus on sustainability, such as Approved Document L – Conservation of fuel and power, Approved Document F – Ventilation and Approved Document O – Overheating. This could also be further extended to possibly investigate the potential to aid in compliance of new designs to standards such as Future Homes, or potentially implemented to assess existing building stock and provide an automated report on refurbishment requirements to bring as-built properties up to low energy standards.

The research undertaken in this study focussed on the various aspects which impact fire safety design in construction and the adoption of digital technologies. When considering its research outcomes, the importance is also placed on providing influence for future research opportunities. Hopefully this research project will inspire others to progress and develop topics which aid the industry’s desire to improve, be that in terms of fire safety, sustainability, or other.

References

Abraham, F., Cahn, J., Fitzgerald, B. & Greenberg, E., 2019. *Strategy in the Face of Disruption.* [Online]
Available at: https://www.mckinsey.com/industries/private-equity-and-principal-investors/our-insights/strategy-in-the-face-of-disruption-a-way-forward-for-the-north-american-building-products-industry
[Accessed 28 March 2022].

Abrahamsson, P., Conboy, K. & Wang, X., 2017. 'Lots done, more to do': the current state of agile systems development research. *European Journal of Information Systems,* pp. 281-284.

Ahmed, F., 2019. *Developing a Computational Framework for a Construction Scheduling Decision Support Web Based Expert System,* Mississippi: University of Southern Mississippi.

Ahn, C. & Kim, J., 2011. A study for a fire spread mechanism of residential buildings with numerical modeling. *Transactions on the Built Environment,* Volume 117, pp. 185-196.

Akerkar, R. & Sajja, P., 2009. *Knowledge based systems.* 1 ed. Sudbury: Jones & Bartlett.

Ala'raj, M. & Abbod, M., 2016. Classifiers consensus system approach for credit scoring. *Knowledge-based systems,* Volume 104, pp. 89-105.

Amir-Heidari et al, P., 2017. Worst-case scenario consequence modelling in natural gas transmission pipeline using PHAST software. *The Journal of Pipeline engineering,* Volume 4th Quarter, pp. 231-239.

Aram, M., Zhang, X., Qi, D. & Ko, Y., 2021. A state-of-the-art review of fire safety of photovoltaic systems in buildings. *Journal of Cleaner Production,* 308(127239).

ARB, 2022. *ARB safety and sustainability guidelines for architects.* [Online]
Available at: https://arb.org.uk/architect-information/guidance-notes/arb-safety-sustainability-guidelines-architects/
[Accessed 26 05 2022].

Arcadis, 2022. *2022 Global Construction Disputes Report,* Amsterdam: Aracdis Global.

Architects' Journal, 2021. *Government 'collusion' led to combustibles loophole, Grenfell inquiry hears.* [Online]
Available at: https://www.architectsjournal.co.uk/news/government-collusion-led-to-combustibles-loophole-grenfell-inquiry-hears
[Accessed 10 06 2023].

Argawal, R., Chandrasekaran, S. & Sridhar, M., 2016. *Imagining construction's digital future.* [Online]

Available at: https://www.mckinsey.com/capabilities/operations/our-insights/imagining-constructions-digital-future

Autodesk, 2016. *What is BIM Level 2?.* [Online]
Available at: https://bim360.autodesk.com/what-is-bim-level-2/
[Accessed 20 10 2022].

Autodesk, 2021. *Dynamo.* [Online]
Available at: https://dynamobim.org/
[Accessed 20 11 2022].

Bain, D., 2020. *10th Annual National BIM Report 2020,* Newcatle upon Tyne: NBS.

Barker, P., 2019. *Fire door testing explained,* Milton Keynes: Chiltern fire.

BBC, 2015. *Volkswagen: The Scandal Exposed.* [Online]
Available at: https://www.bbc.co.uk/news/business-34324772
[Accessed 26 03 2020].

BBC, 2019. *Grenfell Tower: What happened.* [Online]
Available at: https://www.bbc.co.uk/news/uk-40301289
[Accessed 20 April 2020].

BBC, 2019. *Grenfell Tower: What happened.* [Online]
Available at: https://www.bbc.co.uk/news/uk-40301289
[Accessed 20 04 2020].

Birkland, T., 1997. *After Disaster: Agenda Setting, Public Policy, and Focusing Events.* 1 ed. Washington: Georgetown University Press.

Boje, C., Guerriero, A., Kubicki, S. & Rezgui, Y., 2020. Towards a semantic Construction Digital Twin: Directions for future research. *Automation in Construction,* Volume 114.

Borowska, K., 2020. *The Slow Revolution - Five Technology Trends In Construction 2020.* [Online]
Available at: https://www.forbes.com/sites/kasiaborowska/2020/11/19/the-slow-revolutionfive-technology-trends-in-construction-2020/?sh=65976949419a
[Accessed 09 March 2022].

Braaksma, J., 2012. *Asset information for FMEA-based maintenance,* Groningen: University of Groningen.

BRAC, 2021. *Golden thread report,* London: Building Regulations Advisory Committee.

BRAC, 2021. *Golden Thread Report,* London: Ministry for housing and local government.

Brandon, D., Plathner, F. & Mikkola, E., 2021. SAFITS - Statistical Analysis of Fires in. *RISE: Rsearch Institute of Sweden,* p. 97.

BRE, 2020. *Fire Modelling.* [Online]
Available at: https://www.bregroup.com/a-z/fire-modelling/
[Accessed 26 03 2020].

Broquetas, M., Bryde, D. & Volm, J., 2013. The project benefits of Building Information Modelling (BIM). *International Journal of Project Management,* Volume 31, pp. 971-980.

Bruner, J., Goodnow, J. & Austin, G., 1956. *A Study of Thinking.* London: Chapman & Hall Ltd.

BSI, 2003. *PD 7974-7 Probablistic Risk Assessment..* Watford: British Standards Institute.

BSI, 2008. *BS 8214:2008 - Code of Practice for Fire door asseblies.* Watford: British Standards Institute.

BSI, 2014. *BS EN 13823:2010+A1:2014 - Reaction to fire tests for building products. Building products excluding floorings exposed to the thermal attack by a single burning item.* s.l.:British Standards Institute.

BSI, 2014. *PAS 1192-3:2014 Specification for information management for the operational phase of assets using BIM.* Watford: British Standards Institute.

BSI, 2015. *BS 9991: Fire safety in the design, management and use of residential buildings – Code of practice.* Watford: British Standards Institute.

BSI, 2017. *BS 9999-2017 Fire safety in the design, management and use of buildings – Code of practice..* Watford: British Standards Institute.

BSI, 2018. *BS EN 13501-1:2018 - Fire classification of construction products and building elements. Classification using data from reaction to fire tests.* s.l.:British Standards Institute.

BSI, 2018. *BS EN 1634-1:2014+A1:2018. Fire resistance and smoke control tests for door and shutter assemblies, openable windows and elements of building hardware. Fire resistance test for door and shutter assemblies and openable windows.* Watford: British Standards Institute.

BSI, 2018. *BS EN ISO 19650 - 1 Information Management using BIM - concepts and Principals..* Watford: British Standards Institute.

BSI, 2018. *BS EN ISO 19650 Part 2,* Watford: British Standards Institute.

BSI, 2018. *BS EN ISO 19650-2 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM).*

Information management using building information modelling - Delivery phase of the assets. Watford: British Standards Institute.

BSI, 2018. *BS EN ISO 19650-2:2018 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling. Delivery phase of the assets.* Watford: British Standards Institue.

BSI, 2019. *BS7974:2019 – Application of Fire safety engineering principles to the design of buildings – Code of practice'.* s.l.:British Standards Institute.

BSI, 2021. *BSI Identify.* [Online]
Available at: https://identify.bsigroup.com/
[Accessed 30 March 2022].

Burgess, G., Jones, M. & Muir, K., 2018. *BIM in the UK house building industry: opportunities and barriers to adoption,* Cambridge: Cambridge University.

Burggräfa, P., Dannapfela, M., Ebade-Esfahania, M. & Scheidlera, F., 2021. *Creation of an expert system for design validation in BIM-based factory.* Aachen, Procedia engineering.

Cadena, J. & Munoz, F., 2013. The Link between Fire Research and Process Safety: An Evolution from Specific Needs to General Concern. *Chemical Engineering Transactions,* Volume 31, pp. 679-684.

Carlsson, C., 2021. *Milan apartment block fire "closely recalled Grenfell Tower" says mayor,* London: Dezeen.

Champneys, A., Fresneda-Portillo, C., Hewitt, I. & Liu, X., 2013. *Estimating the spread of fire in buildings. ,* Bristol: Researchgate.

Chauhan, S., 2019. *Lego Boost Creative Tool Box Review.* [Online]
Available at: https://www.techradar.com/reviews/lego-boost-creative-toolbox
[Accessed 20 11 2022].

Cheng, H. & Hadjisophocleous, G., 2011. Dynamic modelling of fire spread in buildings. *Fire Safety Journal,* 46(4), pp. 211-224.

Chen, T. et al., 2019. Fire Risk Assessment of Combustible Exterior Cladding Using a Collective Numerical Database. *Fire,* 2(1), p. 11.

CIRIA, 2020. *Methodology for quantifying the benefits of offsite construction,* London: Construction Industry Research and Information Association.

CMM, 2017. *Post-Grenfell report slams Building Regs.* [Online]
Available at: http://www.constructionmanagermagazine.com/news/complex-building-regulations-criticised-post-grenf/
[Accessed 20 Jan 2020].

CPA, 2019. *Construction Product Information Survey,* s.l.: Construction Products Association.

Crawford, A., 2011. *Fire safety and sustainability – the perfect combination?.* [Online] Available at: https://www.ifsecglobal.com/uncategorized/fire-safety-and-sustainability-the-perfect-combination/
[Accessed 10 09 2022].

CSG, C. S. G., 2020. *Raising the Bar - Interim Report of the Competence Steering Group,* London: Construction Leadership Council.

Cummins, F., 2017. *Buliding the agile enterprise.* 2nd ed. s.l.:Elsevier.

Curtis, R., 2020. Grenfell Inquiry has exposed design and build as our dirty little secret. *Architects Journal*, 28 02.

D3Web, 2021. *D3Web.* [Online]
Available at: https://www.d3web.de/Wiki.jsp?page=Main
[Accessed 11 05 2021].

Dadashzadeh et al, M., 2013. An integrated approach for fire and explosion consequence modelling. *Fire Safety Journal,* pp. 324-337.

Damon, R., 2012. Sustainable fire safety design for building frontages. *Journal of applied sciences,* 15(1), pp. 19-24.

Darley PCM Ltd, 2020. *The Principal Designer Role, Duties And Responsibilities.* [Online]
Available at: https://www.haspod.com/blog/cdm/principal-designer-role-duties-responsibilities#:~:text=The%20principal%20contractor%20manages%20the,all%20of%20the%20designers%20appointed.
[Accessed 20 10 2022].

Davies et al, A., 2018. *Modern Methods of Construction: A forward-thinking solution to the housing crisis,* London: RICS.

Davies, C., 2021. *Construction Update on Building Safety and the Golden Thread.* [Online]
Available at: https://www.lexology.com/library/detail.aspx?g=0c83825a-a26b-4289-845f-c188f32076bb
[Accessed 16th October 2021].

Day, M., 2018. *NBS Chorus.* [Online]
Available at: https://aecmag.com/technology/nbs-chorus/
[Accessed 03 January 2022].

Dewey, J., 1938. *Logic: The theory of Inquiry.* New York: Henry Holt and Company.

DHLGH, 2022. *building regulations.* [Online]
Available at: https://www.gov.ie/en/publication/1d2af-building-regulations/
[Accessed 14 11 2022].

Diaz, L. B. et al., 2020. Meta-Review of Fire Safety of Lithium-Ion Batteries: Industry Challenges and Research Contributions. *Journal of The Electrochemical Society,* 167(9).

DLUHC, 2022. *Consultation on implementing the new building control regime for higher-risk buildings and wider changes to the building regulations for all buildings.* [Online]
Available at: https://www.gov.uk/government/consultations/consultation-on-implementing-the-new-building-control-regime-for-higher-risk-buildings-and-wider-changes-to-the-building-regulations-for-all-buildings/consultation-on-implementing-the-new-building-control-regime
[Accessed 15 11 2022].

D'mello, A., 2020. *COVID-19 has sped up digital transformation by 5.3 years.* [Online]
Available at: https://www.iot-now.com/2020/07/23/104031-covid-19-has-sped-up-digital-transformation-by-5-3-years-says-study/
[Accessed 25 November 2020].

Donegan, H., Taylor, I. & Meehan, R., 1991. *An Expert System to Assess Fire Safety in Dwellings.* Ulster, FIRE SAFETY SCIENCE-PROCEEDINGS OF THE THIRD INTERNATIONAL SYMPOSIUM, pp. 485-494.

Drools, 2021. *Drools DMN.* [Online]
Available at: https://www.drools.org/learn/dmn.html
[Accessed 11 05 2021].

DSTDC, 2022. *CAD a brief history.* [Online]
Available at: https://www.digitalschool.ca/cad-a-brief-history/
[Accessed 18 11 2022].

DT Rules, 2021. *DT Rules.* [Online]
Available at: http://www.dtrules.com/newsite/
[Accessed 11 05 2021].

Duncan, J., 2019. *Technical Review of Approved Document B of the Building Regulations - A Call for Evidence,* London: Royal Institute of British Architects.

Easterby-Smith, M., Thorpe, Jacson & Lowe, 2008. *Management Research: An Introduction. 3rd edition.* London: Sage.

Eastman, C., 1974. An Outline of the Building Description System. Research Report No.50.

El-Ghalayini, H. & Kharbat, F., 2008. *Building Ontology from Knowledge Base Systems.* 1 ed. Rijeka: Intech.

EPIC, 2011. *Insulated panels for external roof and wall cladding - a guide to fire safety and performance in fire.,* Manchester: Engineered Panels in Construction.

Farmer, M., 2016. *Modernise or Die,* London: Construction Leadership Council.

FCP, 2021. *How Digital Tools Can Fill the Construction Workforce Management Gap.* [Online]
Available at: https://www.forconstructionpros.com/business/labor-workforce-development/article/21796300/laborchart-how-digital-tools-can-fill-the-construction-workforce-management-gap
[Accessed 14 12 2022].

Fire Brigades Union, 2021. *Bradford City FC stadium fire - 11th May 1985,* Surrey: Fire Brigades Union.

Fire Protection Online, 2020. *How does a fire spread?.* [Online]
Available at: https://www.fireprotectiononline.co.uk/info/how-does-a-fire-spread/
[Accessed 16 december 2020].

Fire Protection Online, 2023. *how does a fire spread.* [Online]
Available at: https://www.fireprotectiononline.co.uk/info/how-does-a-fire-spread/
[Accessed 06 07 2023].

Fire Safety Advice Centre, 2020. *BS 746 set of documents.* [Online]
Available at: https://www.firesafe.org.uk/british-standard-476-fire-tests/
[Accessed 26 03 2020].

Firerite, 2022. *The Difference Between Active and Passive Fire Protection.* [Online]
Available at: https://www.firerite.co.uk/fire-protection-companies-news/difference-between-active-passive-fire-protection/#:~:text=Active%20fire%20protection%20requires%20action,an%20alarm%20or%20automatic%20sprinkler.
[Accessed 17 12 2022].

Fraser-Mitchell, J., 2020. *An object oriented simulation (Crisp II) for fire risk assessment,* s.l.: Internation association for fire safety science.

Frye, M., Olynick, D. & Pinkneyl, R., 1992. Development of an Expert System for the Fire Protection Requirements of the National Building Code of Canada. *Unknown (Department of Civil Engineering. University of Manitoba, Canada),* pp. 215-226.

Gardener, J., 2020. *New fire safety programme to cover more buildings.* [Online]
Available at: https://www.building.co.uk/news/new-fire-safety-programme-to-cover-more-buildings/5105382.article
[Accessed 04 April 2020].

Gardiner, J., 2020. *New fire safety programme to cover more buildings.* [Online]
Available at: https://www.building.co.uk/news/new-fire-safety-programme-to-cover-more-buildings/5105382.article
[Accessed 4 4 2020].

Garvin, S., 2019. *Fire Safety Standards – latest changes.* [Online]
Available at: https://blogs.gov.scot/building-standards/2019/11/01/fire-safety-standards-latest-changes/
[Accessed 04 April 2020].

Gerrard, M., 2003. DISASTERS FIRST: RETHINKING ENVIRONMENTAL LAW. *Widener Law Symposium Journal,* 9(2), pp. 223-235.

GMFARS, 2019. *The Cube, Incident Report and Key Observations,* Manchester: Greater Manchester Fire and rescue service.

