BIM-enabled “Digital by Default” Vision for Fire Safety

Dr. Kirti Ruikar[1*], Dr Peter Wilkinson[2] and Judith Schulz[3]
[1]Loughborough University
[2]Pyrology Limited
[3]Arup
* email: k.d.ruikar@lboro.ac.uk

Abstract

In England and Wales, building regulations apply to the design and construction of new buildings, extensions and changes of use. Regulation 38 (BRE, 2019) is a requirement to provide fire safety information to the responsible person at the completion of a project, or where the building or extension is first occupied. Regulations require as-built Fire Safety Information to be handed over by the design and construction teams to the responsible person to maintain and operate a building with reasonable safety. The responsible person is the owner, occupier, or manager of the building. The information would typically include; a fire safety strategy of the building that accurately reflects the fire safety precautions; and design and construction information, services information; and information about fixtures, fittings and equipment. Unfortunately, Regulation 38 has been far from successful and the required information is rarely communicated to the dutyholders in a manner that meets the intention of the authors. There is no requirement for the information to be presented to either the Fire Service or the Building Control Body for assessment. The requirement is merely for the person carrying out the work to confirm that the required information has been passed over (CIC, 2017). The guiding philosophy of legislation requires organisations to assess the potential risks associated with their work activities and to introduce effective measures to control risks. However, in reality the current regulations set the bar too low, with the industry looking to satisfy the minimum standards by the cheapest means possible, magnified by a lack of approval scrutiny.

In the wake of the Grenfell Tower fire in 2017 that killed 72 people, the UK Government commissioned the Hackitt Review (2018) of building regulations and fire safety. The Hackitt Review calls for radical change in culture in the construction industry and the regulatory system that assigns responsibility and holds people accountable. It also states that the Government should mandate a digital standard of record-keeping for design, construction and occupation of new Higher Risk Residential Buildings (HRRB) and refurbishments within HRRBs. A BIM-driven dataset is suggested, which requires duty-holders to generate a suitable evidence-base through which to deliver their responsibilities and maintain safety and integrity throughout the lifecycle of a building. This paper will examine the requirements set out in the Hackitt review and explores the need for a digital record of lifecycle building information. It examines examine the role of BIM as an enabler of the digital building information record and presents a conceptual framework that enables rapid realisation of the digital by default vision, via a Safe by Default Asset Delivery framework. It outlines the potential outcomes of the safe by default approach and discusses the potential opportunities and challenges likely to be considered if the BIM enabled “digital by default" vision was to be realised.

Keywords: Fire Safety, BIM, Hackitt Review, Safe by Default

.

1. Background

Fire safety within the built environment has been a subject of concern for thousands of years (Wilkinson, 2013). In the 20th century, experiences from fires during the second world war were incorporated into the Post-war Building Studies on Fire Grading of Buildings (Wilkinson et al, 2010) and these were landmark documents of their time (Malhotra 1987 in Wilkinson et al 2010) that influenced the technical content of subsequent Building Regulations. Before amendments were made in 1976, regulations were highly prescriptive (Wilkinson et al 2010) and criticised to be "understood only by lawyers" (Law, 1991 in Wilkinson et al 2010). Despite the criticism, prescriptive Building Regulations resulted in the achievement of safety levels within buildings that were largely accepted by the community (Hasofer et al in 2007 in Wilkinson et al 2010). The events of the Grenfell fire, however, shook public confidence and 2017/18 also saw a 27% increase in fire related fatalities as a result of the tragic events of the Grenfell fire. In 2017/18, of the primary fires (74,118 fires) attended by the Fire and Rescue Services (FRS) in 2017/18, 63% were in dwellings and other buildings. The remaining were road vehicle and outdoor fires. The Grenfell tragedy and several before it, point to systemic failures, some of which can be attributed to 'piece meal approaches' to design development and construction, lacking holistic consideration, unsafe building components and material choices, failures in keeping maintenance audits of safety work, major or minor buildings works, all of which adversely impact on the integrity of the building structure and its fabric and result in a compromised safety function. The fire statistics (Home Office, 2018) and systemic failures call for radical improvements in practice so that mistakes are not repeated, and lessons are learnt. In the "Building a Safer Future" review by Dame Judith Hackitt (2018), there are several recommendations calling for radical changes in practice. Discussed in this paper are the recommendations to mandate a digital standard for record-keeping of through-lifecycle, design, construction and occupation information. This applies to Higher Risk Residential Buildings and refurbishments within those buildings and requires duty-holders to generate an evidence-base through which to deliver their responsibilities and maintain safety and integrity throughout the life-cycle of a building. The Hackitt review identifies a "Golden Thread of Building Information", to comprise of a digital record and a Fire and Emergency File (FEF). The review recommends that the client, principal designer and contractor maintain the FEF. The FEF to include technical specifications, product information, O&M manuals and inspection/commissioning records. More specifically, the Hackitt outlines the contents of such a FEF to include:

