Factors contributing to Building Fire Incidents: A review

R.M.D.I.M. Rathnayake, P. Sridarran and M.D.T.E. Abeynayake
Department of Building Economics
University of Moratuwa
Moratuwa, Sri Lanka
ra-ishara@uom.lk, psridarran@uom.lk, mabeynayake@uom.lk/ maheshbecon@uom.lk

Abstract

Buildings are long-lasting infrastructures which usually designed to withstand over 60 years. Durability or performance of the building is affected by numerous reasons and among that fire incidents may cause direct or indirect impacts to the present building or even in old age. Building collapses, implied damages and potential injury can be identified as outcomes of fire incidents. Moreover, fire fatalities are reported frequently as a red light to the safety of buildings. Despite, many fire detection and protection techniques are available for buildings, building fires are still considered as a major threat to the occupants. Thus, to ensure fire safety of the building, comprehensive review of past fire incidents to identify factors affecting to the fire is needed. Hence, this study aimed at reviewing the factors which are mostly affecting to the building fire incidents worldwide. A comprehensive literature review was directed to explore the behaviour of building fire, hardware and software measures of fire safety, models for fire impact evaluation, global fire incidents in different buildings and factors affecting to the building fire incidents. Building design features, refurbishment practices, human behaviour, fire regulations, policies and building codes, fire fighting tools and techniques and perceptions of architects and fire protection engineers were identified as factors affecting to the building fire incidents. Finally, the paper proposes a conceptual framework for better understanding on past fire incidents and to strive for fire resistant buildings in the future.

Keywords
Building Fire, Fire Incidents, Factors and Review.

1. Introduction

Fire incidents have considerably increased during last years by endangering human lives and have caused economic and ecological damages (Félix et al. 2014). Shocking fire events challenged the essence of the building performance. Further, among various reasons, uncontrolled fires, is one of the major reasons for building collapses, implied damages, potential injury and loss (Wong and Jan 2003). Not only that, at local to regional scales and at global scale, emissions due to fire incidents have significant impact on air quality and atmosphere. Moreover, after a fire, people tend to be traumatised due to the losses of belongings. Among that, losing the building is one of the most stressful factor for building owners (Caia et al. 2010). World Fire Statistics Report 2018 No. 23, which reported fire incidents in year 1993-2016, 2.5 to 4.5 million fires occurred and nearly 62 000 fire deaths were reported from 57 countries (International Association of Fire and Rescue Services 2018). Accordingly, failure to consider the causes for building fire incidents leads to under-performance of existing fire safety system in the building (Xiuyu et al. 2012). This implies that there is a necessity of reviewing factors affecting to the building fire incidents, which so far not has been addressed as a research area. Therefore, the focus of this paper is to have a precise consideration on the factors affecting to the building fire incidents.

2. Research Methodology

In order to review the contributing factors for building fire, an extensive literature review was conducted. Current knowledge on this area was explored through keyword searching (Building fire*, Fire incidents* Factors* Review*). Databases such as; Science Direct, Emerald Insight, SAGE, Springer Link and IEEE Xplore were involved to conduct the literature review. Mainly 24 journal articles from 15 journals, 5 conference papers, 8 books and official websites were referred to conduct the literature synthesis. Behaviour of building fire, hardware and software measures of fire safety, models for building fire impact evaluation, global fire incidents in different buildings and factors affecting to the building fire were explored after a thorough literature review. Table 1 depicts summary of referred sources for literature synthesis.

Table 1: Referred journals for literature synthesis

Journal name	Article name
Architectural Science Review	Building fire safety in the far east
Building and Environment	Correlation equations on fire-induced air flow rates through doorway derived by large eddy simulation
	Italian experiences on acoustic classification of buildings
	Total building performance evaluation of academic institution in Singapore
Fire Safety Journal	Analyses of the effects of cooling and fire spread on steel-framed buildings
	Simulation of ventilation and fire in the underground facilities
	Flame and smoke detection method for early real-time detection of a tunnel fire
	Compartment fire phenomena under limited ventilation
	Building safety and human behaviour in fire: A literature review
Fire Technology	A water requirements estimation model for fire suppression: a study based on integrated uncertainty analysis
	Enhancing building fire safety performance by reducing miscommunication and misconceptions,
	A fire safety evaluation system for prioritizing fire improvements in old high-rise buildings in Hong Kong
Heat Transfer—Asian Research	Ventilation effect on fire smoke transport in a townhouse building
International Journal of Building Pathology and Adaptation	Sustainable refurbishment for school buildings: a literature review
International Journal of Heat and Technology	Analysis of mechanical system ventilation performance in an atrium by consolidated model of fire and smoke transport simulation
International Journal of Scientific Research	Theoretical and conceptual framework: mandatory ingredients of a quality research
Journal of Architectural Engineering	Benchmarking current conceptual high-rise design processes
Journal of Housing and the Built Environment	The role of temporary accommodation building for post-disaster housing reconstruction
Journal of Environmental Psychology	Container vs. dacha: The psychological effects of temporary housing characteristics on earthquake survivors
Optical Engineering	Color model and method for video fire flame and smoke detection using Fisher linear discriminant
Procedia Engineering	Factor Analysis of High-Rise Building Fires Reasons and Fire Protection Measures
	Factor analysis of high-rise building fires reasons and fire protection measures
Safety Science	An occupant response shelter escape time (ORSET) model
Social Science Quarterly	Normative collective behaviour in the station building fire