Gogh, M., 2019. *Reimagining construction: The vision for digital transformation, and a roadmap for how to get there.,* California: Autodesk.

GovUK, 2011. *Government construction strategy,* London: HM Government.

GovUK, 2018. *Independant review of building regulations and fire safety.* [Online]
Available at: https://www.gov.uk/government/publications/independent-review-of-building-regulations-and-fire-safety-final-report
[Accessed 26 03 2020].

Greatbatch, 2005. Telephone triage, expert systems and clinical expertise. *Sociology of Health & Illness,* 27(6), pp. 802-830.

Greene, K., 2022. *Building Safety Act 2022 - what's changed?.* [Online]
Available at: https://www.lexology.com/library/detail.aspx?g=bb7cfa7b-24bf-4ed2-a0c9-1166d63a8f35
[Accessed 30 05 2022].

Grenfell Tower Inquiry, 2022. *End of Phase 2 Hearings.* [Online]
Available at: https://www.grenfelltowerinquiry.org.uk/
[Accessed 12 11 2022].

Grenfell United, 2020. *We are Grenfell United.* [Online]
Available at: https://grenfellunited.org.uk/
[Accessed 18 11 2022].

Haag, M. & Hubbard, B., 2017. *Dubai Tower Burns a 2nd Time, and Flammable Cladding Is Again Under Scrutiny,* New York: New York Times.

Hackitt, D. J., 2017. *Building a Safer Future - Interim Report,* London: HM Government.

Hackitt, D. J., 2018. *Building a Safer Future. Independent Review of Building Regulations and Fire Safety: Final Report,* s.l.: UK Government.

Hackitt, D. J., 2020. *NBS Construction Product Leaders Summit.* Birmingham, NBS.

Hadjisophocleous, G., Benichou, N. & Tamim, A., 1998. Literature Review of Performance-Based Fire Codes and Design Environment. *Journal of Fire Protection Engineering. 1998;9(1):12-40,* 9(1), pp. 12-40.

Hamil, S., 2018. *What is COBie?.* [Online]
Available at: https://www.thenbs.com/knowledge/what-is-cobie
[Accessed 14 12 2022].

Hamil, S., 2019. *Specifications and classification.* [Online]
Available at: https://www.thenbs.com/knowledge/specifications-and-classification
[Accessed 03 January 2022].

Hanson, M., 2005. *Fire protection demands threaten to stifle design innovation.* [Online]
Available at: https://www.newcivilengineer.com/archive/fire-protection-demands-threaten-to-stifle-design-innovation-30-06-2005/
[Accessed 14 11 2022].

Hickie, D. H. &. J., 2021. The impact of Industry 4.0 on supply chains and regions: innovation in the aerospace and automotive industries. *European Planning Studies,* 29(9), pp. 1606-1621.

Hintze, A., 2016. Understanding the Four Types of Artificial Intelligence. *Government Technology*, 14 November.

HM Government, 2011. *Government construction strategy..* London: HM government.

HM Government, 2012. *Industrial strategy: government and industry in partnership; Building Information Modelling.* [Online]
Available at:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/34710/12-1327-building-information-modelling.pdf
[Accessed 09 March 2022].

HM Government, 2018. *HM Government (2018) Independant review of building regulations and fire safety.* [Online]
Available at: https://www.gov.uk/government/publications/independent-review-of-building-regulations-and-fire-safety-final-report
[Accessed 26 03 2020].

HM Government, 2019. *Approved Document B - Part 1, Dwellings.* s.l.:UK Government.

HM Government, 2019. *Approved Document B - Part 2. Buildings other than Dwellings.* s.l.:UK Government.

HM Government, U., 2019. *Prepare to use UKCA MArking after Brexit.* [Online]
Available at: https://www.gov.uk/guidance/prepare-to-use-the-ukca-mark-after-brexit
[Accessed 20 02 2020].

HM Government, U., 2020. *CE Marking.* [Online]
Available at: https://www.gov.uk/guidance/ce-marking
[Accessed 26 03 2020].

HMFSI, 2020. *FSE - A basic guide for fire authority enforcement,* London: HM Fire Inspectors.

Holland, C., Crowder, D. & Shipp, M., 2016.. *External fire spread - part 2. Experimental research.,* London: Building Research Establishment.

Holland, C., Crowder, D. & Shipp, M., 2016. *External Fire Spread – Part 1 Background research,* Watford: BRE Global.

Home Office, 2017. *Fires in purpose built flats, England, April 2009 to March 2017.,* London: UK Home Office.

HSE, 2010. *Fire Safety in Construction (2nd Edition),* London: Health and Safety Executive.

HSE, 2021. *Building Safety Regulator,* London: Health and Safety Executive.

HSE, 2021. *Building Safety Regulator.* [Online]
Available at: https://www.hse.gov.uk/building-safety/regulator.htm
[Accessed 10 12 2021].

Huang, X., Xiqiang, W. & Usmani, A., 2022. Perspectives of Using Artificial Intelligence in Building Fire Safety. *Handbook of Cognitive and Autonomous Systems for Fire Resilient Infrastructures,* pp. 139-159.

Hughes, M., 2019. *Grenfell Tower Insurance Implications.,* London: The Bartlett Group.

Inside Housing, 2019. *Warning signs: a timeline of major residential fires post-Grenfell..* [Online]
Available at: https://www.insidehousing.co.uk/insight/insight/warning-signs-a-timeline-of-major-residential-fires-post-grenfell-64191
[Accessed 08 10 2020].

IPCC, 2022. *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge: Cambridge University Press.

ISO, 2020. *ISO 23386:2020 - Building information modelling and other digital processes used in construction — Methodology to describe, author and maintain properties in interconnected data dictionaries.* s.l.:International Standards Organisation.

JCT, 2021. *Joint Contracts Tribunal: Traditional/Conventional.* [Online]
Available at:
https://corporate.jctltd.co.uk/products/procurement/traditionalconventional/
[Accessed 15 06 2023].

Jefferies, 2012. Assessment of Professional Competence in a Construction Management Problem-based Learning Setting. *Australasian Journal of Construction Economics and Building,* 2(1), pp. 47-56.

Jess, 2021. *Jess.* [Online]
Available at: http://www.jessrules.com/
[Accessed 11 05 2021].

Johnson, E., 2020. *The different types of fires.* [Online]
Available at: https://cpdonline.co.uk/knowledge-base/health-and-safety/the-different-types-of-fires/
[Accessed 06 07 2023].

JSTOR, 2015. *The Stigma of Prefab homes.* [Online]
Available at: https://daily.jstor.org/stigma-prefab-homes/
[Accessed 14 12 2022].

Kernik, G., 2021. *Catastrophe and Systematic Change.* 1st ed. London: London Publishing Partnership.

Kharbat, F. & El-Ghalayini, H., 2008. Building ontology from knowledge base systems.. *Data Mining in Medical and Biological Research*, November, pp. 55-68.

Krasniqi, X. & Hajrizi, E., 2016. Use of IoT Technology to Drive the Automotive Industry from Connected to Full Autonomous Vehicles. *IFAC Papers Online,* 49(29), pp. 269-274.

Kubba, S., 2012. *Building Information Modeling.* 978-0-12-385128-4 ed. s.l.:Elsevier.

LABC, 2022. *Guidance on the use of movement joints,* Birkinhead: LABC.

Laczkowski et al, K., 2018. *How OEMs can seize the high-tech future in agriculture and construction,* s.l.: McKinsey.

Lea, R., 2021. *Toxic and dysfunctional industry in race to the bottom.* [Online]
Available at: https://www.thetimes.co.uk/article/toxic-and-dysfunctional-industry-in-race-to-the-bottom-kmd8n7ct9
[Accessed 16 October 2021].

Lee, J., 2022. *Is the customer always right? How consumers can help drive innovation..* [Online]
Available at: https://www2.deloitte.com/ca/en/pages/consumer-business/articles/consumer-driven-innovation.html
[Accessed 14 12 2022].

Lei, Y. et al., 2019. Numerical Simulation of Fire Smoke Spread in a Super High-Rise Building for Different Fire Scenarios. *Advances in Civil Engineering,* pp. 1-11.

Liu et al, X., 2018. *Consequence modelling of CO2 pipeline failure.* Hong Kong, Energgy Procedia.

Liu, H., Chen, X., Duan, C. & Wang, Y., 2019. Failure mode and effect analysis using multi-criteria decision making methods: A systematic literature review. *Computers & Industrial Engineering,* September, Volume 135, pp. 881-897.

Macleod, F. & Richardson, S., 2018. *Piper Alpha: The Disaster in Detail.* [Online]
Available at: https://www.thechemicalengineer.com/features/piper-alpha-the-disaster-in-detail/
[Accessed 10 06 2023].

Maher Ala'raj, A. & Maysam, F., 2016. Classifiers consensus system approach for credit scoring. *Knowledge Based Systems,* Volume 104, pp. 89-105.

Maher, J., 1985. HI-RISE and beyond: directions for expert systems in design. *Computer aided design,* 17(9), pp. 420-427.

Mahmoud, 2008. *Expert System for Banking Credit Decision.* Singapore, ICCSIT '08.

Manes, M. & Rush, D., 2019. A Critical Evaluation of BS PD 7974-7 Structural Fire Response Data Based on USA Fire Statistics. *Fire Technology,* Volume 55, p. 1243–1293.

Marr, B., 2017. *What is digital twin technology - and why is it so important?,* New York: Forbes.

Marr, B., 2017. *What Is Digital Twin Technology - And Why Is It So Important?.* [Online]
Available at: https://www.forbes.com/sites/bernardmarr/2017/03/06/what-is-digital-twin-technology-and-why-is-it-so-important/#506321dd2e2a
[Accessed 05 May 2020].

Marsh, P., 2020. *Buncefield Incident Summary,* Essex: XBP Refining Consultants Ltd.

Mayhew, F., 2022. *Grenfell five years on: Cladding scandal still haunts thousands across UK..* [Online]
Available at: https://www.bigissue.com/news/housing/grenfell-five-years-on-cladding-

scandal-still-haunts-thousands-across-uk/
[Accessed 20 11 2022].

McKinsey Global Institute, 2017. *Reinventing Construction: A route to higher productivity,* Chicago: McKinsey & Company.

McKinsey, 2020. *The next normal in construction,* Atlanta: McKinsey and Company.

MCRMA, 2022. *GD36 Cavity Barriers for Ventilated Rainscreen Facades.* [Online]
Available at: https://mcrma.co.uk/wp-content/uploads/2022/04/GD36-Cavity-barriers-guidance.pdf
[Accessed 26 10 2022].

MHCLG, 2020. *A reformed building safety regulatory system,* London: HM Government.

MHCLG, 2020. *Bill 121 (Fire Safety Bill 2020).* London: House of commons.

MHCLG, 2020. *Draft Building Safety Bill.* [Online]
Available at: https://www.gov.uk/government/publications/draft-building-safety-bill
[Accessed 08 Oct 2020].

MHCLG, 2022. *Building Safety Act 2022.* [Online]
Available at: https://www.legislation.gov.uk/ukpga/2022/30/contents/enacted
[Accessed 18 August 2022].

MHCLG, 2023. *Approved Document L: Conservation of Fuel and Power.* London: HM Government.

Minett, A., 2022. *8 UK Construction Industry Trends Of 2022 To Watch Out For.* [Online]
Available at: https://www.chas.co.uk/blog/construction-industry-trends-2022/
[Accessed 15 11 2022].

Misnan MS, M. A., 2007. *Development of Safety Culture in the Construction Sector: A Conceptual Framework.* [Online]
Available at: https://www.arcom.ac.uk/-docs/proceedings/ar2007-0013-0022_Misnan_and_Mohammed.pdf
[Accessed 03 January 2022].

Mohammed, et al., 2020. *The Building Safety Bill explained.* [Online]
Available at: https://www.building.co.uk/comment/the-building-safety-bill-explained/5107275.article
[Accessed 16th October 2021].

Moore-Bick, M., 2019. *Grenfell Tower Enquiry - Phase 1 report overview,* London: HM Government.

Moore, J., 2018. *Knowledge-based system (KBS).* [Online]
Available at: https://www.techtarget.com/searchcio/definition/knowledge-based-systems-KBS#:~:text=A%20knowledge%2Dbased%20system%20(KBS,their%20reliance%20on%20human%20expertise.
[Accessed 18 11 2022].

Moore, J., 2018. *Knowledge-based Systems (KBS).* [Online]
Available at: https://www.techtarget.com/searchcio/definition/knowledge-based-systems-KBS
[Accessed 28 06 2022].

Moushtakim, B., Islam, M. & Bin Ali, R., 2018. Fire Fighting of a Tall Bulding: A Review. *World Scientific News,* Volume 102, pp. 17-29.

Mróz, K., Hager, I. & Korniejenko, K., 2016. Material Solutions for Passive Fire Protection of Buildings and Structures and Their Performances Testing. *Procedia Engineering,* 151(1), pp. 284-291.

Murray, A. & Schulz, J., 2019. *The Current Fire Legislation & the challenges facing the Construction Industry in complying with these regulations,* London: ARUP.

Namikawa, S. et al., 2017. *Photovoltaics and Firefighters' Operations: Best Practices in Selected Countries,* Kawasaki: IINTERNATIONAL ENERGY AGENCY.

NASA, 2023. *The Causes of Climate Change.* [Online]
Available at: https://climate.nasa.gov/causes/
[Accessed 09 07 2023].

National Statistics, 2011. *Fire statistics Great Britain, 2010-2011,* London: MHCLG.

NBS, 2016. *A place to be proud of.* [Online]
Available at: https://www.thenbs.com/knowledge/a-place-to-be-proud-of
[Accessed 30 05 2022].

NBS, 2019. *National BIM Report 2019,* Newcastle upon Tyne: The NBS.

NBS, 2020. *Uniclass 2015.* [Online]
Available at: https://www.thenbs.com/our-tools/uniclass-2015
[Accessed 27 03 2020].

NBS, 2020. *What are Archtectural Specifications.* [Online]
Available at: https://www.thenbs.com/knowledge/what-are-architectural-specifications
[Accessed 01 April 2022].

NBS, 2021. *Digital Construction Report 2021,* Newcaste-upon-Tyne: NBS.

NFPA, 2017. *Fire causes and risks.,* London: NFPA.

NFPA, 2020. *Top fire causes.* [Online]
Available at: https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Top-fire-causes
[Accessed 16 December 2020].

NHBC, 2016. *Modern Methods of construction: Views from the Industry,* London: RICS.

NHS, 2020. *nhs-111-online.* [Online]
Available at: https://digital.nhs.uk/services/nhs-111-online
[Accessed 19 May 2020].

NIDirect, 2022. *ACM Cladding checks.* [Online]
Available at: https://www.nidirect.gov.uk/articles/acm-cladding-checks#:~:text=Aluminium%20composite%20material%20(ACM)%20is,a%20copper%20or%20zinc%20effect.
[Accessed 17 12 2022].

Nunamaker, J., Chen, J. & Purdin, T., 1990. Systems development in information research. *Systems Sciences Vol.7 No.3,* pp. 89-106.

Okpala, 2020. *Utilizing Emerging Technologies for Construction Safety Risk Mitigation.* [Online]
Available at:
https://www.academia.edu/52610756/Utilizing_Emerging_Technologies_for_Construction_Safety_Risk_Mitigation?from=cover_page
[Accessed 03 January 2022].

Open Expert, 2021. *Open Expert.* [Online]
Available at: https://sourceforge.net/projects/law-expert/
[Accessed 11 05 2021].

Oxford University Press, 2022. *Oxford English Dictionary Online.* [Online]
Available at: https://www.oed.com/
[Accessed 15 11 2022].

Park, H., 2014. *Development of a holistic approach to integrate fire safety performance with building design.* s.l., Environmental Science.

Parliament, U., 1667. *An Act for rebuilding the City of London.* [Online]
Available at: https://www.parliament.uk/about/living-heritage/transformingsociety/towncountry/towns/collections/collections-great-fire-1666/1666-act-to-rebuild-the-city-of-london/#:~:text=The%20Act%20for%20the%20Rebuilding,of%20abodes%20to%20eliminate%20overcrowding.
[Accessed 18 05 2022].

Philp, D., 2019. *Government Soft Landings - Revised guidance for the public sector on applying BS8536 parts 1 and 2.,* London: UKBIMFramework.org.

Pyke, 2021. *Pyke.* [Online]
Available at: http://pyke.sourceforge.net/
[Accessed 11 05 2021].

Rada, R., 2008. Expert systems and evolutionary computing for financial investing: A review. *Expert Systems with Applications,* 34(4), pp. 2232-2240.

Rehak, D. & Howard, C., 1985. Interfacing expert systems with CAD systems. *Computer aided design,* 17(9), pp. 443-454.