- A copy of the fire strategy design report for the building which details the strategic measures that are provided in the building to satisfy Parts B1-B5 of Schedule 1 of the Building Regulations (HM Government, 2010) (for which compliance related guidance is provided in Approved Document B); and
- For each Parts B1-B5 the FEF should include:
  - All relevant technical specifications
  - Product datasheets
  - Operations and maintenance manuals
  - Inspection and commissioning records

A BIM-driven (Building Information Modelling) dataset has been recommended for the digital record and the FEF. The next section will examine the requirements set out in the Hackitt review and explore the need for a digital record of lifecycle building information.

2. Hackitt Review and the Need for a Digital Record of Lifecycle Building Information

Currently, the precise extent of the as-built fire safety information and the level of detail that is provided to the owner or occupier varies and is dependent on the complexity of the building's design, its function and its susceptibility to a fire. The typical design considerations include: provision of passive fire protection measures designed to control fire spread, limit the effects of fire, protect escape routes and prevent structural collapse; inclusion of active detection and alarm systems to alert occupants to elicit a rapid response; use of smoke control systems to limit smoke spread; and provision of fixed firefighting systems to detect and extinguish fires or at least control their spread. The precise extent of as-built fire safety information and the level of detail that is provided to the owner or occupier varies and is dependent on the complexity of the building's design, its function and its susceptibility to a fire. According to Dobson (2018), *"Our current regulatory, testing and compliance regime has produced a complex ecosystem of contradictory guidance and conflicted interests, and in the process, we seem to have lost sight of the basics of fire-safe design." "While fire engineering on high-specification, high-budget projects with experienced client bodies can support innovation in design, on more typical projects it is too often a method of subverting core principles that have been developed over generations since the Great Fire of London."* The current regulations set the bar too low, with the construction industry looking to satisfy those minimum standards by the cheapest means possible (Timson in Brister, 2013), compounded by a lack of approval scrutiny (Ruikar and Glockling, 2015). This coupled with the, complete lack of application of fire regulation requirements results in incomplete, inadequate or sub-standard fire-safety information being handed over to the owner or occupier of a building. Such adversarial practices continue to put buildings at risk. Post-occupancy Fire Risk Assessments (FRAs) routinely reveal a variety of operational, maintenance, design and construction-related defects that present risks to the building's occupants; and negatively impact on the building's resilience to fires (Ruikar, 2018). This problem is compounded by the fact that several stakeholders are responsible for creating and maintaining building information, whose collective inputs affect the safety objectives. Generally, the stakeholders who are responsible for generating the information (designers, engineers, manufacturers) are different from those responsible for maintaining the asset (owners, occupiers, facilities managers) and/or those responsible for protecting it (fire and rescue services). In an emergency, the fire and rescue services are required to make snap decisions with the information at hand and often the effectiveness of the decision is based on the availability, correctness, and/or the completeness of the information available to them.

In the wake of the Grenfell tragedy, the Hackitt Review (2018) called for a digital record of building information to be maintained through lifecycle. The intent being to preserve a digitally driven dossier of building information that holds up-to-date and accurate information in a secure and accessible environment. Such a digital record would enable duty-holders to deliver their responsibilities and maintain safety and integrity throughout. BIM tools provide an environment in which the digital record could be maintained. It is envisioned (Hackitt Review, 2018) that a BIM-driven dataset would ensure decision-making is based on robust data, quality and compliance is assured, and efficiency is achieved through collaboration and innovation.

To create a digital record would require gathering the information requirements that are critical to various stakeholders at different stages of the building lifecycle i.e. design, manufacture, construction and operations. This is an under-researched and under-explored area of work. To truly automate the information cycle, it is critical to ensure that essential safety information is engrained in the building lifecycle process. To achieve an automated outcome, how the 'intelligent' process and product data (e.g. product specifications, properties, product life) could be input into BIM would need to be firstly established. Then, operational safety performance data of the product, extracted from BMSs and IoTs could be linked to the intelligent process and product data within BIM to validate and/or update 'operational' fire safety information.