3. Behaviour of Building Fire

Civilisation might not even exist or would be radically different without presence of the fire (Stollard and Abraham 2002). Fire can be beneficial but it can also be deadly. Further, fire is one of the most common accidents which damage can be limited or wide range (Chow 2005). Even there are plenty of active and passive fire safety measures

available, fire resistant building is still a major challenge worldwide (Chow 2005). Building designers' and constructors' intention is to design a building which long-lasting over 60 years (Le et al., 2018). However, the intention is failed due to various reasons and among that fire can be identified as critical. The fire impacts to the durability and performance of building in the present building structure or even old age. Therefore it is necessity to examine the behaviour of fire to have a better understanding of fire safety in a building.
The combustion phenomenon of fire is defined as rapid oxidation accompanied by light and heat. Chemical combination of any substances with oxygen can be recognised as oxidation (Hasofer et al. 2011). The classic triangle concept of fire is identified oxygen in some form, fuel (material) and heat to maintain combustion as three key factors for a fire (Hasofer et al. 2011). Further, the concept is explained that removing one factor will extinguish a fire by opening the triangle and to prevent a fire from starting, any one factor should be keep from joining the other two factors. Later, classic triangle concept was challenged by a recent research which introduced a fourth factor (Hasofer et al. 2011). The study explains that combustion process is not as simple as the classic triangle, there is a fourth factor; chemical chain reaction which acts as a reaction chain to accelerate the burning. Hasofer et al. (2011) formulated tetrahedron theory which discuss the diffusion flame combustion fire phenomenon. Author symbolised the concept as a tetrahedron instead of a square since the four factors are adjoining and each factor is connecting with other three factors.

Chang and Huang (2005) have discussed about rate of fire growth based on the exponential growth, which explain effect of fire growth coefficient of burning material. Accordingly, Bailey et al. (1996) have found that fires spread both horizontally and vertically within the building. Common reasons for horizontal fire spread are open of fire doors, breakdown of compartment walls, extinction, ventilation conditions and to balance of fuel supply (Bailey et al. 1996).Vertical spread of fires can be due to flames being directed through broken windows, through a lobby or vertical shafts. Further, Chang and Huang (2005) have discovered nine fire curves according to different fire growth rates. Fire growth involving synthetic materials such as polyurethane is known as ultra-fast fire growth. Accordingly, researchers have declared that fire growth rate is a vital factor in determining fire effects (Kobes et al. 2010; Sime 2001). Hasofer et al. (2011) have defined the transition from growing fire in a compartment or a building to a fully developed fire as a flashover. In a flashover, all combustible materials in the building are involved in the fire. As results of classical and tetrahedron concepts, and other fire phenomena lead to discover, hardware and software measures of fire safety (Hasofer et al 2011).

4. Hardware and Software Measures of Fire Safety

Fire safety system of a building is designed with the aim to reduce the effect of fire in the building aspects in terms of likelihood and consequences. A fire safety system of building can be considered to ensure fire safety within the building where the fire is initiated and outside the building where the fire is initiated. Early fire detection is very important as preliminary firefighting method. As early fire detection measure ultraviolet and infrared detectors, particle sampling, relative humidity sampling, temperature sampling and transparency testing can be identified (Wei et al. 2013). These fire detection techniques provide emergency warning to escape or activate fire protection features. Visual based approach for fire identification acts as the most reliable information generating method (Liu 2012). Wei et al. (2013) recognised colour video technique as a method to identify fire flame from smoke. Complex hybrid system with multiple inputs from visual camera, infrared camera, meteorological sensors and geographical information database is supported to identify massive fires (Han and Lee 2009).

Control the growth and development of fire in early stage as well as facilitate sufficient evacuation paths and early warnings to building occupants are considered as safety considerations within the building. Further, fire safety in outside the building is examined to limit the spread of fire, control the spread of smoke and offer sufficient structural stability to escape and allow reasonable fire brigade activities. With the above objectives and function, each of these aspects are considered as sub systems of fire safety system in detailed (Hasofer et al. 2011). Five main subsystems can be identified as control of fire ignition and development in early stage, control of flame spread, control of smoke and toxic, facilitate of means to allow occupants avoidance and provision of sufficient structural stability. Different fire safety measures can be identified for each five subsystems and the measures can be categorised under hardware and software. Physical systems that are incorporated with the building are named as hardware whereas software refers to direct or indirect influence of human on fire safety or reliability of hardware systems. Table 2 presents the measures for three subsystems.

Table 2: Fire safety subsystems and their measures

Fire safety subsystem	Measures	
	Hardware	Software
Control of fire growth and development in early stages	Material of construction	Human monitoring
	Earth leakage devices	Maintenance of mechanical and electrical systems
	Surveillance system	Trained occupants for early fire fighting
	Alarm and detection systems	Maintenance of alarm and detection system
	Sprinklers, hose reels and extinguishers	Maintenance of sprinklers, hose reels and extinguishers
	Other automatic fire suppression devices	Presence of occupants within the building
Limit of flame spread	Materials of construction including linings	Management and maintenance of alarm and detection system
	Physical barriers	Maintenance of fire barriers
	Alarm, detection system and fire brigade	
Control of spread of smoke and toxic products	Smoke exhaust system including purging	Management and maintenance of smoke exhaust and pressurisation systems
	Physical barriers	Maintenance of barriers
	Stairs or zones pressurisation system	
Facilitate means to allow occupant avoidance	Exits	Evacuation drills
	Signage	Presence of trained wardens
Provision of structural stability	Structural behaviour	Maintenance of fire protective coating
	Concrete cover and fire protective coating	
	Size of structural members	