Rhumbix, 2023. *Breaking Down Silos in Construction: Overcoming the Obstacles to Collaboration.* [Online]
Available at: https://www.rhumbix.com/blog/breaking-down-silos-in-construction-overcoming-the-obstacles-to-collaboration
[Accessed 23 01 2024].

RIBA, 2020. *Recent changes to fire safety regulations.* [Online]
Available at: https://www.architecture.com/knowledge-and-resources/knowledge-landing-page/fire-safety-regulations-changes-january-2020
[Accessed 04 April 2020].

RIBA, 2020. *RIBA Plan of Work Overview,* London: RIBA.

RIBA, 2021. *2030 Climate Challenge (Version 2).* [Online]
Available at: https://www.architecture.com/about/policy/climate-action/2030-climate-challenge
[Accessed 15 06 2023].

RIBA, 2021. *Learn about the relaunched RIBA Health and Safety Test.* [Online]
Available at: https://www.architecture.com/knowledge-and-resources/knowledge-landing-page/learn-about-the-relaunched-riba-health-and-safety-test
[Accessed 22 December 2021].

RIBA, 2021. *RIBA Plan of Work.* [Online]
Available at: https://www.architecture.com/knowledge-and-resources/resources-landing-page/riba-plan-of-work
[Accessed 30 05 2022].

RIBA, 2022. *CPD obligations for RIBA chartered Architects,* London: Royal institute of British Architects.

Richardson, S. & Gardener, J., 2014. *How vital is government as a construction client?.* [Online]
Available at: https://www.building.co.uk/focus/how-vital-is-government-as-a-construction-client/5069470.article
[Accessed 14 12 2022].

Rodrigues, M., 2022. *BIM’s role in achieving a single source of truth in construction.* [Online]
Available at: https://www.pbctoday.co.uk/news/digital-construction-news/bim-news/bims-role-single-source-of-truth-construction/110624/
[Accessed 23 01 2024].

Ruxandra, D., 2012. sustainable fire safety design for building frontages. *Journal of applied sciences,* 2(15)(1), pp. 19-24.

Santos, 2020. BRICKS: Building’s reasoning for intelligent control knowledge-based system. *Sustainable Cities and Society,* 52(Article 101832), pp. 1-15.

Saunders, M., Lewis, P. & Thornhill, A., 2009. *Research Methods for Business Students - Fifth Edition.* London: Prentice Hall.

Saxon et al, R., 2018. *Going Digital,* London: UK BIM Alliance.

Schmid, J. & Frangi, A., 2021. Structural Timber In Compartment Fires – The Timber Charring and Heat Storage Model. *Open Engineering,* 11(1), pp. 435-452.

Schneidera, K., Lædrea, O. & Lohnea, J., 2016. Challenges found in handover of commercial buildings. *Procedia - Social and Behavioral Sciences,* Volume 226, pp. 310-317.

Science and Media museum, 2021. *Houses of the future.* [Online]
Available at: https://www.scienceandmediamuseum.org.uk/objects-and-stories/british-post-war-architecture-modernism-futurism
[Accessed 14 12 2022].

Scott, B., 2020. *Traditional Procurement vs Design & Build: Which One is Better?.* [Online]
Available at: https://urbanistarchitecture.co.uk/traditional-vs-design-and-build/
[Accessed 14 11 2022].

Scottish Government, 2019. *Building standards technical handbook 2019: non-domestic.* [Online]
Available at: https://www.gov.scot/publications/building-standards-technical-handbook-2019-non-domestic/2-fire/2-9-escape/
[Accessed 14 11 2022].

Scottish Government, 2019. *Fire safety standards latest changes.* [Online]
Available at: https://blogs.gov.scot/building-standards/2019/11/01/fire-safety-standards-latest-changes/
[Accessed 04 04 2020].

Sedacca, B., 2010. Verifying safety-critical aerospace and automotive applications. *Engineering and Technology*, 06 September.

Seng, W. & Aminah, Y., 2006. *THE SUCCESS FACTORS OF DESIGN AND BUILD.* Kuala Lumpur, Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference.

Shaba et al, K., 2017. *An introduction to Consequence Modelling,* Nederlands: DNV-GL.

Shafiee, S., K. Marjani Rasmussen, k., Schaffer, E. & Marr Neilson, M., 2022. Application of Expert Systems for Personalizing Financial Decisions. *The proceedings of the design society,* 2(1), pp. 801-810.

Singh et al, J., 2017. Assessment of Failure Mode Effect Analysis in Manufacturing Unit: A Case Study. *The IUP Journal of Operations Management,* 16(4), pp. 7-24.

Soh, C. & Miles, J., 1995. A FRAMEWORK FOR INTEGRATING DATABASES WITH KNOWLEDGE BASES FOR STRUCTURAL ENGINEERING. *Engineering Fracture Mechanics,* 50(5/6), pp. 903-921.

Soloman, R., 2020. *Top 3 benefits of using Revit Vs AutoCAD,* Wakefield: First in Architecture.

Sowards, D., 2013. Quality is key to Lean's success. *Contractor Magazine*, 13 5.

Stanford University, 2021. *Pragmatism.* [Online]
Available at: https://plato.stanford.edu/entries/pragmatism/

Steen-Hansen, A., Storesund, K. & Sesseng, C., 2021. Learning from fire investigations and research – A Norwegian perspective on moving from a reactive to a proactive fire safety management. *Fire Safety Journal,* Volume 120.

Strong, G., 2020. *RICS response to MHCLG building safety announcement.* [Online]
Available at: https://www.rics.org/uk/news-insight/latest-news/press/press-releases/rics-response-to-mhclg-building-safety-announcement/
[Accessed 04 April 2020].

Stuart, K., 2021. *Game Builder Garage review – Nintendo lets you loose on its building blocks.* [Online]
Available at: https://www.theguardian.com/games/2021/jun/16/game-builder-garage-review-nintendo-lets-you-loose-on-its-building-blocks
[Accessed 20 11 2022].

Sun, J., Hu, L. & Zhang, Y., 2013. A review on research of fire dynamics in high-rise buildings. *THEORETICAL & APPLIED MECHANICS LETTERS,* Volume 3.

Swaddle, P., 2021. *Construction Specifications: Everything you need to know.* [Online]
Available at: https://www.thenbs.com/knowledge/construction-specifications-everything-you-need-to-know#:~:text=A%20construction%20specification%20is%20a,which%20evolves%20

across%20a%20project.
[Accessed 13 October 2022].

Takao, W., 1989. Development of Design System For Building Fire Safety.. *Fire Safety Science 2,* Volume 2, pp. 881-895..

Timber frame fires, 2020. *Time for rethink on housing above two storeys and care homes.,* London: timberframefires.co.uk.

Tofiłoa, P. et al., 2013. *Expert System for Building Fire Safety Analysis and Risk Assessment.* Warsaw, Procedia Engineering.

Torero, J., 2011. Fire-induced structural failure: the World Trade Centre, New York.. *Forensic Engineering,* 164(FE2), pp. 69-77.

Tower blocks UK, 2020. *Major fires in the UK since 2019,* London: Towerblocksuk.com.

TQS, 2020. *Value Engineering – The QS' most important job?.* [Online]
Available at: https://thequantitysurveyor.com/value-engineering-the-qs-most-important-job/
[Accessed 20 10 2022].

UK Government, 2005. *The Regulatory Reform (Fire Safety) Order 2005.* [Online]
Available at: https://www.legislation.gov.uk/uksi/2005/1541/contents/made
[Accessed 14 11 2022].

UK Government, 2015. *The Construction (Design and Management) Regulations 2015.* [Online]
Available at: https://www.legislation.gov.uk/uksi/2015/51/introduction/made
[Accessed 14 11 2022].

UKEssays, 2018. *Modern Methods of Construction (MMC) Benefits.* [Online]
Available at: https://www.ukessays.com/essays/construction/drivers-and-barriers-of-modern-methods.php
[Accessed 19 May 2020].

UKGBC, 2016. *climate change.* [Online]
Available at: https://www.ukgbc.org/climate-change/
[Accessed 24 February 2021].

UKGBC, 2022. *Climate change.* [Online]
Available at: https://www.ukgbc.org/climate-change-2/
[Accessed 30 05 2022].

Urbanowicz, R., 2011. *Lecture 11: Rules and Introduction to Expert Systems,* Pennsylvania: URBS-lab.

Valra, A., Madeddu, D., Chiappetti, J. & Farina, D., 2020. *The BIM Management System: A Common Data Environment Using Linked Data to Support the Efficient Renovation in Buildings.* Digital conference due to global pandemic, sustainableplaces.eu.

Visirule, 2021. *Visirule.* [Online]
Available at: https://www.visirule.co.uk/
[Accessed 11 05 2021].

Waite, R. & Tether, B., 2021. *Full AJ100 rankings: Foster + Partners tops league of UK's largest practices again.* [Online]
Available at: https://www.architectsjournal.co.uk/news/full-aj100-rankings-foster-partners-tops-league-of-uks-largest-practices-again
[Accessed 22 10 2022].

Walch, K., 2020. AI Transforming The Construction Industry. *Forbes*, 6 June.

Wall, J. & Ahmed, V., 2006. Delivering continuing professional development for construction management using e-learning. *Researchgate,* Volume 2, pp. 801-809.

Wang et al, J., 2006. Evaluation of CFD Modeling Methods for Fire-induced Airflow in a Room. *Fire Sciences,* 24(5), pp. 393-411.

Watts, G., 2020. *CIC Response to Review of the ban on the use of combustible materials..* London: Construction Information Council.

Watts, G., 2020. *Setting the bar - A new competence regime for building a safer future..* London: Competence steering group for building a safer future.

Woodhead, R., Stephenson, P. & Morray, D., 2018. Digital construction: From point solutions to IoT. *Automation in Construction,* Volume 93, pp. 35-46.

Worldometers, 2021. *World population.* [Online]
Available at: https://www.worldometers.info/world-population/#:~:text=The%20current%20world%20population%20is,currently%20living)%20of%20the%20world.
[Accessed 24 February 2021].

Yanfu, Z. et al., 2022. Artificial Intelligence tool for fire safety design (IFETool): Demonstration in large open spaces. *Case Studies in Thermal Engineering.*

Yehia, S., Abudayyeh, O., Abdel-Qader, I. & Ammar Zalt, 2007. *Evaluation of Sensor Performance for Concrete Applications.* Sharjah, Researchgate.

Yoganarasimhan, H., Barzegary, E. & Pani, A., 2021. *Design and Evaluation of Optimal Free Trials.* Washington, University of Washington, pp. 1-30.

Zalosh, R., Gandhi, P. & Barowy, A., 2021. Lithium-ion energy storage battery explosion incidents. *Journal of Loss Prevention in the Process Industries,* 72(104560).

Zwass, V., 2016. *Expert system.* [Online]
Available at: https://www.britannica.com/technology/expert-system
[Accessed 16 October 2021].

Appendix A. Peer review survey and interview responses.

Architect
Associate Architect and BIM Manager, Franklin Ellis Architects

Fire safety in construction questions:

What are your thoughts on current fire safety regulations today?

- Improving with the building safety bill. Deregulation played a part in the Grenfell disaster, as did the slowness to update regulations and outdated terms such as ‘class 0’. The new regulatory regime will be better.

What are your thoughts on current fire testing procedures and standards today?

- Previously inadequate, improving now.

In respect to testing of construction materials for reaction and resistance to fire. Would you agree or disagree that testing is not fully affective in relation to systems, which typically are made up of individual products?

- Yes, the tests only review certain scenarios which are seldom replicated completely on site.

Currently Fire Safety Engineering processes (i.e., To BS 7974) are typically applied to commercial buildings of a complex nature. Do you think that Fire Safety Engineering approaches should be applied to buildings of all types? If yes, why?

- No. I prefer prescriptive regulations.

Do you think that the current building regulations go far enough with respect to fire safety? Give explanation.

- I believe the building safety bill goes far enough.

Do you think the industry would benefit from bench marking process to assess fire safety design in buildings?

- Yes, systematic benchmarked assessments would be an improvement.

Can you share any experience where robust application of processes may have resulted in greater fire safety design?

- No

Can you share any experience where best practice design was implemented?

- No

Do you foresee digital technology assisting better fire safety design in the future?

- Absolutely. Compliance tracking, data capture and retention, parameterizing of regulations to enable automatic assessment etc.

What developments may assist this?

- As above

Do you foresee offsite manufacture addressing any current issues with fire safety design?

- No

Whom on any given project do you feel should be responsible for ensuring fire safety design parameters are met?

- The whole design team, building control. It's a joint enterprise.

Do you think that more training/continual professional development is required broadly across the industry to improve the benchmark of fire safety design?

- Yes

Finally, what in your opinion is the most fundamental change needed in the construction industry to make buildings safer?

- Better compliance tracking and recording

Proof of concept questions:

Are you familiar with knowledge base/expert systems?

- Yes

Can you give an example of a best practice knowledge base/expert system?

- NHS symptoms system

Do you think that a knowledge base system for fire safety design would be a benefit to the industry?

- Yes. A very simple one could produce a customised digital subset of the approved documents that apply to a particular project, thus enabling better compliance tracking. Going further the system could evaluate compliance with these requirements from user inputs or even from parameters in a bim model.

What is your opinion on the proof-of-concept expert system proposal demonstrated?

- Has great potential to develop into a commercial system or a tool for assisting in regulatory compliance checking?

Where do you think that the proposal could be improved upon / changed?

- Extend it to all approved documents – at least in terms of creating the subset of the approved documents that apply to a particular project.

Do you foresee any issues with a knowledge base system for fire safety design?

- Iteration and development of the design are the biggest challenge. A design is never really completed (although the bsb may change that with gateway 2 signoffs). Best to pitch the assessment at gateway 1 and particularly gateway 2 submissions as the major assessment stages. Questions may be too broad and require detailed answers which are not yes or no (or the knowledge base behind the system is not expert enough to determine compliance)

When considering software that may aid fire safety design, would integration into an existing platform be seen as more beneficial than a new standalone platform?

- Integration with NBS chorus specifications and bim model platforms like Revit, ArchiCAD and Vectorworks

Anything else you would like to add?

- There are 4 ways this system could develop.

1. a tool to produce a customised digital subset of the approved documents that apply to a particular project.
2. a compliance tracker that can be used in a tabular format, but also with a gateway assessment dialog-box interface for use either by the design team or building control.
3. a report builder for use by the design team to prepare a submission report for building regulations to the building control body – e.g., by assisting in adding relevant regulatory parameters and values to a digital specification (e.g., NBS chorus) or by producing a separate building regs submission report.
4. a system to parameterize the approved documents with a view to be able to put these parameters into a bim model, and thus digitally assess compliance, either by the design team, a specialist assessor, or by building control.

- Try and establish what central government / the building safety regulator are producing by way of a compliance tracker, to avoid overlap.

Architectural technologist

Architectural Technologist, NBS

Fire safety in construction questions:

What are your thoughts on current fire safety regulations today?

- Unanswered

What are your thoughts on current fire testing procedures and standards today?

- Through many conversations with manufacturers, the cost of testing products is the biggest barrier to having certifications for all their portfolio.

In respect to testing of construction materials for reaction and resistance to fire. Would you agree or disagree that testing is not fully affective in relation to systems, which typically are made up of individual products?

- Completely agree. If you factor in different installation scenarios, site locations, system build up permutations and associated testing cost, only the very largest product manufacturers have the resources to test on the masses.

- As with all systems, execution (installation) will have an impact on fire performance. You just need to read the press on quality of UK housing to understand there is an issue in UK.

Currently Fire Safety Engineering processes (i.e., to BS 7974) are typically applied to commercial buildings of a complex nature. Do you think that Fire Safety Engineering approaches should be applied to buildings of all types? If yes, why?

- Completely agree that any processes or regulations should apply to all buildings. If there is a risk to life, there should be an equal importance whether I am sat in my home study or at my office desk working.

Do you think that the current building regulations go far enough in respect to fire safety? Give explanation.

- Unanswered.

Do you think the industry would benefit from bench marking process to assess fire safety design in buildings?

- Benchmarking tends to provide a minimum acceptance which is a good starting point, but I always want to see organisations going above and beyond = quality.

Can you share any experience where robust application of processes may have resulted in greater fire safety design?

- Unanswered.

Can you share any experience where best practice design was implemented?

- Unanswered.

Do you foresee digital technology assisting better fire safety design in the future?

- The benefits of digital technology are plain to see, such as the implementation of BIM in the UK. As with all technology, it takes time for the industry to buy into new ways of working but if we can change processes and move towards a digital collaborative approach, technology has an opportunity to use this information in much more intelligent ways and removes the potential for human error.

What developments may assist this?

- As alluded to above, what value can we place on Information? The choices we make are generally based upon what we have read, but does this decision process always get recorded? The result will be recorded in the form of specification for example, but how did you get to that conclusion?