3. BIM as an Enabler of the Digital Building Record

BIM has been mandated in the UK since 2011 (Cabinet Office, 2011). It has been defined by the HM Government BIM Task Group (2016) as, "value creating collaboration through the entire life-cycle of an asset, underpinned by the creation, collation and exchange of shared 3D models and intelligent, structured data attached to them". The UK Government's BIM hypothesis has been that the Government as a client can drive significant improvements in cost, value and carbon performance using open sharable asset information. For instance, the UK Government's construction 2025 (HM Government, 2013) targets, among other targets for the construction industry, have been to drive down costs by 33% and increase project delivery times by 50% for new builds and refurbishment projects. These are ambitious targets that cannot be met without a radical overhaul in current practices. The UK spends approximately £90 billion on Capital Expenditure of built assets each year. Of the total assets, approximately half are public assets. In comparison Operational Expenditure is £122 billion each year. Thus, the Government's urge has been for the industry to explore new ways of being effective. This drive from the Government for the industry to improve isn't new. Historically, there have been several Government reports (see timeline in Figure 1) starting with Sir Michael Latham's report on "Constructing the Team" in 1994 (Latham, 1994) which urged the industry to enhance teamwork and address the adversarial practices that affected its image. Subsequent reports such as "Rethinking Construction" (Egan, 1998), Accelerating Change (Egan, 2002), Never Waste a Good Crisis (Wolstenholme et al, 2009), Government Construction Strategy (Cabinet Office, 2011) and Government Construction Strategy 2016-2020 (2016) all call, among other things, for the industry to improve performance, accelerate change, enhance teamwork, work collaboratively, explore new ways of working, embrace technology and more recently use BIM.

Figure 1: Historic TimeLine of Influential UK Construction Industry Government Reports

There are several BIM standards that provide a framework for information management through-lifecycle. Examples include the BS EN ISO 19650 series (ISO 19650-1 and ISO 19650-2) (BSI, 2019) of international standards for managing information over the lifecycle of a built asset using BIM. These are founded on UK standards for information management using BIM. The Hackitt review calls for a through-lifecycle digital record of asset information to be maintained and made available to the duty-holders to perform their duties and maintain a facility. BIM is an enabler of the digital record. A typical BIM, depending on the level of maturity, would hold information about the asset generated by different stakeholders, including architects, structural engineers, fabricators, building services engineers and bridging engineers. The BIM would hold contextual information about the objects (e.g. building components) contained within the model. Typically, this would include information such as product (or object) data (Eastman et al, 2011; Emmitt and Ruikar, 2013) product specifications, properties (physical attributes, geometries, chemical composition) (Eastman et al, 2011; Emmitt and Ruikar, 2013) and other user-defined attributes such as performance characteristics, costs and fire ratings, combustion properties and ignition properties, as examples.

PAS 1192-3, now superseded by ISO 19650 (HM Government, 2007), provides a framework for information management at the operational phase. It requires the duty-holders to capture information in the asset information model, at various "trigger" points when the information about the asset is likely to change. Changes to be recorded are those due to minor works, major works, refurbishments, maintenance, end-of-life and other similar triggers, which affect the integrity of the asset information. Thus, a BIM environment provides a means to generate up-to-date, asset lifecycle information, as is recommended by the Hackitt Review. The creation of an up-to-date asset information model that holds critical information about fire safety is very important, as it forms an integral part of the digital record and the FEF to be handed over to the Fire and Rescue Services, in the event of an emergency. The effectiveness of a timely response would be dependent on the completeness of the information that preserves the design intent and maintains the asset's history in the FEF. Providing access to up-to-date building information to owners and/or duty-holders is thus, critical for effectively carrying out FRAs (fire risk assessments) and taking remedial actions to mitigate potential risks and ensure occupant safety. This digital replica of the as-built physical asset which models related product and process data is a 'digital twin'. This concept is not new and has had its roots in the Aerospace industry. It has grown in prominence in the UK construction literature (Savian, 2019; and Fryer, 2019; Madni et al, 2019) due to the digital drive in the construction industry. For instance, according to Fryer (2019), modelling products and processes has been around for a few decades, but recently we have seen an emergence of digital twins (Ross, 2019), which have their origins in the design process. Over the years this has transformed design and manufacturing due to the creation of repeatable and reusable automated processes to predict and optimise performance and to realise the fully automated potential. These changes would need to be supported by developing digital workflows. Such a digital twin would fulfil the digital record related requirements outlined in the Hackitt Review, which recommends that the FEF should be a clearer obligation on the client, Principal Designer and Principal Contractor to initiate, update and finalise and then pass onto building owner to help them to better understand how a building management is improved in the event of a fire. The review includes a non-exhaustive example list of the type of information to be recorded, maintained and made available to the duty holders, as follows:

- Size and height of the building
- Full material and manufacturer product information
- Identification of all safety critical layers of protection
- Design intent and construction methodology
- Escape and fire compartmentation
- Records of inspections/reviews/consultations
- Building structure and fabric
- Permanent fixtures and fittings

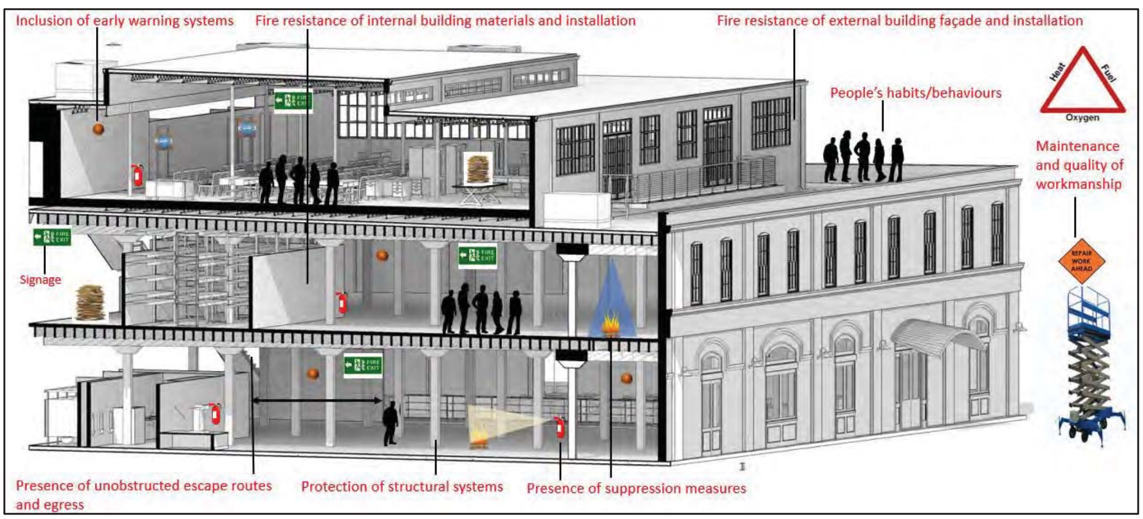

Figure 2: Fire engineering and safety information to be recorded in a BIM

It is widely recognised that several, 'disparate' stakeholders are responsible for creating and maintaining building information, whose collective inputs affect the fire safety objectives. Often the stakeholders who are responsible for generating the information (e.g. designers, engineers) are different from those constructing the building (e.g. contractors, sub-contractors) and from those responsible for maintaining the building (e.g. owners, occupiers, facilities managers) and/or those responsible for protecting it (e.g. fire and rescue services). In an emergency, the fire and rescue services are required to make snap decisions with the information at hand and often the effectiveness of the decision is based on the availability, correctness, and/or the completeness of the information available at hand. Thus, any future digital FEF would need to ensure that the needs of those responsible for safeguarding the interests of the asset are engaged in critical stages of the design and development processes so the information that is collected is of use to them in an emergency. Because, in a typical project, there are different stages and different stakeholders involved, each with their own set of information requirements, it is critical that each stakeholder group is represented at the requirements capture stage, so their needs are appropriately met. For this purpose, an approach to design 'digitally' with the end in mind is adopted so that the resultant asset is safe by default.

4. Proposed Conceptual Framework for a Safe by Default Asset Delivery

The Hackitt review recognises the potential risks to occupants and visitors of buildings in emergency situations and recommends that "relevant professional bodies" can help determine the scope of information to be included in the FEF. Representation from the relevant bodies would ensure that their requirements, from a fire safety perspective, are met. These bodies represent disparate stakeholder groups, each of which are involved at different stages of the project. In a typical project, project teams form, disband and (sometimes) reform at different lifecycle stages. Throughout the lifecycle of the process these teams use discrete software systems to process documents, graphical and non-graphical building information. This information could be potentially lost, if not captured in context. To mitigate the risk of knowledge loss and to control its adversarial impact on the project's safety objectives, it is critical that the digital record and the FEF are contained within a 'digitally tracked' process that progressively records the information as the project progresses. Also, from a fire safety objective perspective, there is an underlying need to capture the information within context and structure it such that the information requirements of the stakeholders (to meet fire safety objectives) are firstly understood and then met. For this purpose, the "safe by default" conceptual framework has been developed with the collective stakeholder perspective in mind. It recognises that the collective inputs of interdisciplinary stakeholders affect lifecycle fire safety objectives and subsequent safety outcomes. Because, those responsible for generating the information (e.g. designers, engineers), are different from those who maintain the building (owners, occupiers, facilities managers) and those who protect it (Fire and Rescue Services), a digital approach to designing with the end in mind and ensuring lifecycle safety objectives are met from the start, is proposed. The conceptual framework thus, encourages interdisciplinary stakeholder representation at different lifecycle stages of a building, so their requirements are met. The inter-disciplinary engagement promotes a joint-up, interdisciplinary approach to problem-solving to understand 'holistic fire-safety' information requirements, facilitate information capture and process, validate and disseminate information beyond what is currently possible. Safe by default framework (Figure 3) promotes a BIM-enabled, cross-sector stakeholder-driven best practice approach to capture and maintain contents of a digital FEF at key lifecycle stages (RIBA 0-7).