Source: Hasofer at al. 2011

5. Models for Building Fire Impact Evaluation

Consolidated Model of Fire and Smoke Transport (CMFST) is known as the world's most accurate simulation to evaluate impact of fire on the building environment (Alkhazaleh and Duwairi 2015). Further integration of CMFST to Berkeley Architectural Walkthrough (BAW) system, it delivers scientific visualisation of building condition during fire incident from the view of a person walking through a burning building. Through the BAW system natural visual effects of smoke and flame in fire condition can be evaluated and toxic compound in the air such as hydrogen cyanide and carbon monoxide and also temperature of the walls, floor and atmosphere can be evaluated (Alkhazaleh and Duwairi 2015). These technologies can be involved to enhance the architects and engineers understanding about the building fire. Fitzgerald's Building Fire Safety Evaluation Model (BFSEM) is analysed the sequential fire growth from ignition to spread beyond the origin point using network diagrams (ICC 2009; Satti and Krawczyk 2004). Fire Safety Evaluation System (FSES) is a parameter ranking model for the evaluation of fire safety performance which assigns weighted points to different fire safety parameters (Park et al. 2014). Based on the FSES, some similar fire safety parameter ranking methods were developed in Hong Kong and United Kingdom (Ding et al. 2004; Greenwood et al. 2010). While, BFSEM and FSES involves quantified values, Fire Safety Concept Tree (FSCT) is used structured tree diagram which evaluate fire safety objects as prevent fire ignition and manage fire impact (Park et al. 2014; Tubbs 2007). With the help of FSCT, engineers can easily understand the variability of different design solutions for different safety strategies (Park et al. 2014). Fire Dynamics Simulator (FDS) model which developed by National Institute of Standard Technology, analyses the behaviour of smoke and ventilation in different vent sizes of the building (McGrattan 2004). Further, FDS model with large eddy simulation can be used to analyse the thermal condition of the building (Lin et al. 2006). Generic Fire Response Model (GFRM) is developed to assist various stakeholders in the processes of fire development and fire response (Park et al. 2014). GFRM includes features and relationships of people, building, and fire responses. This model can be used as a generic model when stakeholders need to understand the big picture of fire safety performance. Not only that, GFRM provides fire safety strategies for stakeholders who are unfamiliar with the fire phenomena. When consider about the relationship between fir and building, fire consists with ignition, fire seize increase and propagation. Detection or notification, suppression, and separation are included in building component. Ignition activate the detection sub component which pass signals to notification and suppression system. The separation sub component discusses the compartmentation, assemblies, smoke control systems and fire related building components. Further, people component consists with occupants and fire services (Park et al. 2014). With the GFRM, stakeholders can easily recognised the relationship, importance and dynamic features of each components and communicate each other effectively. Whereas Integrated Characteristics Interaction Model (ICIM) denotes cause and effect relationship of fire incidents (Park et al. 2014). ICIM is identified as a supporting model to GFRM for defining specific interaction within any scenario. ICIM was introduced three individual models between building and people, people and fire, and fire and building. Further, this ICIM can be identified as a more detailed version of GFRM consisting hard and soft characteristics and their interconnection. To indicate the cause and effect relationship arrows are used, arrow head for effect and arrow root for cause and dotted lines between two characteristics show that one is considered as a sub-characteristic of the other. Figure 1 presents an individual model which describes the relationship between fire and building characteristics.

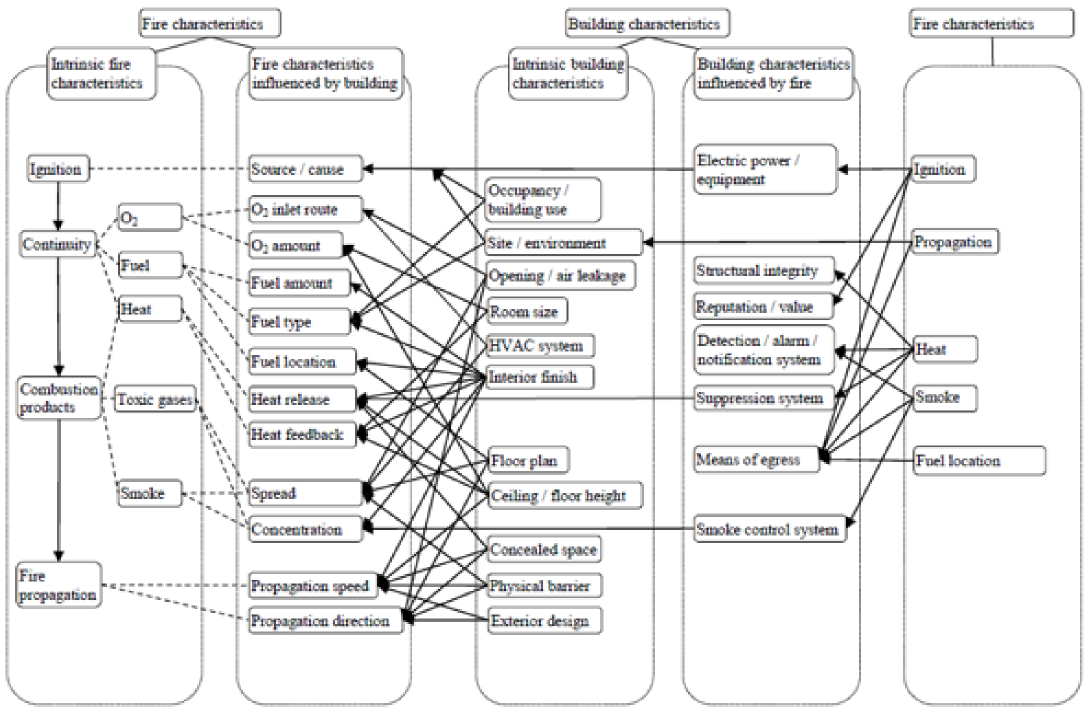

Figure 1: Relationship between fire and building characteristics

Source: Park et al. (2014)