Do you foresee offsite manufacture addressing any current issues with fire safety design?

- Offsite construction would certainly improve the quality aspect, but there are still testing issues etc.

Whom on any given project do you feel should be responsible for ensuring fire safety design parameters are met?

- I do believe there is still a ‘blaming culture’ within UK construction and there should be a defined responsibility matrix for all stakeholders to contribute. Each of them do play a role in providing a duty of care and therefore should be a collective responsibility.

Do you think that more training/continual professional development is required broadly across the industry to improve the benchmark of fire safety design?

- All stakeholders have an obligation to keep up to date in my opinion. If I wanted to buy a new TV, I would research what the best screen resolution was, or if I wanted to buy a car, I would look at which manufacturer has the best electric mileage per charge etc.
- The construction industry is a consumer of goods in the masses and is no different. Everybody needs to keep up to date, it’s how we learn and improve as humans.

Finally, what in your opinion is the most fundamental change needed in the construction industry to make buildings safer?

- Buy in form all stakeholders. Everybody has a responsibility to build better and build safer and ultimately achieve the same goal. If the human emotional element played a greater part, it what we build, I would like to think the gift of life is seen as far greater than the cost of bricks and mortar. I genuinely believe most people think like this so why don’t elevate its importance? Is it because we instinctively separate our personal and business interests? Maybe.

Proof of concept questions:

Are you familiar with knowledge base/expert systems?

- Very basic knowledge such as online fault finding tools or booking online doctors’ appointments and working through symptoms.

Can you give an example of a best practice knowledge base/expert system?

- I am involved with looking into how digital geometric building elements could be classified according to a series of questions. As a very simple example
- Is the pipe below Elevation 0 (ground level)?
    - Yes = Pr_65_52_07 Below-ground drainage pipes and fittings
    - No = Pr_65_52_03 Above-ground drainage pipes and fittings

Do you think that a knowledge base system for fire safety design would be a benefit to the industry?

- I believe any form of automation is of real benefit and doesn't need to stop at fire safety!

What is your opinion on the proof of concept expert system proposal demonstrated?

- Really like the concept, it's great to see how information is being utilised and used for improvement purposes.

Where do you think that the proposal could be improved upon / changed?

- There is a reliance on information to be formatted correctly for the purposes of computer reading. This is easily rectified by introducing standardised selection criteria in the first instance.
- I would also note that is the information is being pulled from design models for example, there needs to be a defined Level of Information (LOI) as part of the Employers Information Requirements (EIRs).

Do you foresee any issues with a knowledge base system for fire safety design?

- There is always a degree of apprehension when relying on questions sets to arrive at an outcome. It can take one incorrect interpretation of a question to arrive at a completely different outcome.

When considering a software that may aid fire safety design, would integration into an existing platform be seen as more beneficial than a new standalone platform?

- One solution fit all is the dream, but in reality, we already see many technological issues to overcome with the number of different design software's in today's construction world. One common denominator exits in the form of Ifc and is seen as the 'holy grail' of interoperability and would be an interesting avenue to explore. It still requires a manual output before export, but this could be where validation rules are bolted on. The web could also be the neutral platform where no export is required but instead is plugged into proprietary software and information fed into the cloud.

Anything else you would like to add?

- Unanswered.

Facilities Manager
Home Group Housing Association

FM specific Interview:

As a facilities manager, what information do you find difficult to obtain in relation to the assets within your building?

- A comprehensive lifecycle schedule that includes all assets. The O&M has everything as an individual item and there's nothing joined up.

What are the key pieces of information you need in relation to the buildings design and specification to conduct your role?

- I need to know how to maintain each item in accordance with recognised compliance, so I don't have to research each asset.

Have changes to fire safety regulations impacted FM in recent years?

- Yes. There is always a battle between compliance and reasonable day to day operations. For example, if I wanted to store paints on site, they'd have to be out of the main core of the building (but a basement is never the best place) correctly labelled, in a metal cupboard, locked away, with only specific people having access, I have to prove who has got keys, who had access, when the keys were last signed out etc. For a maintenance person to do this extends the task quite a bit if they were only touching up one area. It's also sometimes complicated to know what can/cannot be stored together. FM are practical people not chemical experts.

Are there any specific moments that you can recall where fire safety would have benefited from improved decision making?

- Senior mgmt. rarely sees the importance of basic fire safety when inductions for new staff are needed and people knowing where the exits are and the muster point. It's the same as H&S, fire safety is everyone's responsibility, but people rarely see it as such. Having a robust policy from the top down and more transparency of risks and responsibilities would go a long way. I've lost count of the amount of blocked fire exits I've seen over the years with the typical response 'oh I just put it there because there was nowhere else' or 'its ok its getting collected at the end of the week so it's best left close to the external door'. I see that as a stern conversation to have but others see it as a misdemeanour. Another recent scenario was for a new building and a living wall. We procured it and only at the last minute did anyone think to check the product fire rating. Not only did it fail it had no fire rating at all. I would have expected this to be part of the specification of the building, but it seemed to be an afterthought.

Having seen the FSES do you think that having the log of all material specifications and the reasons that they were specified will be beneficial for future maintenance?

- Absolutely. Depending on the FM role and the size of the business we can't be experts at everything, but many FM's are the jack (or Josephine!) of all trades and master of non. Its only when you work for a very large company that FM's will have a specific area of expert knowledge for example electric, mechanical or plumbing.

Do you think that the building owner would feel more re-assured knowing that the design and construction had been assessed in this way?

- Yes, I do. I think that as building design evolves the gap between form and functionality increases and whilst the architects probably feel their creative side is being supressed for functional reasons the FM's are having to come up with creative ideas to maintain concepts that don't work in the real world. The balance of who wins those arguments shifts with each new building. Current example – fabric curtains to block off areas of office and provide a little privacy cover fire exit signs when curtains are fully extended so we now have to think of a way around it as the architect wants the curtains but doesn't want to hear about the fire safety element. They look at form not functionality.

Do you see any other benefits? i.e., insurance or anything else?

- Yes, I think knowing that a building has been thoroughly reviewed at the design stage as well as the as built stage (in the form of a fire risk assessment) would help the architect with their design features and the FM can have confidence knowing that the designs have been through a thorough assessment before the construction phase. Insurance, future proofing of the asset and lifecycle all play a part too.

Would you see benefit in the FSES being kept updated during the buildings use? i.e., when materials are replaced?

- Yes. You can't keep using the as built info indefinitely.

Anything additional to add?

- Nope I think that's all my views above. Hope it's of some help.

Manufacturer
Technical Director and Technical Services Engineer, Kingspan Insulated Panels

Can you explain briefly what the benefits are to rain screen cladding systems?

- Light weight finish – low weight brick. Cavity prevents moisture buildup. Easier to design cavity. Unlimited finishes. Fast build speed. Less materials, cost, waste. Easily replaced to refurb later down the line.
- Aesthetic allows more contemporary design.
- Ventilated. No way moisture can get trapped or condensation. Providing well designed.
- NHBC resistant to face sealed.

What is the most common misconception with rain screen cladding?

- People believe it to be fully watertight and it's not. It is ventilated. People don't think they need a breather membrane.

- Structure is often overlooked when designing. Cavity consideration to vent moisture.

When designing a rain screen cladding system / cavity barrier details, what are the most common pit falls designers make when including these details within their designs?

- Overlooking structure.
- Where responsibility lies for cavity barriers. Drawings marked up with red lines. Cladding installer gets left holding baby.

When installing a rain screen cladding system / cavity barrier details, what are the most common pit falls contractors might make during install?

- Need to keep cavity barriers continues. Allowing mullions to run through.
- Understanding different system types.
- Ad hoc fixtures on site.
- Wider range of cavity barriers now available to cover depths. Depths can be more expansive.
- Vertical seem to be fixed states. Horizontal are open state.
- Cavity depths seem to become deeper in designers details but not known why.

What are the most obvious factors to consider within a rain screen cladding system? i.e., additional materials/products that interact with the system and how they may impact overall performance.

- Weather, thermal performance. Interaction with other products/systems could cause issues to arise. If not co-ordinated fully.
- SFS deflection movement joints. Deflection heads at Slabs.
- Thermal calcs at early stage make assumption of ‘helping hand’ system. Brackets that attach to the SFS system and go through the insulation point. Bracket frequency is not factored in. Aluminium increases heat dissipation. Some new ones have polyamide break in them.

What advice would you give to designers considering using rain screen cladding systems?

- Read up on local legislation.
- CWCT regulations – extensive check list, have I considered this.
- Make sure product is suitable, consult manufacturer.
- Don’t spec cassette sizes that cannot be made.

In respect to the current building regulations, in particular ADB. What are your thoughts on how robust these are?

- Doc B is very clear, particularly for reaction to fire.
- Junctions to external wall with internal compartment walls is not clear. ‘Maintained to external facing’ is not a clear requirement.

- What material cavity barriers should be is not covered.
- 2019 amends is much clearer.
- Cavity barrier section is still slightly misleading. Particularly with respect to material. 0.5 metal can't achieve thermal requirements.
- If opening is passing through a stud wall, this could potentially be the stud or a piece of 0.5 metal. Rainscreen should be purpose design cavity barrier.

Do you agree or disagree that the building regulations are easy for designers to follow when considering fire safety?

- ADB are straight forward over flame spread. Reliance on diagram in previous iteration was not clear, where is showed class 0. Other parts are quite complicated.
- Unprotected areas.

Are you familiar with the term expert system? i.e., a software programme that asks questions to ensure rules are followed to achieve a desired outcome.

- No

Do you think that designers would benefit from access to an expert system when reviewing fire safety design?

- Yes – would like to see how logic works around table 12.1.1.

What do you think may be a negative in using an expert system?

- Cannot think of anything of top of head

Software Developer
Director, NBS

Are you familiar with knowledge base/expert systems?

- Knowledge base yes, expert no.

Can you give an example of a best practice knowledge base/expert system?

- NBS Chorus is a knowledge base. CAWS is static however uniclass is in early stages of potentially becoming an 'expert system' as it has drop down selection and could filter clauses dependant on previous responses. This could have a lot of potential for product selection, i.e., if you set performance then it only shows you suitable products and systems.

Do you think that a knowledge base system for fire safety design would be a benefit to the industry?

- Unanswered.

What is your opinion on the proof-of-concept expert system proposal demonstrated?

- Unanswered.

Where do you think that the proposal could be improved upon / changed?

- What prelim questions do clients put to designers etc.?
- On BIM demo add room location and door ref, possibly update doors by colour and show visually by switching off other types.
- BIM screen grab for KBS wireframe, use larger screen and show it alongside Chorus spec to remove silos.
- On Chorus slides use hyperlinks (or chips) to the relevant clauses in the spec.

Do you foresee any issues with a knowledge base system for fire safety design?

- Unanswered.

When considering a software that may aid fire safety design, would integration into an existing platform be seen as more beneficial than a new standalone platform?

- Yes, e.g., NBS Chorus

Anything else you would like to add?

- No

Invitation to interview letter

Dear [ADD NAME]

I am conducting a research project as part of my PhD research project into the golden thread of information and fire safety in building design. I would be extremely grateful based on your experience, if you would be prepared to answer a few questions relating to this industry topic and my research.

The survey/Interview [deleted where appropriate] should take no longer than 15 minutes. Your valuable time is greatly appreciated.

Kind Regards,

Lee Jones

PhD candidate

University of Derby

Informed consent form

Dear [ADD NAME]

Thank you for accepting the invitations to partake in this survey/interview [DELETE WHERE APPROPRIATE]. In line with GDPR regulations please find below information as to how your data will be handled.

- Participant's name and profession will be kept until the research project has been completed and PhD has been attained. Expected 12-24 months.
- Participant's details will be held securely and will subsequently be deleted safely once the PhD has been attained.
- All responses will be held until PhD has been attained, though some responses will likely be published as part of the thesis publication to achieve PhD.
- The participant reserves the right to remove their details from file at any time through written request.
- The participant reserves the right to be removed from the research project at any time prior to publication of thesis through written request.

Please confirm that you are ok with the above by response email.

Thank you again for agreeing to partake in this survey.

Kind Regards

Lee Jones

PhD candidate

University of Derby

Participant information sheet

This survey/interview relates to a research project conducted via the University of Derby titled - The Golden Thread of Information and Fire Safety in Construction: Making our buildings safer through the development of a Robust Design Strategy and BIM Framework Integration.

The research intends to critically evaluate current methodology, standard and regulations in respect to fire safety design within the construction industry.

The aim of the research is to develop a robust application for assisting fire safety design.

All questions conducted via survey or interview will be focussed solely on the subjects of architectural design in relation to fire safety and digital technologies that enable improved processes within industry.

All information will be handled in line with GDPR regulations of which details can be found within the participant consent form.

For any further information or requests in respect to the research, survey or how your data will be handled, please contact myself directly with clear detail as to your query. I will aim to respond to your enquiry within 48 hours.

Kind Regards

Lee Jones

PhD candidate

University of Derby

Participant debriefing information

Thank you for taking the time to contribute to this research project. The survey/interview relates to a research project conducted via the University of Derby titled - The Golden Thread of Information and Fire Safety in Construction: Making our buildings safer through the development of a Robust Design Strategy and BIM Framework Integration.

A copy of the questions and your responses can be made available upon request should you wish.

The responses to the survey/interview may likely be published within the thesis of this research. Should you wish to remain anonymous or be removed from the project at any time prior to publication, please contact myself directly? All information will be handled professionally and will only be used in contribution to the research project.

All information will be handled in line with GDPR regulations of which details can be found within the participant consent form.

For any further information or requests in respect to the research, survey or how your data will be handled, please contact myself directly with clear detail as to your query. I will aim to respond to your enquiry within 48 hours.

Kind Regards

Lee Jones

PhD candidate

University of Derby

Appendix B. Rainscreen cladding full specification

Systems

Ss_25_20_70_65 Pressure equalized rainscreen cladding systems

9. Description: PhD Project Cladding Example
10. System manufacturer: Varies.
11. Thermal insulation: Pr_25_57_06_56 Mineral wool slab insulation
12. Breather membrane
    - 12.1. Material: Pr_25_57_10_94 Vapor permeable sheets
    - 12.2. Fasteners: Pr_20_29_56_12 Carbon steel wire nails
13. Secondary support structure: Pr_20_85_07_10 Carbon steel carrier rails
14. Cavity fire barriers: Pr_25_80_80_79 Sleeved mineral wool cavity barriers Vertical barriers; Pr_25_80_80_79 Sleeved mineral wool cavity barriers Horizontal barriers
15. Cladding panels
    - 15.1. Material: Ss_25_20_70/320 Custom-made carbon steel panels
    - 15.2. Panel joints: Labyrinth joints.
16. Execution: Ss_25_20_70/625 Assembly and erection: components; Ss_25_20_70/615 Assembly and erection: quality; Ss_25_20_70/620 Assembly and erection: tolerances

Products

Pr_20_29_56_12 Carbon steel wire nails

1. Description: Insulation fixings.
2. Manufacturer: Contractor's choice.
3. Standard: To **BS EN 10230-1**.
4. Nail details
    - 4.1. Form: Round plain head nails.
    - 4.2. Finish coating: Hot dip galvanized.
5. Diameter: 5.0 mm.
6. Length: 140 mm.

Pr_20_85_07_10 Carbon steel carrier rails

1. Description: Cassette carrier rails.
2. Manufacturer: **Steadmans**
3. Contact details
    - 3.1. Address: Warnell
      Welton
      Carlisle

Cumbria
United Kingdom
CA7 5HH

3.2. Telephone: **+44 (0)1697 478277**

3.3. Web: **www.steadmans.co.uk**

3.4. Email: **info@steadmans.co.uk**

4. Product reference: **Bar & Bracket Spacing System**
5. Location: Horizontal, see drawing ___
   Vertical, see drawing ___
6. Brackets, height: 100 mm
7. Rails, length, effective cover: As per fabrication drawings.

Pr_25_57_06_56 Mineral wool slab insulation

1. Description: Cladding insulation slabs.
2. Manufacturer: **Knauf Insulation Ltd**
3. Contact details

3.1. Address: Knauf Insulation
Stafford Road
St Helens
Merseyside
WA10 3LZ

3.2. Telephone: **+44 (0)1744 766 666**

3.3. Web: **www.knaufinsulation.co.uk**

3.4. Email: **technical.uk@knaufinsulation.com**

4. Product reference: **RockSilk® RainScreen Slab BGV**
5. Standard: To BS EN 13162.
6. Thickness: 100 mm.
7. Facing: Tissue faced.
8. Edges: Board.
9. Density: 30–250 kg/m³.
10. Thermal conductivity (maximum): 0.034 W/mK.
11. Compressive strength (minimum): High.
12. Fire performance: Euroclass A1 to BS EN 13501-1.