4.1 Safe by Default Approach Using a Participatory Workshop Method

The research proposes a participatory workshop method to actively encourage people to participate in workshop activities, instead of being passive recipients in the research inquiry process. Thus, rather than passively receiving information from outside experts, who may not have local understanding of the issues (e.g. concerning an emergency response, fire-engineering in design, maintaining FEFs), participants are encouraged to share information, learn from each other, and work together to solve common problems (Newman, 2019). This method relies on active participation from workshop stakeholders, who are intrinsic to the 'problem' of study. The sample size can have a considerable effect on the quality of qualitative research (Coyne, 1997). An adequate sample is that in which the breadth and depth of information has been achieved (O'Reilly and Parker, 2012 in Zanni, 2016). Through enabling an inter-disciplinary dialogue that brings together cross-disciplinary stakeholders with representation (i.e. *sample*) from the various stages of the lifecycle process, the key areas of inquiry in relation to fire-safety and BIM could be determined. This would accelerate the emergency response and ensure that the response is based on *"readily available digital building information that is accurate, updated, complete and accessible"*. The approach enables rapid realisation of the requirements of the Hackitt Review (2018). For this, an approach that promotes a series of workshops at critical stages of the project process is proposed. Each workshop [W1-3] will enable identification of the information needs to be captured in the digital record, [WI] before occupying the building (during design and construction); [W2] during occupation (post-handover and in-use); and [W3] in an emergency to protect the building. This would ensure that the golden thread of information, as recommended by the Hackitt Review, persists throughout the building's lifecycle, and thus, delivers a digitally-tracked twin.

The safe by default approach will enable gathering and developing the information requirements that are critical at different stages of the building lifecycle i.e. design, regulatory approval, manufacture, construction and operations. This is an under-researched and under-explored area of work. It is critical to ensure that essential safety information is embedded from the design stage onwards, to inform manufactured components used in construction, to be carried through so it is available to the end users, preferably in an automated fashion. To achieve the aspiration of 'safe by default' through automatic validation and updating of product and strategic data within BIMs at different lifecycle stages of an asset will require knowledge capture from various stakeholders and connecting it to the BIM. For this purpose, cross disciplinary workshops will be conducted, they will include stakeholder representation from designers, fire safety experts, fire and rescue services, building component manufactures, safety systems manufacturers, health and safety experts, regulatory bodies with duties to approve plans and enforce fire safety matters, technology solution providers, building insurers and building owners.