6. Global Fire Incidents in Different Buildings

Every building has a risk of fire, and it is believed that complete safety from fire is an impossible task (Stollard and Abraham 2002). There are vast number of fire events happened worldwide but they are highlighted and attracted public attention only when fire caused serious damages or fatalities (Stollard and Abraham 2002). According to World Fire Statistics Report 2018 No. 23, highest fire rates relative to population are found in Australia, Bulgaria and Israel (International Association of Fire and Rescue Services 2018). United States of America as a developed country reported 1 342 000 fires and 3 390 fire deaths in year 2016 (International Association of Fire and Rescue Services 2018). India Risk Survey 2017 report has stated a total of 18, 450 fires with 1, 193 injuries and 17, 700 deaths in 2015 (Jha 2017). Accordingly, not only in developed countries, same risk can be seen in developing countries too. Asian region is identified as the second highest region with fire safety non-compliance and fire incidents have identified as the second highest disaster topology in Sri Lanka (Sedex Information Exchange, 2013; Disaster Management Centre, United Nations Development Programme in Sri Lanka, & United Nations Development Programme Regional Centre, Bangkok, 2009). Sri Lanka National Report on Disaster Risk, Poverty and Human Development Relationship-2009 has reported 2703 fires between year 1974 – 2007 (Disaster Management Centre, United Nations Development Programme in Sri Lanka, & United Nations Development Programme Regional Centre, Bangkok, 2009). Considering past fire incidents in different building perspective, worthwhile findings can be revealed. Most of the fatal fires happen at night in residential buildings, hotels, hospitals and hostels where people are sleeping, in buildings occupied by those who are unable to escape on their own, and in assembly buildings which have high density occupancy. Disastrous result of fire happen when it occur in crowded buildings (Li and Zlatanova 2007). These life threatening situations leading to fatalities as people are crushed or trampled. The Cocoanut Grove Dance Hall Fire in 1942 can be identified as one of the shocking fire incident happened in the history (Kobes 2010). The fire was resulted 490 deaths. A video of Station Nightclub fire revealed that within ninety seconds of ignition, fire turned into massive conflagration and whole environment of night club became indefensible, and resulted 100 deaths and 200 injured people (Grosshandler 2005; Bryner 2007).

The fire at the Station Nightclub in 2003 is considered as the fourth deadliest fire in United States history (Aguirre 2011). A fire in a coffee vending machine was caused to the fire in the Faculty of Architecture Building, Delft University of Technology in Netherland (Gane and Haymaker 2009). The fire was started around 9 AM in the 6th floor and rapidly spread vertically to the 11th floor of the south tower in year 2003. Then fire spread to the north tower and around eight hours after the fire started the north tower collapsed partially. Further, famous fire incidents in King's Cross underground station in 1987, where 31 people died and Bradford City football ground in 1985, where 56 people died (Cheng et al. 2001). Summerland indoor multi-storey leisure complex in Douglas which was the largest and most innovative indoor entertainment centre in the world. The complex was built with wall and roof of transparent acrylic sheeting. Small fire started due to discarded smoking materials in a fire glass kiosk. Later, kiosk collapsed into the building and spread fire rapidly along flammable walls and roof of the complex, resulting warped, melted and then collapsed the structure (EffectiveSOFTWARE 2017). A massive fire occurred at a high-rise building in Hong Kong in year 1996 (Wong and Lau 2007). Due to the ongoing construction, all the lift doors had been removed and this vertical openings allow rapid spread of flames throughout the building (Wong and Lau 2007) According to John (2017) the Grenfell Tower in London turned into a torch in 2017 which has recognised as the deadliest structural fire in the United Kingdom. The fire was started by a faulty refrigerator on the 4th floor and rapidly spread to building exteriors which resulted 72 deaths, 151 houses destroyed and more than 70 injured people. As a timely requirement with the previous severe fire incidents, there is a noteworthy necessity of examining the factors affecting to the building fire.

7. Factors affecting to the Fire Incidents in Buildings

Average five or six people die in fires each day in the United Kingdom and this case is more similar to many countries around the world, therefore to identify various causes that are result in massive fires is a major requirement since cost of fires are in uncontrollable level.

7.1 Building Design Features

Various design features and their integration in to the fire safety system can be identified as one of reasons for poor fire safety in buildings (Park et al. 2014). Dominant influence for fire can be seen from openings in the compartment by supporting to combustion with air supply. Further, researchers insisted that the flow of air is directly impacted on burning rate of the fire (Chow and Zou 2005; Utiskul 2005). This impact was demonstrated in past research test which has involved three enclosures in same geometry but with different openings locations which alter the air flow. Fire incident in the Faculty of Architecture building, Delft University of Technology in Netherland was an example for massive fires due to design features (Lottman et al 2013). The building was consisted with horizontally continuous window which installed throughout the structure and a mezzanine floor which were allowed openness and closeness. The Faculty of Architecture building was made of concrete and steel and with excellent fire resistant materials and also structure had complied with building codes in the Netherland. However, neither vertical fire suppression nor horizontal fire suppression was achieved (Park et al. 2014). Fire investigation revealed that there were various building features which contributed to the speed fire development and supported to a vertical fire spread (Park et al. 2014).

Moreover, the tall exterior window was encouraged large flames and horizontally continuous window acted as a channel for horizontal fire spread. In detailed, fire spread was due to open of fire doors, breakdown of compartment walls, extinction and ventilation conditions can be identify as reasons for horizontal fire spread in the University building (Lottman et al 2013). Moreover, vertical spread of fire was due to flames being directed through broken windows, through a lobby or vertical shafts (Lottman et al 2013). Further, old and wooded building structure were recognised as causes for fire incidents in King's Cross station and Bradford City building (Cheng et al. 2001). Fire incident at the Crowne Plaza Hotel in Denmark reported that firefighters took nearly 8 minutes to just find the door to reach the fireman's elevator which is placed within less than a 30 meter radius (Moriarty 2019). Later, investigators were identified that the reasons for took this much of time to find a door is due to absent of proper naming on the fireman's elevator and had the same colour for door and its background walls which make difficult to identify the door (Moriarty 2019). This design was considered as effective from architects' viewpoint because it provides a sense of a hidden space which actually intended to be used only for hotel staff. However, due to this design error critical delay happened in rescue process.