Pr_25_57_10_94 Vapour permeable sheets

1. Description: Cladding membrane.
2. Manufacturer: **Obex Protection Ltd**
3. Contact details

3.1. Address: Unit 12
Horn Hill Road
Nunnery Park
Worcester

Worcestershire
United Kingdom
WR4 0SX

3.2. Telephone: **+44 (0)1905 337800**
3.3. Web: **www.obexuk.com/**
3.4. Email: **sales@obexuk.com**

4. Product reference: **Cortex 0220FR Class A1 Breather Membrane**
5. Standard: To EN 13501-1.
6. Performance characteristics: Manufacturer's standard.
7. Class (minimum): Class W2.
8. Material: Fiberglass cloth with polymer.
9. Form: Manufacturer's standard.
10. Thickness (minimum): 0.20 ±0.50 mm.
11. Purpose: Water resistant, vapor permeable, A1 fire classification (EN 13501-1).
12. Colour: White.
13. Length x width: 50 000 x 1500 mm.

Pr_25_80_80_79 Sleeved mineral wool cavity barriers Horizontal barriers

1. Description: Horizontal cavity barriers
2. Manufacturer: **Siderise Group**
3. Contact details
    3.1. Address: Forge Industrial Estate
    Maesteg
    Bridgend
    Mid Glamorgan
    CF34 0AH
    3.2. Telephone: **+44 (0)1656 730833**
    3.3. Web: **www.siderise.com**
    3.4. Email: **sales@siderise.com**
4. Product reference: **SIDERISE RH Open State Horizontal Cavity Barriers (formerly Lamatherm CW-RS) (RH25-90/30)**
5. Residual cavity width: 49–425 mm.
6. Fire performance: To EN 13501-1, Class A1; To EN 13501-1, Class E.
7. Thermal Conductivity: 0.038 W/m·K.
8. Fixing brackets: Manufacturers standard.
9. Fire resistance: To ASFP TGD19, EI 90.

Pr_25_80_80_79 Sleeved mineral wool cavity barriers Vertical barriers

1. Description: Vertical cavity barriers.
2. Manufacturer: **Siderise Group**
3. Contact details

3.1. Address: Forge Industrial Estate
Maesteg
Bridgend
Mid Glamorgan
CF34 0AH

3.2. Telephone: **+44 (0)1656 730833**

3.3. Web: **www.siderise.com**

3.4. Email: **sales@siderise.com**

4. Product reference: **SIDERISE RV Vertical Cavity Barriers (formerly Lamatherm CW-RS) (RH25-90/30)**
5. Size: To suit 76-425 mm deep cavity.
6. Fire performance: Integrity (E): 120 minutes; Insulation (I): 90 minutes.
7. Length: 1200 mm.
8. Thermal Conductivity: 0.038 W/m·K.
9. Fixing brackets: Manufacturers standard.
10. Type: Horizontal cavity barriers with galvanized brackets for voids between 76–425 mm.

Pr_35_31_68_66 Powder coatings

1. Description: Panel finish
2. Manufacturer: Kingspan Insulated Panels
3. Standard: **BS EN 13438**.
4. Powder formulation: Suitable for urban environment.

Ss_25_20_70/320 Custom-made carbon steel panels

1. Manufacturer: Kingspan Insulated Panels KS600-1000 AWP.
2. Standards: To relevant parts of BS 1449-1, **BS EN 10048**, **BS EN 10051**, **BS EN 10111**, **BS EN 10131**, BS EN 10132, **BS EN 10139**, **BS EN 10140**, BS EN 10149, **BS EN 10209** and **BS EN 10268**.
3. Reaction to fire: to BS EN 13501–1:2007+A1:2009: B-s1,d0.
4. Thermal conductivity: 0.46 W/m²K.
5. Grade and thickness: Suitable for application, and for galvanizing or other protective coating.
6. Panel type: Cassette.
7. Panel profile: Flat.
   7.1. Thickness: 45 mm.
8. Dimensions: As per detail drawings.
9. Panel finish
   9.1. Coating: Pr_35_31_68_66 Powder coatings
   9.2. Colour: RAL 7001 Grey.
   9.3. Film thickness (minimum): 25 micrometres.

Execution

Ss_25_20_70/615 Assembly and erection: quality

1. Accuracy: As specified in CWCT **Standard for systemised building envelopes**, clause 2.20 for fabrication and erection.
2. Assembly works: Carry out as much assembly as possible in the workshop prior to installation on-site.
3. Joints, other than movement joints and designed open joints: Secure rigidly, reinforce where necessary and fix with hairline abutments.
4. Identification of products: When marking or tagging products to facilitate identification during assembly, handling, storage and installation, do not mark surfaces visible in the completed installation.
5. Protective coverings: *Remove all coverings at completion*.
6. Installation of interfaces: Locate flashings, closers, cavity barriers etc. correctly. Neatly overlap to form a weathertight junction.

Ss_25_20_70/620 Assembly and erection: tolerances

1. Standard: In accordance with the CWCT **Standard for systemised building envelopes**, section 7.
2. General requirements: Accommodate tolerances within the various component parts of the rainscreen system without compromising system performance requirements, e.g., fire and ventilation, etc. Cumulative effect of tolerances should not compromise the integrity and performance of intumescent and fixed cavity fire barriers and other fire-stopping.
3. Accuracy of erection
    - 3.1. Line: ±2 mm of any line expressed by the framing or panels in any one-story height, or structural bay width, and ±5 mm overall.
    - 3.2. Level: ±2 mm of horizontal in any one structural bay width, and ±5 mm overall.
    - 3.3. Plumb: ±2 mm of vertical in any one-story height, and ±5 mm overall.
    - 3.4. Plane: ±2 mm of the principal plane in any one-story height, or structural bay width, and ±5 mm overall.

Ss_25_20_70/625 Assembly and erection: components

1. Secondary support structure
    - 1.1. Secondary support structure arrangement: Vertical and horizontal carrier rails.
    - 1.2. Secondary support fixings: *Hexagon head stainless steel screws*.
2. Cavity
    - 2.1. Width (minimum): *Overall cavity width 50 mm, 25 mm between back of cladding and front edge of cavity barrier*.
    - 2.2. Additional requirements: Install accessories located within the cavity to ensure effective drainage and ventilation, and without compromising the fire performance of the rainscreen cavity.

3. Thermal insulation: Attach to outer face of, or support within, the backing wall so as not to bulge, sag, delaminate or detach during installation or in situ during the life of the rainscreen cladding.
4. Cavity fire barriers: *Locate fire barriers at fire separating walls and floors and around openings and penetrations. Spacing (maximum): 20 m*.
5. Rainscreen panel fixing
   5.1. Panel fixings: Through.
   5.2. Fixing type: Mechanical.
   5.3. Number and position: As per detail drawings.
   5.4. Centres: As per detail drawings.
6. Tightening mechanical fasteners: To manufacturer's recommended torque Figures. Do not overtighten fasteners intended to permit differential movement.
7. Protective coverings: *During erection, remove only where necessary to facilitate installation and from surfaces which will be inaccessible on completion*.

End of Specification

Appendix C. Cladding BIM model data set

Cladding Data Set

COBie	
AccessibilityPerformance	n/a
AssetIdentifier	n/a
AssetType	Fixed
BarCode	n/a
Category	Ss_25_20_14_54: Metal insulating sandwich panel cladding systems
CodePerformance	BS 476: Part 2009, Part 7 1997, BS EN 13501-1:2007 + A1:2009, BS EN 10346:2015, BS EN 10346: 2015, BS EN 10088, BS EN ISO 9001, BS EN ISO 14001, BS EN 14509: 2013, CE certified
Color	Spectrum silver
Constituents	n/a
Description	Architectural wall panel
DurationUnit	Year
ExpectedLife	n/a
Features	Immune from mould, fungi, mildew and vermin, lightweight
Grade	n/a
InstallationDate	31/12/1900 23:59
Manufacturer	marketing@kingspanpanels.com
Material	Steel
ModelNumber	KS600-1000
ModelReference	QuadCoreArchitecturalWallPanel_KS600-1000_60mm
Name	MetalInsulatingSandwichPanelCladdingSystem_QuadCoreArchitecturalWallPanel_KS600-1000_60mm_KingspanInsulatedPanels
NominalHeight	0
NominalLength	17000
NominalWidth	1000
Replacement Cost	n/a
SerialNumber	n/a
Shape	n/a
Size	17000 x 1000 x 60 mm
Sustainability Performance	n/a
TagNumber	n/a

WarrantyDescription	40 year thermal and structural performance warranty, up to 40 year external coating warranty
WarrantyDurationLabor	n/a
WarrantyDurationParts	n/a
WarrantyDurationUnit	year
WarrantyGuarantorLabor	n/a
WarrantyGuarantorParts	n/a
WarrantyStartDate	31/12/1900 23:59
BOS_General	
Author	NBS
BIMObjectName	NBS_KingspanInsulatedPanels_MetalInsulatingSandwichPanelCladdingSystem_QuadCoreArchitecturalWallPanel_KS600-1000_60mm_Horizontal
ManufacturerName	Kingspan Insulated Panels
ManufacturerURL	https://www.kingspan.com/gb/en-gb/about-kingspan/kingspan-insulated-panels
NBSCertification	www.nationalbimlibrary.com/cert/wplkbizw
NBSDescription	Metal insulating sandwich panel cladding system
NBSReference	25-80-52/150
ProductInformation	https://www.kingspan.com/gb/en-gb/products/insulated-panel-systems/wall-panel-systems/quadcore-architectural-wall-ks1000-awp
Revision	n/a
Uniclass2015Code	Ss_25_20_14_54
Uniclass2015Title	Metal insulating sandwich panel cladding systems
Uniclass2015Version	Systems v1.14
Version	2
NBS_Data	
AirLeakage	3m³/hr/m² at 50Pa
Applications	Suitable for vertical or horizontal application
CoreInsulationThickness	60 mm
FixingDetail	Secret-fix
MaxStandardPanelLength	14.5 metres

MinimumPanelLength	1.8 metres
NumberOfPanelsPerPack	18
ProductCompatibility	All profiles integrate with each other as well as with optimo and kingspan day-lite architectural (AWP only)
Profiles	Curvewall, convex, euro-box, flat, flat-stucco, louvre, mini-micro, micro-rib, plank, tramline, wave
SpanningCapability	Longspan - up to 8.2 m, frame to frame
UValue	0.32 W/m²K, 0.28 W/m²K for Curvewall, 0.31 W/m²K for Louvre
Weight	10.3 kg/m², 12.4 kg/m² for Curvewall, 13.0 kg/m² for Louvre
Pset_CoveringCommon	
AcousticRating	24 dB
Combustible	TRUE
Finish	n/a
FireRating	B-s1,d0
Flammability Rating	n/a
FragilityRating	n/a
IsExternal	TRUE
Reference	n/a
Status	UNSET
SurfaceSpreadOfFlame	n/a
ThermalTransmittance	0
Quick links	
COBie	
AccessibilityPerformance	n/a
AssetIdentifier	n/a
AssetType	Fixed
BarCode	n/a
Category	Pr_25_57_06_56:Mineral wool slab insulation
CodePerformance	BS EN 13501-1, BS 2972:1989 Section 12, BS EN 13162, ISO 50001, ISO 9001, ISO 14001, BBA certified
Color	n/a
Constituents	n/a
Description	Earthwool RainScreen BGV Slabs are non-combustible Rock Mineral Wool slabs, manufactured using our revolutionary ECOSE® Technology and a water repellent additive, and are designed for use in rainscreen façade systems both below and above 18m in height

DurationUnit	year
ExpectedLife	n/a
Features	Excellent thermal performance;, Non-combustible A1 Euroclass Reaction to Fire classification;, Excellent sound absorption characteristics provide high levels of sound reduction;, Suitable for use on all buildings including those above 18m in height providing compliance with fire related building regulations;, Contributes to building regulation compliance without reliance on separate testing or desktop studies;, Provides a unique combination of thermal, fire and acoustic performance
Grade	n/a
InstallationDate	12/31/1900 11:59:59 PM
Manufacturer	technical.uk@knaufinsulation.com
Material	Rock mineral wool
ModelNumber	n/a
ModelReference	EarthwoolRainScreenSlab_BGV_100mm
Name	MineralWoolSlabInsulation_EarthwoolRainScreenSlab_BGV_100mm_KnaufInsulationLtd
NominalHeight	100
NominalLength	1200
NominalWidth	600
ReplacementCost	n/a
SerialNumber	n/a
Shape	Rectangular
Size	100 x 1200 x 600 mm
SustainabilityPerformance	Contains no ozone-depleting substances or greenhouse gases
TagNumber	n/a
WarrantyDescription	n/a
WarrantyDurationLabor	n/a
WarrantyDurationParts	n/a
WarrantyDurationUnit	Year
WarrantyGuarantorLabor	n/a
WarrantyGuarantorParts	n/a
WarrantyStartDate	12/31/1900 11:59:59 PM
BOS_General	

Author	NBS
BIMObjectName	NBS_KnaufInsulationLtd_MineralWoolSlabInsulation_EarthwoolRainScreenSlab_BGV_100mm
Manufacturer Name	Knauf Insulation Ltd
Manufacturer URL	www.knaufinsulation.co.uk
NBSCertification	www.nationalbimlibrary.com/cert/1cl4cr4e
NBSDescription	Mineral wool slab insulation
NBSReference	45-45-70/385
ProductInformation	https://www.knaufinsulation.co.uk/products/rock-mineral-wool/earthwool-rainscreen-slab-bgv-black-glass-veil#:~:text=Earthwool%20RainScreen%20BGV%20Slabs%20are,and%20above%2018m%20in%20height.
Revision	n/a
Uniclass2015 Code	Pr_25_57_06_56
Uniclass2015 Title	Mineral wool slab insulation
Uniclass2015 Version	Products v1.18
Version	1
NBS_Data	
Application	Rainscreen facade insulation
AreaPerPack	2.88 m²
AreaPerPallet	34.56 m²
Durability	Odourless, rot proof, non-hygroscopic, do not sustain vermin and will not encourage the growth of fungi, mould or, bacteria
Facing	Faced
ThermalConductivity	0.034 W/mk
ThermalResistance	2.9 m²K/W
Pset_CoveringCommon	
AcousticRating	n/a
Combustible	FALSE
Finish	n/a
FireRating	Euroclass A1 non-combustible
Flammability Rating	n/a
FragilityRating	n/a
IsExternal	FALSE

Reference	n/a
Status	UNSET
SurfaceSpreadOfFlame	n/a
ThermalTransmittance	0

Insulation Data Set

COBie	
AccessibilityPerformance	n/a
AssetIdentifier	n/a
AssetType	Fixed
BarCode	n/a
Category	Pr_25_80_80_79:Sleeved mineral wool cavity barriers
CodePerformance	ASFP TGD19 (prEN 1364-6): șOpen Stateș Cavity Barrier used in External Envelope or Fabric of Buildings
Color	Silver Foil / colour code - Green
Constituents	n/a
Description	Mineral wool with silver foil facing top and bottom and a black facing on one edge
DurationUnit	Year
ExpectedLife	25 Year Product Design Life
Features	25 mm gap for ventilation & drainage in external cavity, fully compliant to latest ASFP & CWCT guidelines
Grade	n/a
InstallationDate	12/31/1900 11:59:59 PM
Manufacturer	sales@siderise.com
ModelNumber	n/a
ModelReference	SIDERISE RH Open State Horizontal Cavity Barriers (formerly Lamatherm CW-RS)
Name	SleevedMineralWoolCavityBarriers_RH25-90-30_SideriseGroup
NominalHeight	75
NominalLength	1200
NominalWidth	425
ReplacementCost	n/a
SerialNumber	n/a
Shape	n/a
Size	n/a
SustainabilityPerformance	Contains no Volatile Organic Compounds (VOCs) and no very Volatile Organic Compounds (vVOCs), Zero Ozone Depleting Potential,Zero Global Warming Potential,Recyclable
TagNumber	n/a
WarrantyDescription	n/a