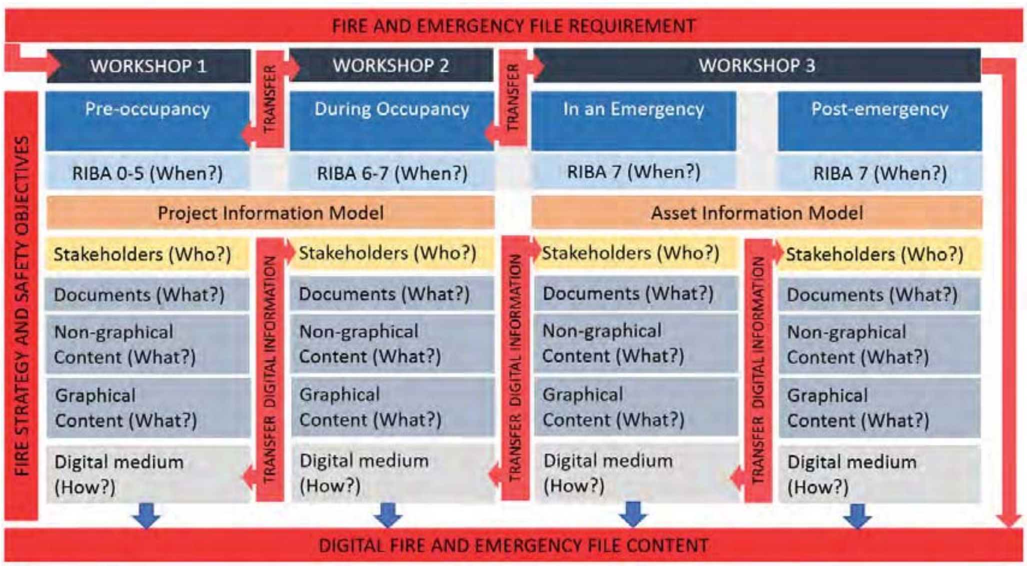

Figure 3: Safe by Default Conceptual Framework

For this it would be essential to initiate and grow a cross-industry interest group (CSSIG) with a focus on fire safety information needs of end-users, to fill a gap in policy and provide guidance on how fire safety is properly considered in BIM that does not exist currently. This will ensure public safety and quick emergency response are at the heart of the digital transformation that the construction industry is currently undergoing. The novelty of the proposed approach lies in connecting currently 'disparate' cross-disciplinary stakeholders, whose collective actions affect the 'safe by default' aspirations. Doing so, would enable the special interest group to work alongside technology providers to achieve a common goal of identifying the ingredients of the 'golden thread of building information' and the delivery of digitally tracked twin, by leveraging current and emergent technologies and their requirements for information capture and validation, so safety is by default and design is with the end in mind. This research group will also be able to identify the information and skills gaps that are apparent within the current construction supply chain and those that are required to be developed to achieve this safe by default vision. For example, embedding safety information within manufactured components and then allowing automated verification and relaying of the information to BIM is one of the key challenges' manufacturers face in both, technology and workforce skills development. Identifying these skills gaps and upskilling the supply chain is a requirement and in line with the expectations of the Industrial Strategy Construction Sector Deal. This could revolutionise the way in which UK designs, constructs and operates buildings and infrastructure by realising the potential to integrate advanced construction product manufacturing with state-of-the-art digital design, for a safe and resilient outcome.

4.2 Workshops and Outputs

Digital stakeholder requirements would be captured through three stakeholder workshops [W1-3] representing different lifecycle stages (see Figure 3). The proposed workshops would engage construction's academic and industrial communities and connect them with those communities that are responsible for safe-guarding the interests of the public in delivering the 'safe by default' asset in the event of a fire-related emergency.

The Government's soft landings guidance recommends that the building's 'in-use' or 'operations' phase should be considered throughout the project's lifecycle- from cradle to grave. Given that BIM has been mandated for publicly procured buildings (Cabinet Office, 2011), the clients are increasingly acquiring information in digital forms. The information exists in documents and in graphical and non-graphical formats. As the amount of information progressively increases in complexity, level of detail and changes formats from the early design, through construction and to the in-use phases of the project, so does the need to effectively manage the information become critical, particularly so that the safety objectives are met. Also, the information is collectively generated by a range of stakeholders, whose participation at the requirements capture stages is critical for the quality and completeness of the information generated. The typical stakeholders who would participate in the workshops would include representatives from (but not limited to): Clients, Representatives from Local Council, Designers (architects, structural), Manufacturers, Product suppliers, BIM managers, Technology tool providers, Contractors and sub-contractors, Fire Engineers, Fire and rescue services, Occupants (Duty-holders), Facilities Managers of High Risk Highrise Buildings, Academics, Government and Policy-makers.

To ensure that the golden thread of building information is captured using BIM as a vehicle, the safe by default approach would, through a series of workshops, capture:

- [W1] Project Information Model (PIM) requirements at the pre-occupancy stage of a project to represent RIBA 0-5;
- [W2] PIM requirements during-occupancy stage of a project to represent RIBA 6-7; and
- [W3] Asset Information Model (AIM) requirements of response teams in-an-emergency and post-emergency to represent RIBA 7.

With reference to the fire strategy and the intended fire-safety objectives, each of the above information requirements [from W1-3] would be categorised into templates [T1-3] that capture the digital information about:

1) Who is responsible? Stakeholder/s responsible for creating, organising, storing, sharing and (re)using the fire-safety information.
2) What is the information? Identifying documents, standards, graphical and non-graphical contents created, organised, stored, shared and (re)used at different stages of the RIBA (0-7) lifecycle. Here consideration would be given to capturing the content at "triggers" identified in the AIM (BS EN ISO 19650)8, when the information is likely to change.
3) How the information will be created, organised, stored, shared and (re)used? Identifying digital tools that are used to create, store, share and (re)use the digital record. Consideration would be given to the longevity of the information, so that it is migrated to systems that are current (i.e. not obsolete).