7.2 Refurbishment Practices

A high-rise building in Hong Kong was caught for fire due to improper refurbishment practices (Wong and Lau 2007). Lift shaft which was undergoing refurbishment was analysed as the reason for the quick fire spread in the building. One of the lift shafts was undergoing refurbishment with all of its lift doors removed. Temporary plywood panels were constructed but they were not well sealed, with some doors left open prior during the fire. Bamboo scaffolding had been erected inside the lift shaft for construction work. These vertical openings allow rapid development of flames throughout the building (Wong and Lau 2007).

7.3 Human Behaviour

The Hong Kong fire incident in high-rise building further discovered that the floor at the bottom of the lift shaft was assumed to have had garbage, papers, and wasted materials, hence supporting a massive fire hazard (Wong and Lau 2007). Welding work which had electric sparks was reported as ignition source with highly flammable materials. Not involving the building for its' original design function was identified as a cause for a fire incident in Hong Kong. The high-rise building was constructed for commercial and residential purpose, but later the building was used for industrial practices. Lack of quick response of fire brigade has identified as a reason for recent fire event happened in Kandy, Sri Lanka (Daily News, 2019). Further, Wong and Lau (2007) have explained that many construction workers are flipped away their cigarette while there are working in the refurbishment project. Careless smoking in the refurbishment, sloppy maintenance on electrical tools, faulty wiring, and lack of adequate fire watch can be identified as common human errors. Not only that, many multi-story building can be seen with lot of debris and waste items around the building. Further, careless or disgruntled workers and uneducated occupants can create fire hazards

7.4 Fire Regulation, Policies and Building Codes

Both designs for fire safety and protection in building are determined by building regulations. Legislation tries to assign minimum standards of safety which building stakeholders must comply (Li and Zlatanova 2007). Most of the building design does influence fire safety while others not. Building fire safety is basically maintained by fire safety regulations and building codes. These building fire safety codes and standards are established to avoid any unexpected losses in the building. But, building owners and responsible parties are tend to fulfil only minimum fire safety levels in the codes or standards (Li and Zlatanova 2007). On the other hand, some buildings are over maintained by fire safety provisions which are not cost-effective. Architects are reported that traditional building codes are not integrated with fire scenarios (Li and Zlatanova 2007). Furthermore, architects are complained that they cannot easily incorporate novel building concepts due to restrictive building codes. Therefore, they tend to follow basic requirements, such as exit with and travel distance (Li and Zlatanova 2007). Further, the technical standard UNI 11367 is still not a mandatory and it acts as voluntary requirement because the need of significant amount of time and other resources for proper implementation. Further, Sri Lankan Fire Bridge identified as poor equipped by international fire codes and standards (Daily News, 2019). However, attempts to meet the requirement without understanding the basic logic behind the law will be laid to ineffective fire safety of the building (Stollard and Abraham 2002). Table 3 presents the Difference between policy and actual fire situations.

Table 3: Differences between considerations in policy and actual fire findings

Considerations in policies	Knowledge developed from experiments and incident evaluation	Source
Fire growth is depended on standard fire curve, irrespective of the building materials and use of the building	Fire growth is depended on building materials available in the building; for example, combustion of synthetic materials direct to ultra-fast fire growth.	Kobes et al. (2010)
Occupants escape through the nearest emergency exit	Occupants usually escape through the familiar exit routes and hardly through emergency exits. Familiar routes are evidence as being shortest than unfamiliar routes	Li and Zlatanova (2007) Stollard and Abraham (2002)
People who are mobile can escape without assistance	All occupants are not self-reliant, they may need some degree of assistance	Park et al. (2014)
Occupants escape quickly after hearing a fire alarm	Generally occupants more quickly response to verbal signals ambiguous, especially people in groups commonly ignore the uncertain fire alarms.	Kobes et al. (2010) Stollard and Abraham (2002)
Occupants use escape route signage to find the nearest exit	Evaluation of four-hundred (400) cases shows that 92% of survivors were not aware of the escape route signage	Park et al. (2014)

7.5 Fire Fighting Tools and Techniques

Even though, advanced fire related simulation came-up to manage fire catastrophes, still uncertainties can be seen in fire prediction, detection and suppression techniques (Hasofer 2011). Even though many computer simulation fire related software have been developed, practical application is still in debate. According to Hasofer et al. (2011) many residential building's fire spread quickly due to appliances such as heating and lighting appliances, electric outlets and extension cords. Further, Daily News (2019) has identified that recent massive fire in the Kilinochchi, Sri Lanka has exposed many inadequacy in firefighting services and lack of proper equipment. Only 40 fire stations can be seen in Sri Lanka and half of them are located in the one province. Further, Yadav (2019) has stated that Delhi, India fire department reeling under lack of equipment and staff. Sky lifter is an essential vehicle during fire incident which is currently in shortage. Identified

7.6 Perceptions of Architects and Fire Protection Engineers

Park (2014) have recognised communication style, language problem and over designing as common reasons for the gap between architects and engineers. Communication style is indicated that architects as right-brain' dominated people who start a project with a pictorial representations and or qualitative expresses, while engineers as 'left-brain' dominated people start the project with quantitative aspects such as mathematical equations, calculation and formulas etc. When architects and engineers work together, engineers may feel that architects' expressions as imprecise expressions (Park 2014). Sometimes, architects do not compromise or do not have flexibility to change their artistic ideas according to the fundamental building requirements. Sometimes, architects may play the project manager's role by overseeing the whole project from design stage to stage of building occupation. Generally, functional and aesthetic requirements are concerned by architects when making design decisions (Park et al. 2014). Not only that, needs of clients and other stakeholders are also needed to fulfil. Further, fire safety is one of the considerations which always draw less attraction. Some argue that architect often fail to consider fire safety even though it considered as a public requirement. For that reason, fire protection measures have been enforced in the forms of codes and standards. Accordingly, architects design decisions may need to be modify to fulfil the codes and standards. This can be identified as the one of the reasons that architects consider these requirements as design constraints (Park et al. 2014).