WarrantyDurationLabor	n/a
WarrantyDurationParts	n/a
WarrantyDurationUnit	Year
WarrantyGuarantorLabor	n/a
WarrantyGuarantorParts	n/a
WarrantyStartDate	12/31/1900 11:59:59 PM
BOS_General	
Author	NBS
BIMObjectName	NBS_SideriseGroup_SleevedMineralWoolCavityBarriers_RH_25-90-30
ManufacturerName	Siderise Group
ManufacturerURL	www.siderise.com
NBSCertification	www.nationalbimlibrary.com/cert/shb5kzam
NBSDescription	Sleeved mineral wool cavity barriers
NBSReference	45-45-70/465
ProductInformation	http://www.siderise.com/applications/products/open-state-cavity-barriers?facades
Revision	n/a
Uniclass2015Code	Pr_25_80_80_79
Uniclass2015Title	Sleeved mineral wool cavity barriers
Uniclass2015Version	Products v1.1
Version	4
NBS_Data	
AirGaps	25mm
FireResistanceRating	90/30 integrity/ insulation to ASFP TGD 19 (prEN 1364-6),
Fixings	3 brackets per length
Sleeves	Green
SuitableForCavityWidth	27-425mm
ThermalRating	λ10 = 0.038 W/mK
ThirdPartyProductCertification	ewcl5 ME 5101 and Intertek WHI20-32944302 iss. 1
Pset_CoveringCommon	
AcousticRating	n/a
Combustible	FALSE
Finish	Aluminium foil tape to top and bottom surfaces
FireRating	90/30 integrity/ insulation to ASFP TGD 19 (prEN 1364-6),
FlammabilityRating	Primary seal Class A1 to EN 13501-1, intumescent Class E to EN 13501-1
FragilityRating	n/a
Material	Stonewool
Reference	n/a

SurfaceSpreadOfFlame	Class A1 to EN 13501-1
TotalThickness	75

Horizontal Cavity Barrier Data Set

COBie	
AccessibilityPerformance	n/a
AssetIdentifier	n/a
AssetType	Fixed
BarCode	n/a
Category	Pr_25_80_80_79:Sleeved mineral wool cavity barriers
CodePerformance	ASFP TGD19 (prEN 1364-6): șOpen Stateș Cavity Barrier used in External Envelope or Fabric of Buildings
Color	Silver Foil / colour code - Green
Constituents	n/a
Description	Mineral wool with silver foil facing top and bottom and a black facing on one edge
DurationUnit	year
ExpectedLife	25 Year Product Design Life
Features	25 mm gap for ventilation & drainage in external cavity, fully compliant to latest ASFP & CWCT guidelines
Grade	n/a
InstallationDate	12/31/1900 11:59:59 PM
Manufacturer	sales@siderise.com
ModelNumber	n/a
ModelReference	SIDERISE RH Open State Horizontal Cavity Barriers (formerly Lamatherm CW-RS)
Name	SleevedMineralWoolCavityBarriers_RH25-90-30_SideriseGroup
NominalHeight	75
NominalLength	1200
NominalWidth	425
ReplacementCost	n/a
SerialNumber	n/a
Shape	n/a
Size	n/a
SustainabilityPerformance	Contains no Volatile Organic Compounds (VOCs) and no very Volatile Organic Compounds (vVOCs), Zero Ozone Depleting Potential,Zero Global Warming Potential,Recyclable
TagNumber	n/a
WarrantyDescription	n/a
WarrantyDurationLabor	n/a

WarrantyDurationParts	n/a
WarrantyDurationUnit	Year
WarrantyGuarantorLabor	n/a
WarrantyGuarantorParts	n/a
WarrantyStartDate	12/31/1900 11:59:59 PM
BOS_General	
Author	NBS
BIMObjectName	NBS_SideriseGroup_SleevedMineralWoolCavityBarriers_RH_25-90-30
ManufacturerName	Siderise Group
ManufacturerURL	www.siderise.com
NBSCertification	www.nationalbimlibrary.com/cert/shb5kzam
NBSDescription	Sleeved mineral wool cavity barriers
NBSReference	45-45-70/465
ProductInformation	http://www.siderise.com/applications/products/open-state-cavity-barriers?facades
Revision	n/a
Uniclass2015Code	Pr_25_80_80_79
Uniclass2015Title	Sleeved mineral wool cavity barriers
Uniclass2015Version	Products v1.1
Version	4
NBS_Data	
AirGaps	25mm
FireResistanceRating	90/30 integrity/ insulation to ASFP TGD 19 (prEN 1364-6),
Fixings	3 brackets per length
Sleeves	Green
SuitableForCavityWidth	27-425mm
ThermalRating	λ10 = 0.038 W/mK
ThirdPartyProductCertification	ewcl5 ME 5101 and Intertek WHI20-32944302 iss. 1
Pset_CoveringCommon	
AcousticRating	n/a
Combustible	FALSE
Finish	Aluminium foil tape to top and bottom surfaces
FireRating	90/30 integrity/ insulation to ASFP TGD 19 (prEN 1364-6),
FlammabilityRating	Primary seal Class A1 to EN 13501-1, intumescent Class E to EN 13501-1
FragilityRating	n/a
Material	Stonewool
Reference	n/a
SurfaceSpreadOfFlame	Class A1 to EN 13501-1

TotalThickness	75

Vertical Cavity Barrier Data Set

COBie	
AccessibilityPerformance	n/a
AssetIdentifier	n/a
AssetType	Fixed
BarCode	n/a
Category	Pr_25_80_80_79:Sleeved mineral wool cavity barriers
CodePerformance	EN1366-4:2006+A1: 2010
Color	n/a
Constituents	n/a
Description	Mineral wool with silver foil facing top and bottom
DurationUnit	year
ExpectedLife	60 Year Product Design Life
Features	Accommodates façade movement
Grade	n/a
InstallationDate	12/31/1900 11:59:59 PM
Manufacturer	sales@siderise.com
ModelNumber	n/a
ModelReference	SIDERISE RV Vertical Cavity Barriers (formerly Lamatherm CW-RS)
Name	SleevedMineralWoolCavityBarriers_RV-90-30_SideriseGroup
NominalHeight	75
NominalLength	1200
NominalWidth	450
ReplacementCost	n/a
SerialNumber	n/a
Shape	n/a
Size	n/a
SustainabilityPerformance	Contains no Volatile Organic Compounds (VOCs) and no very Volatile Organic Compounds (vVOCs), Zero Ozone Depleting Potential,Zero Global Warming Potential,Recyclable
TagNumber	n/a
WarrantyDescription	n/a
WarrantyDurationLabor	n/a
WarrantyDurationParts	n/a
WarrantyDurationUnit	Year
WarrantyGuarantorLabor	n/a

WarrantyGuarantorParts	n/a
WarrantyStartDate	12/31/1900 11:59:59 PM
BOS_General	
Author	NBS
BIMObjectName	NBS_SideriseGroup_SleevedMineralWoolCavityBarriers_RV_90-30
ManufacturerName	Siderise Group
ManufacturerURL	www.siderise.com
NBSCertification	www.nationalbimlibrary.com/cert/c5zish0u
NBSDescription	Sleeved mineral wool cavity barriers
NBSReference	45-45-70/465
ProductInformation	https://www.siderise.com/products/facades/vertical-cavity-barriers-cladding
Revision	n/a
Uniclass2015Code	Pr_25_80_80_79
Uniclass2015Title	Sleeved mineral wool cavity barriers
Uniclass2015Version	Products v1.1
Version	4
NBS_Data	
CertifiedEffectiveLifeMinimum	n/a
Depth	75
EvidenceOfCompliance	n/a
FireResistanceRating	90/30 integrity/ insulation to EN1366-4:2006+A1: 2010
Fixings	2 brackets per length
RecycledContent	20-30%
ThermalRating	$\lambda 10$ = 0.038 W/mK
ThirdPartyProductCertification	ewcl5 ME 5101 and Intertek WHI20-32944302 iss. 1
WidthRange	26-450 mm
Pset_CoveringCommon	
AcousticRating	n/a
Combustible	FALSE
Finish	Aluminium foil to surfaces exposed to cavity
FireRating	90/30 integrity/ insulation to EN1366-4:2006+A1: 2010
FlammabilityRating	Class A1 to EN 13501-1
FragilityRating	n/a
Material	Stonewool
Reference	n/a
SurfaceSpreadOfFlame	Class A1 to EN 13501-1
TotalThickness	75

Table 5 - Cladding system BIM data. (Source: Author)

Appendix D. FSES logic development templates

Project and Assessment details	
1)	**Name of Project**
2)	**Site Location**
3)	**What best describes your role within this project?**
a	Principal Fire Safety Engineer
b	Other Fire Safety engineer
c	Architect
d	Member of the design team
e	Operational Manager
f	Services engineer
g	Structural engineer
h	Fire Authority
i	Approvals body
j	Insurer
k	Contractor
l	Client
m	Other (Please specify)
4)	**Please list the name of your organisation**
Qualitative Design Review	
QDR Stages	
A	Architectural Design and Material Selection Review
B	Functional Objectives for Fire
C	Fire hazards and possible consequences
D	Trial FSE Designs
E	Acceptance criteria
F	Method of analysis
G	Fire scenarios establishment
H	Documentation
Architectural Design and Material Selection Review	-
A	**Building Characterization**
A1	Number of storeys (above and below ground)
A2	General dimensions
A3	Nature of construction
A4	Geometry and interconnection of spaces
A5	Internal subdivision of building

A6	Normal circulation routes
A7	Escape routes
A8	Wall and ceiling linings
A9	Provision for dispersal of people from vicinity of building
A10	Possible fire and smoke spread routes
A11	Proposed fire detection and alarm system
A12	Location relative to other buildings or site boundary
A13	Planning constraints (e.g., listed building of historical interest)
A14	Any other factors (that may influence FSE)
B	**Fire Hazards**
B1	Unusual fire hazards (e.g., Flammable liquids stored in offices)
B2	Potential ignition sources
B3	Combustible contents and structure
B4	Fire load density
B5	Any other factors (that may influence FSE)
C	**Environmental Influences**
C1	Ambient noise levels
C2	Any other factors (that may influence FSE)
D	**Occupant characterization**
D1	Number and distribution
D2	Single or multiple tenancy of use
D3	Mobility, vulnerability and need for assistance
D4	State of wakefulness
D5	Familiarity with the building
D6	Social groupings
D7	Roles and responsibilities of key individuals
D8	Commitment to an activity (e.g., eating in a restaurant)
D9	Presence of a focal point (e.g., Stage)
D10	Any other factors (that may influence FSE)
E	**Management of Fire Safety**
E1	Quality and extent of continuing management control
E2	Number of people on site responsible for the fire safety management
E3	Staff to occupant ratio
E4	Level of fire safety training
E5	Security arrangements which might conflict with evacuation strategy
E6	Level of control over work on site (e.g., hot works)
E7	Level of planning and adaptability for changes to risk on site

E8	Level of knowledge and understanding to implement the fire safety strategy
E9	Contacts for provision of additional information
E10	Any other factors (that may influence FSE)
F	**Fire Fighting**
F1	Fire and rescue service response time
F2	Access for fire appliances
F3	Fire-Fighting access to, safety within and safe egress from the building
F4	Water supplies
F5	Any other factors (that may influence FSE)
G	**Other requirements**
G1	Future changes of layout or changes that might be anticipated
G2	any commercialisation of the space (e.g., mall areas)
G3	Fire protection systems specified by the client (e.g., sprinklers for loss control)
G4	Any other factors (that may influence FSE)
G5	Impact of fire on business continuity as set out in a business impact analysis (BIA) if available

Table 6 – Draft QDR FSES overview page (source: Author)

A10 Possible fire and smoke spread routes

A10.1 Smoke control

A10.1.1 Smoke control for means of escape — As per BS 9991 section 14.1

Whilst the primary aim of smoke control in residential buildings is to protect the staircase enclosure, it can also provide some protection to the adjacent protected corridor or lobby. In extended corridors, the primary objective of the smoke control system is to protect both the common corridor and the staircase enclosure for means of escape. There are three main methods of smoke control: natural smoke ventilation, mechanical smoke ventilation and pressurization.
See Diagram C.7 in the Building Regulations 2010, Approved Document B [14] regarding the free area of smoke ventilators.

	Questions	Notes	Standards compliance
1	Is the building designed to have a 'stay put' strategy?		As per Section 14.1.1 of BS 9991

	Yes	additional protection to the staircase should be provided in the form of a smoke control system. The smoke control system within residential buildings should be located such that it is maintainable from the common parts of the building.	
	No	Proceed to question 4.	

2	Does the Building have a smoke control system?		As per Section 14.1.1 of BS 9991
	Yes	Provide evidence and list any manufacturer systems and uniclass reference	
	No	Design amendments required. Additional protection to the staircase should be provided in the form of a smoke control system.	

3	Is the Smoke control system maintainable from the common parts of the building?		As per Section 14.1.1 of BS 9991
	Yes	Provide evidence and tag drawing/model details.	
	No	Design amendments required. The smoke control system within residential buildings should be located such that it is maintainable from the common parts of the building.	

Optional questions for buildings below 11m height and with a max 3 stories:			
4	Does the building have a single stair and common lobby approach to any separate dwellings within the building?		As per section 14.1.2 of BS 9991
	Yes	Provide evidence and tag drawing/model details.	
	No	Proceed to question 7.	

5	Does the building have an openable vent having a minimum free area of 1 m2, that is inserted at the highest level practicable at each floor level within the staircase?		As per section 14.1.2 of BS 9991
	Yes	Provide evidence and list any manufacturer systems and uniclass reference	

	No	Proceed to question 6.	
6	Does the building have an openable vent having a minimum free area of 1 m2 at the top of the staircase that can be remotely operated at fire and rescue service access level.		As per section 14.1.2 of BS 9991
	Yes	Provide evidence and list any manufacturer systems and uniclass reference	
	No	Design amendments required. The building should have either: 1) an openable vent having a minimum free area of 1 m2, that is inserted at the highest level practicable at each floor level within the staircase; **or** 2) an openable vent having a minimum free area of 1 m2 at the top of the staircase	
7	Does the building have a single stair and no common lobby?		As per section 14.1.2 of BS 9991
	Yes	Proceed to Question 8.	
	No	Please give details if answers to questions 4 & 7 were both no.	
8	Does the building have an AOV (Automatic Opening Vent) with a minimum free area of 1 m2 at the top of the staircase that operates on detection of smoke anywhere within the staircase enclosure?		As per section 14.1.2 of BS 9991
	Yes	Provide evidence and list any manufacturer systems and uniclass reference	
	No	Design amendments required. The building should have an AOV (Automatic Opening Vent) with a minimum free area of 1 m2 at the top of the staircase that operates on detection of smoke anywhere within the staircase enclosure.	
Optional questions for buildings with a floor level over 11 m above ground level and served by a single stair			
9	Does the building have accommodation on two or more sides of the common stair?		As per section 14.1.3 of BS 9991

	Yes	Proceed to question 10.	
	No	Proceed to question 11.	

10	Are all doors which separate the wings of the building from the stair rated at a minimum of FD30?		As per section 14.1.3 & 24.1 of BS 9991
	Yes	Provide evidence and list any manufacturer systems and uniclass reference	
	No	Design amendments required. All doors separating the wings of the building from the stairway, should be minimum FD30 fire rated.	

11	Does the building have AOVs to the exterior of the building with a minimum free area of 1.5 m2, fitted in the common corridor or lobby directly adjacent to the stair at as high a level as is practicable, and an AOV that is sited at as high a level as is practicable on the top storey of the stairway, having a minimum free area of 1 m2?		
	Yes	Provide evidence and list any manufacturer systems and uniclass reference	
	No	Proceed to question 12.	

12	Does the building have a smoke shaft that is fitted in the protected lobby or corridor, and an AOV that is sited at as high a level as is practicable on the top storey of the stairway, having a minimum free area of 1 m2?		
	Yes	Provide evidence and list any manufacturer systems and uniclass reference	
	No	Proceed to question 13.	

13	Does the building have a mechanical smoke ventilation system that is fitted in the protected lobby or protected corridor, directly adjacent to the staircase enclosure, and an AOV that is sited at as high a level as is practicable on the top storey of the stairway, having a minimum free area of 1 m2?		
	Yes	Provide evidence and list any manufacturer systems and uniclass reference	

	No	Proceed to question 14.

14	Do any corridors have excessive travel distance to the point of escape?	
	Yes	Proceed to question 15.
	No	Proceed to question 16.

15	Does the corridor/stairway have a mechanical smoke ventilation system?	
	Yes	Provide evidence and list any manufacturer systems and uniclass reference
	No	Proceed to question 16.

16	Does the building have a pressure differential system?	
	Yes	Provide evidence and list any manufacturer systems and uniclass reference
	No	Design amendments required. The building should be designed with at least one of the following options incorporated: a) AOVs to the exterior of the building with a minimum free area of 1.5 m2, fitted in the common corridor or lobby directly adjacent to the stair at as high a level as is practicable, and an AOV that is sited at as high a level as is practicable on the top storey of the stairway, having a minimum free area of 1 m2; or b) a smoke shaft that is fitted in the protected lobby or corridor, and an AOV that is sited at as high a level as is practicable on the top storey of the stairway, having a minimum free area of 1 m2; or c) a mechanical smoke ventilation system that is fitted in the protected lobby or protected corridor, directly adjacent to the staircase enclosure, and an AOV that is sited at as high a level as is practicable on the top storey of the stairway, having a minimum free area of 1 m2; or d) a pressure differential system.