Templates [T1-3] would be created to identify specifics of the Who? What? When? and How? of the information-cycle at RIBA stages. The 'why', i.e. designing with the 'end in mind' for a safe by default outcome, would form the thread that connects the three workshops and their outputs. [W1-3]. Each template, starting with T1 (through T2 towards T3) will capture digital information requirements of the corresponding stage (i.e. pre-occupancy, during-occupancy and in-an-emergency/post-emergency). This information would be transferred iteratively between stages to refine the template content, so that progressively 'developed' information continues to be captured in context and remains up-to-date. Iterations ascertain that the digital record tracks changes so that the contextual ('fire-safety') characteristics of the physical DNA are identified (and represented) in the DNA of the digital twin.

4.3 Opportunities

The proposed conceptual framework presents opportunities that enable:

- Mapping of the various documents generated through the lifecycle of a building project, within which decisions affecting a building's fire safety objectives (e.g. fire strategy design report) are contained, against the information management requirements identified in the operational phase of the asset using BIM (to fulfil BS EN ISO 19650).
- Agreement on and help with defining the roles and responsibilities of stakeholders to support knowledge processes as per the requirement to source, create, capture, share, transfer and re-use fire-safety knowledge (i.e. information in context).
- Developing a BIM-enabled stakeholder-driven best practice template for digital record keeping at critical stages of the project's lifecycle so digital records and contents of the FEF based on identified stakeholder requirements are captured and maintained at various 'trigger' points identified in the ISO 19650.

4.4 Challenges

Although there are several opportunities to be had from adopting the safe by default approach, the are challenges too, these are:

- Designing with the end in mind requires a radical shift in how projects would be delivered. This necessitates early engagement of stakeholders, who are currently involved much later in the process. For this to happen, new datasets and workflows would need to be defined;
- Defining new datasets and workflows for fire safety requirements in the BIM process would require cross-disciplinary stakeholder engagement at requirements capture stage. Identification of these stakeholders and acquiring buy-in from them would be essential;
- Early engagement of Fire and Rescue services to deliver 'requirement-specific' (in an emergency) BIM datasets and related digital workflows is critical, if this 'radical' vision is to be realised;
- Providing Fire and Rescue services with uninterrupted access to 'current' digital records (and the FEF) during an emergency would require secure access to data;
- Identifying gaps in existing skillsets of the supply-chain which limit the provision of digital records;
- Driving a top down push from Clients to propel ubiquitous adoption of BIM in the construction industry;
- Making sure that the information is available in an accessible format to the different stakeholders throughout the building's lifecycle;
- Ensuring that information storage formats/media are always current (not obsolete); and
- Safeguarding information security and ensuring the record is being regularly updated in the digitally tracked twin.

5. Summary and Conclusions

The paper presented a novel approach to deliver 'safety by default' so costly lessons could be avoided. The basic premise of the proposed conceptual framework has been to ensure that safety isn't an afterthought and designs are done with the 'end in mind' resulting in a building that was safe by default. With this guiding principle, the research, "Safe by Default" enables the rapid realisation of the Hackitt review recommendations by providing a framework that enables the capture and storage of digital building information affecting fire safety of buildings through lifecycle. The approach is built on the premise that BIM provides the backbone to hold critical fire safety building information and assists in creating a safety-enhanced digital twin of the physical asset. There are several opportunities for realising this ambition, but numerous challenges still remain.

References

BRE 2019, Regulation 38 and fire safety engineering. Available from :- http://www.bre.co.uk

Brister, A. (2013). [online]. In the Line of Fire. Modern Building Services. Published 04 April 2013. Available from: - http://modbs.co.uk Accessed (09/03/2015).

British Standards Institution, (2012) PD7974-8 Application of fire safety engineering principles to the design of buildings – Part 8: Property protection, mission continuity and resilience. London: BSI.

British Standards Institution, (2019) Transition guidance to BS EN ISO 19650. London: BSI.

BSI (2019) BS EN ISO 19650 1&2: 2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling. BSI.

Building Information Modelling (BIM) Task Group. 2016. Frequently asked questions. http://www.bimtaskgroup.org/bim-faqs/.

CIC (2017). Construction Industry Council. Submission of evidence to the Independent Review of Building Regulations and Fire Safety.