Park et al. (2014) identified the role of fire protection engineers (FPEs) and emphasised FPEs' understanding on architects as one of the key players for fire safety**.** Further, authors have mentioned that architects should be informed and educated about fire safety in order to enhance the integration of architectural design on fire safety from the early design stages. On the other hand, FPEs also should be aware on effect of design features on fire safety in order to decide mitigation strategies. Moreover, authors have identified that FPEs involvement in late design stage, will be resulted in less or poor fire strategies involvement in building design. Accordingly, FPEs need a holistic understanding of building fire safety including building's physical performance, design features, building occupants and fire system in order to identify their influencing behaviour on each other. Even though, engineers are finding means to mitigate the impact of fire disasters, their frequency seems to be increased. Accordingly, FPEs and architects conduct their role with different perspective on the building, people and fire components.

8. Conceptual Framework

Conceptual framework provides basic structural background to recognise and elaborate facts and their relationship which gathered through literature review. A conceptual framework has developed with the support of the literature findings on research topic. Figure 2 clearly shows the behaviour of fire and factors contributing to building fire incidents.

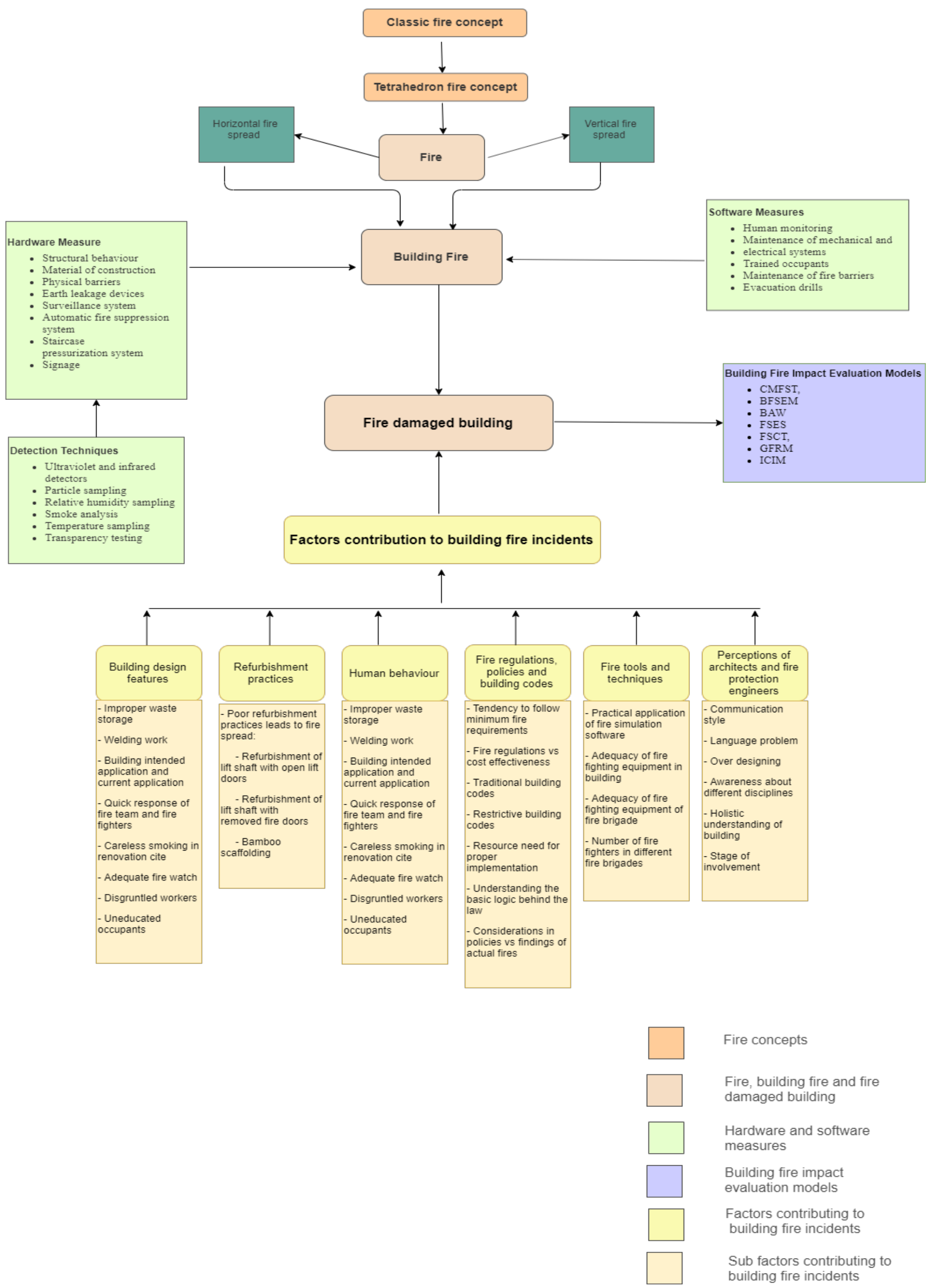

Figure 2: Conceptual Framework

9. Conclusion

Fire incidents are contributed to the economic and ecological damages worldwide. Failure to consider the factors affecting to the building fire incidents leads to under-performance of existing fire safety system in the building and it endangering human lives. This research paper presented the findings on factors affecting to the fire incidents in buildings. An extensive literature review was undertaken to explore the behaviour of building fire, hardware and software measures of fire safety, models for building fire impact evaluation, global fire incidents in different buildings and factors affecting to the building fire incidents. Findings of the paper review behaviour of building fire through classic fire concept and tetrahedron concept and involvement of hardware and software measures in building fire safety. Structural behaviour, material of construction, physical barriers, earth leakage devices, surveillance system, automatic fire suppression system, staircase pressurisation system and signage were recognised as hardware measures. Software measures are consisted with human monitoring, maintenance of mechanical and electrical systems, trained occupants, maintenance of fire barriers and evacuation drills. Early fire detection was recognised as an important preliminary firefighting method which includes ultraviolet and infrared detectors, particle sampling, relative humidity sampling, smoke analysis, temperature sampling and transparency testing. Further, existing models for building fire impact evaluation, such as CMFST, BFSEM, BAW, FSES, FSCT, GFRM and ICIM were examined as a detailed analysis methods for building fires. Different fire incidents in different building structures were also reviewed and the highest fire rates relative to population were found in Australia, Bulgaria and Israel. Asian region was identified as the second highest region with fire safety non-compliance and fire was identified as the second highest disaster topology in Sri Lanka. Accordingly, factors affecting to the fire incidents in building were recognised through various real fires in building worldwide. Building design features, refurbishment practices, human behaviour, fire regulation, policies and building codes, fire tools and techniques and perceptions of architects and fire protection engineers were evaluated as factors.