Optional questions for multiple-stair buildings		
17	Are any vents to the exterior of the building able to be manually operated as well as automatically?	
	Yes	Provide evidence and list any manufacturer systems and uniclass reference
	No	Proceed to question 19.

18	Where manually operable vents are used, is the smoke control system designed to open the vent at the head of the stair either before, or at the same time as the vent on the fire floor?	
	Yes	Provide evidence and list any manufacturer systems and uniclass reference
	No	Design amendments required. The smoke control system should be designed to open the vent at the head of the stair either before, or at the same time as the vent on the fire floor

19	Do any vents discharge into smoke shafts?	
	Yes	Provide evidence and tag drawing/model details.
	No	Proceed to question 25.

20	Are the vents on the fire floor, at the top of the smoke shaft and on the stairway configured to open simultaneously upon automatic activation of the system in the common corridor or lobby? n.b.The vents from the corridors or lobbies on all other storeys should be configured to remain closed.	
	Yes	Provide evidence and list any manufacturer systems and uniclass reference

	No	Design amendments required. Where the vents discharge into a smoke shaft, the vents on the fire floor, at the top of the smoke shaft and on the stairway should all be configured to open simultaneously upon automatic activation of the system in the common corridor or lobby. The vents from the corridors or lobbies on all other storeys should be configured to remain closed.

Optional questions for buildings with balcony approach or deck approach.		
21	Are all staircases in the building provided with an openable vent with a free area of 1 m2 at the top of any enclosed staircase, which can be remotely operated at fire and rescue service access level?	
	Yes	Provide evidence and list any manufacturer systems and uniclass reference
	No	Design amendments required. Buildings with a balcony approach or a deck approach should be provided with an openable vent with a free area of 1 m2 at the top of any enclosed staircase, which can be remotely operated at fire and rescue service access level.

22	Does the building have multiple staircases?	
	Yes	Proceed to question 23.
	No	Proceed to question 25.

23	Does any secondary stairway from the main escape route serve ancillary accommodation?	
	Yes	Proceed to question 24.
	No	Proceed to question 25.

24	Is any secondary stairway serving ancillary accommodation, separated from that ancillary accommodation by a protected lobby or protected corridor?	
	Yes	Provide evidence and list any manufacturer systems and uniclass reference

	No	Design amendments required. Any common stair which does not form part of the only escape route from a flat may also serve ancillary accommodation if it is separated from the ancillary accommodation by a protected lobby or protected corridor.

25	Does any staircase serve an enclosed car park or area with higher fire risk?	
	Yes	Proceed to next question.
	No	Proceed to next section

26	Are the stairways, lobby or corridor provided with an area of permanent ventilation of not less than 0.4 m2 or protected from the ingress of smoke by a mechanical smoke ventilation system?	
	Yes	Provide evidence and list any manufacturer systems and uniclass reference
	No	Design amendments required. If the stair serves an enclosed car park or an area with a higher fire risk, the lobby or corridor should be provided with an area of permanent ventilation of not less than 0.4 m2 or be protected from the ingress of smoke by a mechanical smoke ventilation system.

Table 7 - Draft QDR FSES Section A10

Requirement B3: Section 8: Cavities - Flats

1)	Are cavity barriers provided to divide cavities?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.2 Not to be confused with Fire-stopping details (see section 10)
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref	

2)	Are cavity barriers provided to close the edge of cavities?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.2 Not to be confused with Fire-stopping details (see section 10)
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

3)	Are cavity barriers provided at the edges around openings?	No	Attention required. This is a mandatory requirement!	As per Approved Doc-BV1 B3 8.3 i.e., windows, doors, exit/entry points for services

4)	Are cavity barriers provided at the junction between external wall cavities, every compartment floor and compartment wall?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.3
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

5)	Are cavity barriers provided at the junction between an internal cavity wall, every compartment floor, every compartment wall and other wall or door assembly forming a fire resisting barrier?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.3
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

6)	Do all compartment walls extend to the underside of the roof or floor above?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.4 It is not appropriate to complete a line of compartment walls by fitting cavity barriers above them.
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

7)	Is the fire resisting construction of protected escape routes carried to full storey height and carried to the underside of the roof covering at top storey height?	Yes	Proceed to question 10	As per Approved Doc-BV1 B3 8.5

8)	Are the cavities above or below the line of the fire resisting structure fitted with Cavity barriers on the line of the enclosure?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.5
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

9)	Are any cavities fitted above the fire resisting construction, enclosed on the lower side by a fire resisting ceiling (min EI 30) that extends throughout the building, compartment or separated part?	No	Attention required. This is a mandatory requirement! Design details must comply with either question 8 or 9.	As per Approved Doc-BV1 B3 8.5

10)	Are there any alternative escape routes within the building that contain divided corridors?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.6

11)	Is fire-stopping provided to prevent alternative escape routes being affected by fire and/or smoke?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.6 Fire-stopping is not to be confused with cavity barriers
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

12)	Is the roof of the structure made up of corrugated roof sheeting?	No	Proceed to question 16.	As per Approved Doc-BV1 B3 8.7

13)	Is the roof sheeting rated class A2-s3, d2 or better?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.7
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

14)	Are both surfaces of the roof sheeting rated class C-s3, d2 or better?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.7
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

15)	Do both surfaces of the insulating layer make contact with the inner and outer skins of the cladding?	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.7
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

16)	Do cavity barriers provide a minimum of 30 minutes' integrity (E 30) and 15 minutes' insulation	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.8

	(I 15), when tested from both sides?			
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

17)	Are cavity barriers in a stud wall or partition, or provided around openings, formed of either of the following? a. Steel, a minimum of 0.5mm thick. b. Timber, a minimum of 38mm thick. c. Polythene-sleeved mineral wool, or mineral wool slab, under compression when installed in the cavity. d. Calcium silicate, cement-based or gypsum-based boards, a minimum of 12mm thick.	Yes	Proceed to next question	As per Approved Doc-BV1 B3 8.9 NOTE: Cavity barriers provided around openings may be formed by the window or door frame, if the frame is constructed of steel or timber of the minimum thickness in (a) or (b), as appropriate.
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

18)	Are cavity barriers fixed so that their performance is unlikely to be made ineffective by any of the following? a. Movement of the building due to subsidence, shrinkage or temperature change, and movement of the external envelope due to wind. b. During a fire, collapse of services penetrating the cavity barriers, either by the failure of the supporting system or through degradation of the service itself (e.g., by melting or burning). c. During a fire, failure of the cavity barrier fixings. (In roof spaces, where cavity barriers are fixed to roof members, there is no expectation of fire resistance from roof members provided for the purpose of support.) d. During a fire, failure of any material or construction to which cavity barriers abut. (For example, a suspended ceiling that continues over a fire resisting wall or partition collapses, and the cavity barrier fails prematurely because the ceiling was not designed to provide a minimum fire resistance of EI 30.)	Yes	Proceed to next section	As per Approved Doc-BV1 B3 8.9
		ENTER DETAILS HERE	List manufacturer product or system and Uniclass 2015 ref and provide link to BIM model in BIM project where possible (Sync to Specification)	

Table 8 - FSES template for Approved Doc B, Requirement B3: Section 8: Cavities – Flats

PRELIM QUESTIONS

Question/Response Options Action Guidance

1	Is the building a residential dwelling?	1(a)(1) Flat. 1(b)(2) Dwellinghouse that contains a habitable storey with a floor level a minimum of 4.5m above ground level up to a maximum of 18m. 1(c)(2)(4) Dwellinghouse that does not contain a habitable storey with a floor level a minimum of 4.5m above ground level. This includes; a. A detached garage a maximum of 40m2 in area. b. A detached open carport a maximum 40m2 in area. c. A detached building that consists of a garage and open carport, each a maximum of 40m2 in area.		
	Yes	Select one of the above options.	Proceed to Question 2	
	No	n/a	Refer to Doc B - Vol 2 KBS	

2	Does the proposed building have any exceptional features?	i.e., Is the building very large, over 18m in height? Does it have a 10m deep basement? Is the building an unusual dwelling house?		
	Yes	Note exceptional feature	Referral maybe needed to Doc B - Vol 2 and/or specialist engineer.	
	No	n/a	Proceed to next section.	

Requirement B1: Section 1: Fire detection and alarm systems

1	Is the dwelling of reasonable proportions? This also applies to extensions and material changes.	i.e., not a large dwellinghouse with more than one storey, where at least one storey exceeds 200m2 If an extension or material change the following fall into this category: a. The room is provided above or below the ground storey. b. The room is provided at the ground storey, without a final exit. .		
	Yes		Proceed to next question.	
	No		Proceed to question 5.	

2	Does the dwelling have fire detection and alarm system, minimum Grade D2 Category LD3 standard?			As per Approved Doc-B B1 1.1 Alarm system must be in accordance with the relevant recommendations of BS 5839-6
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

3	Does the building have smoke alarms and are these mains operated?	Smoke alarms must be fitted in circulation areas in dwellings.		As per Approved Doc-B B1 1.2 and 1.9 Smoke alarms must conform to BS EN 14604
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	

	No		Attention required. This is a mandatory requirement.	

4	Does the dwelling have a heat alarm and is this mains operated?			As per Approved Doc-B B1 1.3 Heat alarms must conform to BS 5446-2
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to question 8	
	No		Attention required. This is a mandatory requirement.	

5	If a large dwelling does is this made up of two stories only (excluding basement) or more than two stories?			
	Two stories only (Excluding basement)		Proceed to Question 6	
	More than two stories (Excluding basement)		Proceed to Question 7	

6	Is the two story large dwelling fitted with fitted with a Grade A Category LD3 fire detection and alarm system?			As per Approved Doc-B B1 1.6 Alarm system must be in accordance with BS 5839-6
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

7	Is the large dwellinghouse of three or more storeys (excluding basement storeys)fitted with a Grade A Category LD2 fire detection and alarm system?			As per Approved Doc-B B1 1.7 Alarm system as described in BS 5839-6
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

8	Do all smoke and heat alarms have a standby power supply, such as a battery (rechargeable or non-rechargeable) or capacitor?			As per Approved Doc-B B1 1.4
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

9	Is the dwelling a block of flats?			
	Yes		Proceed to next question	
	No		Proceed to question 11.	

10	Does each flat in the block have its own fire detection and alarm system?			As per Approved Doc-B B1 1.10
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to question 13	
	No		Attention required. This is a mandatory requirement.	

11	Is the dwelling student accommodation which is designed and occupied as a block of flats?			
	Yes		Proceed to next question	
	No		Proceed to question 13.	

12	Does each flat in the block have its own fire detection and alarm system?	Each of the below are reason for compliance with this: a. A group of up to six students shares the flat. b. Each flat has its own entrance door. c. The compartmentation principles for flats in Section 7 have been followed		As per Approved Doc-B B1 1.10
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next section.	
	No		Attention required. This is a mandatory requirement.	

13	Is the dwelling sheltered accommodation which is designed and occupied as a block of flats?			
	Yes		Proceed to next question	
	No		End of section	

13	Does the fire detection and alarm system in the individual flats connect to a central monitoring point or alarm receiving centre?	These provisions do not apply to the following. a. The common parts of a sheltered housing development, such as communal lounges. b. Sheltered accommodation in the 'residential (institutional)' or 'residential (other)' purpose groups (purpose group 2(a) or 2(b)). In these parts, means of warning should follow the guidance for buildings other than dwellings in Volume 2 of Approved Document B.		As per Approved Doc-B B1 1.12
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

14	Do the detection and alarm systems alert the warden or supervisor and identify the individual flat where a fire has been detected?			As per Approved Doc-B B1 1.12
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to	End of section	

		BIM model in BIM project where possible		
	No		Attention required. This is a mandatory requirement.	

Requirement B1: Section 2: Means of escape – dwellinghouses

1	Do all habitable rooms (excluding kitchens) have either/or: a) an opening directly onto a hall leading to a final exit. B) an emergency escape window or door.			As per Approved Doc-B B1 2.1
	Yes	in the case of emergency escape window or door, List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

2	Does the dwelling have upper floors?			
	Yes		Proceed to next question	
	No		Proceed to question 18	

3	Is the highest upper floor within a maximum height of 4.5m above ground level or higher?			

	Max 4.5		Proceed to next question	
	Higher than 4.5		Proceed to question 6	

4	are habitable rooms on the upper floors served only by a single staircase?			
	Yes		Proceed to next question	
	No		Proceed to question 9	

5	Do all habitable rooms (excluding kitchens) on the upper floors have either/or: a) Direct access to a protected stairway. b) an emergency escape window or external door.	Two rooms may be served by a single window if a door between the rooms is provided with access to the window, without passing through the stair enclosure. Both rooms should have their own access to the internal stair.		As per Approved Doc-B B1 2.2
	Yes	in the case of emergency escape window or external door, List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

6	are habitable rooms on the upper floors served only by a single staircase?			
	Yes		Proceed to next question	
	No		Proceed to question 9	

7	Does the dwelling have a protected stairway, separated by fire resistance construction at all levels (min REI 30 rating) that either: a) extends to a final exit. b) Gives access to a minimum of two ground level final exits that are separated from each other by fire resisting construction (minimum REI 30) and fire doorsets (minimum E 20)			As per Approved Doc-B B1 2.5
	Yes	Acme Doors FR60; Ss_25_30_20_25	Proceed to question 10	
	No		Proceed to next question	

8	Does the dwelling have an alternative escape route – a top storey separated from lower storeys by fire resisting construction (minimum REI 30) and with an alternative escape route leading to its own final exit?			As per Approved Doc-B B1 2.5
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

9	Where the dwelling has more than one stairway. Are these stairways physically separated by fire resisting construction (min REI 30) or more than one room?			As per Approved Doc-B B1 2.4
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

10	Does the dwelling have more than one storey above 4.5m height?			
	Yes		Proceed to next question	
	No		Proceed to question 15	

11	Does the dwelling have a protected stairway to an upper storey that is accessed by floors above 7.5m?			
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

12	Are the stairways above 7.5m physically separated by fire resisting construction			As per Approved Doc-B B1 2.6

	(min REI 30) from the lower stories?			
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

13	Do the stories above 7.5m have access to an alternative exit (i.e., external fire escape) other than the main stairway?			As per Approved Doc-B B1 2.6
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Proceed to question 16	

14	Does the dwelling have a sprinkler system throughout?	Sprinkler system must be designed in accordance with BS 9251		As per Approved Doc-B B1 2.6
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required if answer to Q13 was also no. This is a mandatory requirement.	

15	Does the dwelling have a passenger lift that serves stories above 4.5m height?			As per Approved Doc-B B1 2.7
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No			

16	Is the passenger lift located in the enclosure of the protected stairway?			As per Approved Doc-B B1 2.7
	Yes		Proceed to next question	
	No		Proceed to next question	

17	Is the passenger lift located in a fire resisting lift shaft?	min REI 30		As per Approved Doc-B B1 2.7
	Yes		Proceed to next question	
	No		Attention required if answer to Q16 was no. This is a mandatory requirement.	

18	Does the dwelling have an air circulation system?			
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Proceed to question 23	

19	Are any transfer grilles fitted to walls, doors, floors or ceilings of the stair enclosure?			As per Approved Doc-B B1 2.8
	Yes		Attention required. This is a mandatory requirement.	
	No		Proceed to next question	

20	Do any ducts to this system pass through the protected stairway?			
	Yes		Proceed to next question	
	No		Proceed to question 22	

21	are these ducts of rigid steel construction with any joints between the ductwork and stair enclosure fire-stopped?			As per Approved Doc-B B1 2.8
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

22	Do any Ventilation ducts supplying or extracting air directly to or from a protected stairway serve other areas as well?			As per Approved Doc-B B1 2.8

	Yes		Attention required. This is a mandatory requirement.	
	No		Proceed to next question	

23	Does the dwelling have any mechanical ventilation or air re-circulation system that serves both the stairways and other areas?			As per Approved Doc-B B1 2.8
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Proceed to question 25	

24	Is the mechanical ventilation/air-circulation system designed to shut down upon detection of smoke in the system?			As per Approved Doc-B B1 2.8
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

25	Does the dwelling have a ducted warm air system?			As per Approved Doc-B B1 2.8
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Proceed to question 27	

26	Is the thermostat located in the living room and set at a height between 1370mm and 1830mm with a maximum setting of 27deg Celsius?			As per Approved Doc-B B1 2.8
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

27	Do windows providing emergency escape have an unobstructable open area of 0.33m2 min? with a minimum dimension of 450x450mm?			As per Approved Doc-B B1 2.10
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

28	Are emergency escape windows installed as such so that the bottom of the openable area is a max of 1100mm above finished floor level?			As per Approved Doc-B B1 2.10
	Yes		Proceed to next question	

	No		Attention required. This is a mandatory requirement.	