Coyne, I. (1997). Sampling in qualitative research. Purposeful and theoretical sampling; merging or clear boundaries? Journal of Advanced Nursing. Vol. 26 Issue 3, pp. 623-30 Available from :- https://www.ncbi.nlm.nih.gov/pubmed/9378886

Dimyadi, J. and Amor, R. (2018) BIM-based Compliance Audit Requirements for Building Consent Processing, Proceedings of EC-PPM 2018, Copenhagen, Denmark, 12-14 September, pp. 465-471

Dobson, A. (2018). [online]. We need minimum prescriptive requirements in building regulations. Inside Housing. Available from:- https://www.insidehousing.co.uk/comment/comment/we-need-minimum-prescriptive-requirements-in-building-regulations-55212 Accessed on: 07/05/2019

Egan, J. (1998). Rethinking construction. London: Department of Environment, Transport and the Region. Department of Environment, Transport and the Region. London

Egan, J. Sir (2002) Accelerating Change. Rethinking Construction, London.

Fryer, T. (2019). Industry benefits from the digital baby boom. Meet the New You, The rise of the digital twin- from products to people. Virtual Models in medicine, manufacturing, maintenance and more. Engineering and Technology, Volume 14, Issue 1, February 2019.

Government Construction Strategy 2016-2020. (2016). 1st ed. London: Infrastructure and Project Authorities, pp.2-8.

Hackitt, J Dame (2018) Building a Safer Future, Independent Review of Building Regulations and Fire Safety: Final Report.

Hasofer AM, Beck VR, Bennetts ID. (2007). Risk analysis in building fire safety engineering. Oxford: Butterworth-Heinemann, UK.

HM Government (2007). Approved document B. Fire safety. HM Government.

HM Government. (2013) Construction 2025. Industrial Strategy: government and industry in partnership. London.

Home Office (2018). National Statistics. Detailed analysis of fires attended by fire and rescue services, England, April 2017 to March 2018. Available from: https://www.gov.uk/government/statistics/detailed-analysis-of-fires-attended-by-fire-and-rescue-services-england-april-2017-to-march-2018 (Accessed: 09/05/2019).

Latham, M. Sir (1994). Constructing the team. London: HMSO.

Madni, A. M., Madni, C. C. and Lucero, S. D. (2019). Leveraging Digital Twin Technology in Model-Based Systems Engineering. Systems. Volume 7, Issue 1. Available from: - https://doi.org/10.3390/systems7010007 (Accessed 08/05/2019).

Malhotra, H.L., (1987). Fire safety in buildings. Borehamwood, Herts.: Building Research Establishment.

Newman, J, M. (2019). Participatory Workshops Understanding Participatory Approaches to Learning. Published by the International HIV/AIDS Alliance. Available from :- http://www.lupinworks.com/roche/workshops/1-understanding.php. (Accessed: July 2019).

Ross, D. (2019) Editor's Letter, Meet the New You, The rise of the digital twin- from products to people. Virtual Models in medicine, manufacturing, maintenance and more. Engineering and Technology, Volume 14, Issue 1, February 2019.

Ruikar, K and Glockling, J (2015) Dr Kirti Ruikar and Dr Jim Glockling explore whether a digitised owner's manual is the answer to future resilience and examine opportunities presented by Building Information Modelling to facilitate compliance with Regulation 38 of the Building Regulations, Fire Risk Management, (April), ISSN: 1757-1324

Ruikar, K. (2018). Building Information Modelling and Regulation 38; Using information systems for resilience. Workshop 1 Presentation. Fire Sector Summit. 10-11 November 2014. Sopwell House Hertfordshire. UK

Savian, C. (2019). Potential to use BIM data in digital twins is being overlooked'. BIM Plus. Available from :- http://www.bimplus.co.uk/analysis/potential-use-bim-data-digital-twins-being-overloo/

Wilkinson, P.J., Glockling, J.L.D, Bouchlaghem, N.M. and Ruikar, K.D. (2010a) Has fire engineering lived up to expectations? Proceedings: 8th International Conference on Performance-Based Codes and Fire Safety Design Methods, 16-18 June 2000, Lund University, Lund, Sweden. Bethesda, MD and Dept. of Fire Safety Engineering, Lund Universitet.

Wolstenholme, A., Austin, S., Bairstow, M., Blumenthal, A., Lorimer, J., McGuckin, S., Rhys Jones, S., Ward, D., Whysall, D., Le Grand, Z., Guthrie, W. and Richards, D. (2009). Never waste a good crisis: a review of progress since Rethinking Construction and thoughts for our future. London: Constructing Excellence.

Zanni, M. A. (2016). Communication of Sustainability Information and Assessment within BIM-enabled Collaborative Environments. Doctoral Thesis, Loughborough University.