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References

Aguirrebuilding fire, *Social Science Quarterly*, vol. 92, no. 1, pp. 100-118, 2011.ive collective behaviour in the

Alkhazaleh, A., and Duwairi, H., Analysis of mechanical system ventilation performance in an atrium by consolidated model of fire and smoke transport simulation, *International Journal of Heat and Technology*, vol. 33, no. 3, pp. 121-126, 2015.

Bailey, C. G., Burgess, I. W., and Plank, R.J., Analyses of the effects of cooling and fire spread on steel-framed buildings, *Fire Safety Journal*, vol. 26, pp. 273-293, 1996.

Bryner, N., Madrzykowski, D., and Grosshandler, W., Reconstruction the Station Nightclub Fire-Computer Modeling of the Fire Growth and Spread, *International interflam conference,* pp. 3-5, 2007.

Caia, G., Ventimiglia, F., and Maass, A., Container vs. dacha: The psychological effects of temporary housing characteristics on earthquake survivors, *Journal of Environmental Psychology*, vol.30, no. 5, pp. 60-66, 2010.

Chang, C. H., and Huang, C. H., A water requirements estimation model for fire suppression: a study based on integrated uncertainty analysis, *Fire Technology*, vol. 41, pp. 5–24, 2005.

Cheng, L. H., Ueng, T. H.,and Liu, C. W., Simulation of ventilation and fire in the underground facilities, *Fire Safety Journal*, vol. 36, no. 6, pp. 597-619, 2001.

Chow, W. K., and Zou, G. W., Correlation equations on fire-induced air flow rates through doorway derived by large eddy simulation, *Building and Environment*, vol. 40, no. 7, pp. 897-906, 2005.

Chow, W., Building fire safety in the far east, *Architectural Science Review*, vol. 48, no. 4, pp.285-294, 2005.

Daily News, *Kandy Fire: Timely Action Helps Save Family*, Available: http://www.dailynews.lk/2019/01/08/local/173585/kandy-fire-timely-action-helps-save-family, January 8, 2019.

Disaster Management Centre, United Nations Development Programme in Sri Lanka, and United Nations Development Programme Regional Centre, Sri Lanka national report on disaster risk, poverty and human development relationship, Available: https://www.preventionweb.net/english/hyogo/gar/background-papers/documents/Chap3/Asia-overview/Sri-Lanka-DRAFT-march-09.pdfnd-papers/documents/Chap3/Asia-overview/Sri-Lanka-DRAFT-march-09.pdf, 2012.

EffectiveSOFTWARE, Learning from history: a lesson in fire safety, Available: https://www.effective-software.com/blog/learning-from-history-a-lesson-in-fire-safety, May 30, 2017.

Félix, D., Monteiro, D., Branco, J., Bologna, R. and Feio, A., The role of temporary accommodation building for post-disaster housing reconstruction, *Journal of Housing and the Built Environment*, vol. 30, no. 4, pp. 683-699, 2014.

Gane V., and Haymaker J., Benchmarking current conceptual high-rise design processes, *Journal of Architectural Engineering*, vol. 16, no. 3, pp. 100-121, 2009.

Greenwood D., Lockley S., Malsane S., Matthews J., Automated compliance checking using building information models, *The Construction, Building and Real Estate Research Conference of the Royal Institution of Chartered Surveyors*, 2010.

Grosshandler, W., Bryner, N. D., and Madrzykowski, K. K., *Report of the Technical Investigation of the Station Nightclub Fire*, Washington, DC, 2005

Han, D., and Lee, B., Flame and smoke detection method for early real-time detection of a tunnel fire. *Fire Safety Journal*, vol. 44, no. 7, pp. 951-961, 2009.

Hasofer, A.M., Beck, V.R., and Bennetts, I.D., *Risk Analysis in Building Fire Safety Engineering*, 2nd Edition, Routledge, New York, 2011.

ICC, *International building code*, 2009.

International Association of Fire and Rescue Services, *CTIF report-world fire statistics*, Available: https://www.ctif.org/sites/default/files/2018-06/CTIF_Report23_World_Fire_Statistics_2018_vs_2_0.pdf, January 11, 2018.