29	Are the escape windows able to remain open without being held?			As per Approved Doc-B B1 2.10
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

30	Do escape routes lead to a place free from danger of fire?	Where escape from a dwellinghouse is to an enclosed space with exit only possible through other buildings (e.g., a courtyard or back garden), the length of the space should exceed whichever is the greater of the following. a. The height of the dwellinghouse above ground level. b. Where a rear extension is provided, the height of the extension.		As per Approved Doc-B B1 2.10
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

31	Are there any inner rooms in the dwelling?			

	Yes		Proceed to next question	
	No		Proceed to question 33	

32	Are the purpose of these rooms for any use other than the following? a. A kitchen. b. A laundry or utility room. c. A dressing room. d. A bathroom, WC or shower room.			
	Yes		Attention required. This is a mandatory requirement.	
	No		Proceed to next question	

33	Does any flat roof form part of an escape route?			
	Yes		Proceed to next question	
	No		Proceed to question 37	

34	Is the flat roof that forms part of this escape roof, part of the same building?			As per Approved Doc-B B1 2.13
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

35	Does the flat roof escape lead to a storey exit?	Exit at same level		As per Approved Doc-B B1 2.13
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

36	Is the section of the roof that forms the escape route or within 3m of the escape route formed of a REI 30 mini construction?			As per Approved Doc-B B1 2.13
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

37	Is the section of the roof (or a balcony) that forms the escape route fitted with guarding?	Must comply to Approved Doc-K		As per Approved Doc-B B1 2.14
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement. Also refer to Approved Doc-K	

38	If there are inner rooms on any upper stories, do these have escape windows?			

	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

39	Do any of the rooms have a gallery?			
	Yes		Proceed to next question	
	No		Proceed to question 46	

40	is at least 50% of the visible area of floor in the lower section of the room visible from the gallery?			As per Approved Doc-B B1 2.15
	Yes		Proceed to question 42	
	No		Proceed to next question	

41	Does the gallery have a means of emergency escape other than the main stairway such as escape door or emergency escape window?			As per Approved Doc-B B1 2.15
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

42	Is any gallery fitted with cooking equipment?			

	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Proceed to question 44	

43	Is the cooking equipment enclosed with a fire resistance construction and not blocking any means of escape?			As per Approved Doc-B B1 2.15
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

44	Is the furthest distance from within the gallery to the nearest escape route a max of 7.5m distance?			As per Approved Doc-B B1 2.15
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

45	Is the bottom stair that leads to a gallery, a min distance of 3m from the nearest escape exit on that floor?			As per Approved Doc-B B1 2.15
	Yes		Proceed to next question	

	No		Attention required. This is a mandatory requirement.	

46	Does the dwelling have a basement which contains any habitable room(s)?			
	Yes		Proceed to next question	
	No		Proceed to question 48.	

47	Do the habitable rooms have access to either of the following: a) emergency escape window or external door providing escape from the basement? B) A protected stairway leading from the basement to a final exit?			As per Approved Doc-B B1 2.16
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

48	Does the dwelling have external escape stairs?			
	Yes		Proceed to next question	
	No		Proceed to next section.	

49	Is the door from the building to the external stairway fire resistant to a minimum E30 rating?			As per Approved Doc-B B1 2.17
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

50	Is the dwelling wall to the side of the external stairway fireproof to a minimum RE 30 rating? This area must also extend 1800mm either side of the stairway and 1100mm above the top landing.			As per Approved Doc-B B1 2.17
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

51	Are all parts of the dwelling construction inc. doors, windows etc. 180mm from the foot of the stair of the escape route a minimum RE 30 construction?			As per Approved Doc-B B1 2.17
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next question	

	No		Attention required. This is a mandatory requirement.	

52	are the escape stairs more than 6m in height?			
	Yes		Proceed to next question	
	No		Proceed to question 54	

53	Is the stairway protected from the elements/adverse weather?	i.e., prevent build-up of ice or snow		As per Approved Doc-B B1 2.17
	Yes		Proceed to next question	
	No		Attention required. This is a mandatory requirement.	

54	Does any part of the fire resisting construction to which the external escape stairway is attached contain any windows or glazing?			
	Yes		Proceed to next question	
	No		Proceed to next section	

55	Is the glazing fixed shut and fire resisting (in terms of integrity, not insulation) to a minimum E 30 rating?			As per Approved Doc-B B1 2.17

	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible	Proceed to next section	
	No		Attention required. This is a mandatory requirement.	

Requirement B3: Section 8: Cavities - Flats

1	Are cavity barriers provided to divide cavities?	Not to be confused with Fire-stopping details (see section 10)		As per Approved Doc-BV1 B3 8.2
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

2	Are cavity barriers provided to close the edge of cavities?	Not to be confused with Fire-stopping details (see section 10)		As per Approved Doc-BV1 B3 8.2
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

3	Are cavity barriers provided at the edges around openings?	i.e., windows, doors, exit/entry points for services		As per Approved Doc-BV1 B3 8.3
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

4	Are cavity barriers provided at the junction between external wall cavities, every compartment floor and compartment wall?			As per Approved Doc-BV1 B3 8.3
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

5	Are cavity barriers provided at the junction between an internal cavity wall, every compartment floor, every compartment wall and other wall or door assembly forming a fire resisting barrier?			As per Approved Doc-BV1 B3 8.3
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	

	No		Attention required. This is a mandatory requirement.	

6	Do all compartment walls extend to the underside of the roof or floor above?	It is not appropriate to complete a line of compartment walls by fitting cavity barriers above them.		As per Approved Doc-BV1 B3 8.4
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

7	Is the fire resisting construction of protected escape routes carried to full storey height and carried to the underside of the roof covering at top storey height?			As per Approved Doc-BV1 B3 8.5
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to question 10.	
	No		Proceed to next question.	

8	Are the cavities above or below the line of the fire resisting structure fitted with Cavity barriers on the line of the enclosure?			As per Approved Doc-BV1 B3 8.5

	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Proceed to next question.	

9	Are any cavities fitted above the fire resisting construction, enclosed on the lower side by a fire resisting ceiling (min EI 30) that extends throughout the building, compartment or separated part?			As per Approved Doc-BV1 B3 8.5
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement. Design details must comply with either question 8 or 9.	

10	Are there any alternative escape routes within the building that contain divided corridors?			As per Approved Doc-BV1 B3 8.6
	Yes		Proceed to next question.	
	No		Proceed to question 12.	

11	Is fire-stopping provided to prevent alternative escape routes being affected by fire and/or smoke?	Fire-stopping is not to be confused with cavity barriers		As per Approved Doc-BV1 B3 8.6
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

12	Is the roof of the structure made up of corrugated roof sheeting?			As per Approved Doc-BV1 B3 8.7
	Yes		Proceed to next question.	
	No		Proceed to question 16.	

13	Is the roof sheeting rated class A2-s3, d2 or better?			As per Approved Doc-BV1 B3 8.7
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

14	Are both surfaces of the roof sheeting rated class C-s3, d2 or better?			As per Approved Doc-BV1 B3 8.7

	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

15	Do both surfaces of the insulating layer make contact with the inner and outer skins of the cladding?			As per Approved Doc-BV1 B3 8.7
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

16	Do cavity barriers provide a minimum of 30 minutes' integrity (E 30) and 15 minutes' insulation (I 15), when tested from both sides?			As per Approved Doc-BV1 B3 8.8
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

17	Are cavity barriers in a stud wall or partition, or provided around openings, formed of either of the following? a. Steel, a minimum of 0.5mm thick. b. Timber, a minimum of 38mm thick. c. Polythene-sleeved mineral wool, or mineral wool slab, under compression when installed in the cavity. d. Calcium silicate, cement-based or gypsum-based boards, a minimum of 12mm thick.	NOTE: Cavity barriers provided around openings may be formed by the window or door frame, if the frame is constructed of steel or timber of the minimum thickness in (a) or (b), as appropriate.		As per Approved Doc-BV1 B3 8.9
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

18	Are cavity barriers fixed so that their performance is unlikely to be made ineffective by any of the following? a. Movement of the building due to subsidence, shrinkage or temperature change, and movement of the external envelope due to wind. b. During a fire, collapse of services penetrating the cavity barriers, either by the failure of the supporting system or through degradation of the service itself (e.g., by melting or burning). c. During a fire, failure of the cavity barrier fixings. (In roof spaces, where cavity barriers are fixed to roof members, there is no expectation of fire resistance from roof members provided for the purpose of support.) d. During a fire, failure of any material or construction to which cavity barriers abut. (For example, a suspended ceiling that continues over a fire resisting wall or partition collapses, and the cavity barrier fails prematurely because the ceiling was not designed to provide a minimum fire resistance of EI 30.)			As per Approved Doc-BV1 B3 8.9
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	

	No		Attention required. This is a mandatory requirement.	

Requirement B4: Section 10: Resisting fire spread over external walls

1	Is the building 18m+ in height from ground level?			"Above ground level" in relation to a storey means above ground level when measured from the lowest ground level adjoining the outside of a building to the top of the floor surface of the storey.
	Yes		Proceed to next question.	
	No		Continue or move to next section.	The following section considers regulation only for buildings over 18m+ in height, however it would be good practice to adopt these principles for any building above 10m.

2	Is the purpose of the building a dwelling?			inc. student accommodation, care homes, sheltered housing, hospitals and dormitories in boarding schools. See regulation 7(4) for the definition of relevant buildings.
	Yes		Proceed to next question.	
	No		Move to section ??	

2	Are the structural external walls made of fire resisting materials?			i.e., Brick, Concrete.
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No	Refer to sections 3, 6 and 11.	Proceed to next question.	

3	Are external walls fitted with any materials/products or systems?			i.e., Cladding, external insulation, balcony attached to an external wall, any device for reducing heat gain within a building by deflecting sunlight which is attached to an external wall, a solar panel attached to an external wall, or others.
	Yes		Proceed to next question.	For green walls (also called living walls) refer to Fire Performance of Green Roofs and Walls, published by the Department for Communities and Local Government.
	No			

4	do the materials which make up the outermost face of the external walls achieve Fire performance Class A2-s1, d0(1), Class A1 or better?			As per Doc B1 Requirement B4, Table 10.1 Approved Document B1. All 'Relevant buildings' as defined in regulation 7(4) should be constructed with external wall materials of Class A2-s1, d0(1) or better.

	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

5	Are there any insulation products, filler materials or similar used in the external wall façade?			such as the core materials of metal composite panels, sandwich panels and window spandrel panels but not including gaskets, sealants and similar.
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No			

	Do the insulation products, filler materials or similar meet fire performance class A2-s3, d2 or better?			As per Doc B1 Requirement B4. Section 10.6
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

7	Do cavity barriers satisfy Approved Document B1 Requirement B3, section 8?			Refer to separate section of KBS and result.
	Yes		Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

8	Are there any membranes attached to the external wall?			
	Yes		Proceed to next question.	
	No			

9	Do the membranes attached to the external wall meet class B-s3, d0 or better?			
	Yes		Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

10	Are there any thermal breaks designed into the external wall to prevent thermal bridging?			
	Yes		Proceed to next question.	
	No			

11	Do the thermal breaks span two compartments in any area?			

	Yes		Attention required. This is a mandatory requirement.	
	No		Proceed to next question.	

12	Are the thermal breaks limited in size to the minimum required to restrict the thermal bridging?			n.b. the principal insulation layer is not to be regarded as a thermal break.
	Yes		Proceed to next question.	
	No		Attention required. This is a mandatory requirement.	

13	Are there any other attachments to the external wall other than those identified in the prior assessment that may be considered a risk to external fire spread?			
	Yes	List manufacturer product/system and Uniclass 2015 ref(s) and provide link to BIM model in BIM project where possible (Sync to Specification)	Proceed to next question.	
	No		End of section.	

14	Do the fire performance characteristics of any other attachments to the external wall other than those identified in the prior assessment meet the same fire performance as the external face or are deemed not to contribute to the spread of fire to the exterior of the building?			
	Yes		End of section.	
	No		Attention required. This is a mandatory requirement.	

Table 9 - 1st Draft Approved Doc B FSES logic

Appendix E. FSES Test case: Requirement B4: Section 10: Resisting fire spread over external walls

Requirement B4: Section 10: Resisting fire spread over external walls

1	Q	Is the building 18m+ in height from ground level?			"Above ground level" in relation to a storey means above ground level when measured from the lowest ground level adjoining the outside of a building to the top of the

					floor surface of the storey.
	A	Yes	Yes	Proceed to next question.	
	A	No		Continue or move to next section.	The following section considers regulation only for buildings over 18m+ in height, however it would be good practice to adopt these principles for any building above 10m.

2	Q	Is the purpose of the building a dwelling?			inc. student accommodation, care homes, sheltered housing, hospitals and dormitories in boarding schools. See regulation 7(4) for the definition of relevant buildings.
	A	Yes	Yes	Proceed to next question.	
	A	No		Move to Assessment ADB Vol.2	

3	Q	Are the structural external walls made of fire resisting materials?			i.e., Brick, Concrete.
	A	Yes	Ss_25_20_14_54Metal insulating sandwich panel cladding systemsmarketing@kingspanpanels.com	Proceed to next question.	
	A	No		Proceed to next question.	

4	Q	Are external walls fitted with any materials/products or systems?			i.e., Cladding, external insulation, balcony attached to an external wall, any device for reducing heat gain within a building by deflecting sunlight which is attached to an external wall, a solar panel attached to an external wall, or others.
	A	Yes	Yes	Proceed to next question.	For green walls (also called living walls) refer to Fire Performance of Green Roofs and Walls, published by

					the Department for Communities and Local Government.
	A	No		Proceed to next question.	

5	Q	do the materials which make up the outermost face of the external walls achieve Fire performance Class A2-s1, d0(1), Class A1 or better?			As per Doc B1 Requirement B4, Table 10.1 Approved Document B1. All 'Relevant buildings' as defined in regulation 7(4) should be constructed with external wall materials of Class A2-s1, d0(1) or better.
	A	Yes	Ss_25_20_14_54Metal insulating sandwich panel cladding systemsmarketing@kingspanpanels.comB-s1,d0	Proceed to next question.	
	A	No		Attention required. This is a mandatory requirement.	

6	Q	Are there any insulation products, filler materials or similar used in			such as the core materials of metal composite

		the external wall façade?			panels, sandwich panels and window spandrel panels but not including gaskets, sealants and similar.
	A	Yes	Ss_25_20_14_54Metal insulating sandwich panel cladding systems	Proceed to next question.	
	A	No		Proceed to question 7.	

7	Q	Do the insulation products, filler materials or similar meet fire performance class A2-s3, d2 or better?			As per Doc B1 Requirement B4. Section 10.6
	A	Yes	Ss_25_20_14_54Metal insulating sandwich panel cladding systemsmarketing@kingspanpanels.comB-s1,d0	Proceed to next question.	
	A	No		Attention required. This is a mandatory requirement.	

8	Q	Do cavity barriers satisfy Approved Document B1 Requirement B3, section 8?			Refer to separate section of FSES and result.
	A	Yes	Yes	Proceed to next question.	

	A	No		Attention required. This is a mandatory requirement.	

9	Q	Are there any membranes attached to the external wall?			
	A	Yes	Yes	Proceed to next question.	
	A	No		Proceed to question 11.	

10	Q	Do the membranes attached to the external wall meet class B-s3, d0 or better?			
	A	Yes	Yes	Proceed to next question.	
	A	No		Attention required. This is a mandatory requirement.	

11	Q	Are there any thermal breaks designed into the external wall to prevent thermal bridging?			
	A	Yes	Yes	Proceed to next question.	

	A	No		Proceed to question 14.	

12	Q	Do the thermal breaks span two compartments in any area?			
	A	Yes		Attention required. This is a mandatory requirement.	
	A	No	No	Proceed to next question.	

13	Q	Are the thermal breaks limited in size to the minimum required to restrict thermal bridging?			n.b. the principal insulation layer is not to be regarded as a thermal break.
	A	Yes	Yes	Proceed to next question.	
	A	No		Attention required. This is a mandatory requirement.	

14	Q	Are there any other attachments to the external wall other than those identified in the prior assessment			

		that may be considered a risk to external fire spread?			
	A	Yes		Proceed to next question.	
	A	No	No	End of section.	

15	Q	Do the fire performance characteristics of any other attachments to the external wall other than those identified in the prior assessment meet the same fire performance as the external face or are deemed not to contribute to the spread of fire to the exterior of the building?			
	A	Yes	n/a	End of section.	
	A	No		Attention required. This is a mandatory requirement.	

Table 10 - Further Draft Approved Doc B FSES logic