Jha, A., Zaidi, Z., Ramaswamy, S., Gupta, A., and Shama, B., *FICCI* – Pinkerton India risk survey, Available http://www.ficci.in/pressrelease/2806/india-risk-survey-ficci-press-release.pdf, 2017.

John, T., The continuing urgency of the Grenfell Tower inferno, TIME, Available: https://time.com/4830302/grenfell-tower-london-fire/, 2017.

Kobes, M., Helsloot, I., De Vries, B., and Post, J. G., Building safety and human behaviour in fire: A literature review, *Fire Safety Journal*, vol. 45, no. 1, pp. 1-11, 2010.

Le, A., Park, K., Domingo, N., Rasheed, E. and Mithraratne, N., Sustainable refurbishment for school buildings: a literature review, *International Journal of Building Pathology and Adaptation*, 2018.

Li, J., and Zlatanova, S., *Geomatics solutions for disaster management*, Springer, Heidelberg, New York, 2007.

Lin, C. S., Wang, S. C., Hung, C. B., and Hsu, J. H., Ventilation effect on fire smoke transport in a townhouse building, *Heat Transfer—Asian Research,* vol. 35, no. 6, pp. 387-401, 2006.

Liu, X., Zhang, H., and Zhu, Q., Factor Analysis of High-Rise Building Fires Reasons and Fire Protection Measures, *Procedia Engineering*, vol. 45, pp.643-648, 2012.

Lottman, B. B. G., Koenders, E. A. B., Blom, C. B. M., and Walraven, J. C., Spalling of concrete due to fire exposure: A coupled fracture mechanics and pore pressure approach, In *MATEC Web of Conferences*, vol. 6, pp. 78-99, 2013.

McGrattan, K. B., *Fire Dynamics Simulator: Technical Reference Guide*, Gaithersburg, MD, 2004.

Moriarty, R., Electrical fire reported at Crowne Plaza Hotel in Syracuse, firefighters say, Available: https://www.syracuse.com/crime/2019/09/electrical-fire-reported-at-crowne-plaza-hotel-in-syracuse-firefighters-say.html, September 20, 2019.

Park H., Meacham B. J., Dembsey N. A., and Goulthorpe M., Enhancing building fire safety performance by reducing miscommunication and misconceptions, *Fire Technology*, 2014.

Satti H. M., and Krawczyk R. J., Issues of integrating building codes in CAD *ASCAAD International Conference, e-Design in Architecture*, 2004.

Sedex Information Exchange, Fire safety briefing, Available: http://www.sedexglobal.com/member-services/reporting/, June 11, 2018.

Sime, J. D., An occupant response shelter escape time (ORSET) model, *Safety Science*, vol. 38, pp. 109–125, 2001.

Stollard, P., and Abraham, J., *Fire from First Principles: A Design Guide to Building Fire Safety*, 3rd Edition, Routledge, London, 2002.

Tubbs J., and Meacham B. J., *Egress Design Solutions: A Guide to Evacuation and Crowd Management Planning*: Wiley; 2007.

Utiskul, Y., Quintiere, J. G., Rangwala, A. S., Ringwelski, B. A., Wakatsuki, K., and Naruse, T., Compartment fire phenomena under limited ventilation, *Fire Safety Journal*, vol. 40, no. 4, pp. 367-390, 2005.

Wei, Y., Jie, L., Jun, F., and Yongming, Z., Color model and method for video fire flame and smoke detection using Fisher linear discriminant, *Optical Engineering*, vol. 52, no. 2, pp. 027205, 2013.

Wong, L. T., and Lau, S. W., A fire safety evaluation system for prioritizing fire improvements in old high-rise buildings in Hong Kong, *Fire Technology*, vol. *43,* no. 3, pp. 233-249, 2007.

Wong, N., and Jan, W., Total building performance evaluation of academic institution in Singapore, *Building and Environment*, vol. 38, no. 1, pp.161-176, 2003.

Xiuyu, L., Hao, Z., and Qingming, Z., Factor analysis of high-rise building fires reasons and fire protection measures, *Proceedia Engineering*, vol. 45, pp. 643-648, 2012.

Yadav, A., Delhi fire department reeling under lack of staff, equipment, India Today, Available: https://www.indiatoday.in/mail-today/story/delhi-fire-department-reeling-under-lack-of-staff-equipment-1455640-2019-02-14, 2019.

Biographies

R.M.D.I.M. Rathnayake is a visiting lecturer and a research scholar of Department of Building Economics, University of Moratuwa, Sri Lanka. She follows M.Sc. by Research in Project Management and earned B.Sc (Hons) in Facilities Management from University of Moratuwa. She has completed Intermediate in Applied Banking & Finance, the Institute of Bankers of Sri Lanka (IBSL). She is an Associate Member of Institute of Facilities Management. She has published conference papers. Her research interests are sustainability in construction, energy management, operation management and disaster management.

P. Sridarran is a lecturer of Department of Building Economics, University of Moratuwa, Sri Lanka. She earned B.Sc (Hons) in Facilities Management from University of Moratuwa. She earned her PhD from University of Huddersfield, United Kingdom in Disaster Management. She is a member of Institute of Facilities Management Sri Lanka (MIFMSL) and works as a BSc (Hons) in Facilities Management undergraduate degree coordinator and as Industrial Training assistant coordinator. She has published books, journal and conference papers. Her research interests include disaster management, facilities management and building performance.

M.D.T.E. Abeynayake is a senior lecturer of Department of Building Economics, University of Moratuwa, Sri Lanka. Mr. Abeynayake holds M. Phil from University of Moratuwa. He earned L.L.M and L.L.B (Hons) from University of Colombo. He serves as an attorney-at-law of the Supreme Court of Sri Lanka since 2001. Mr. Abeynayake works as a visiting lecturer at College of Quantity Surveying, Sri Lanka. He works as a legal consultant at Institute of Facilities Management, Sri Lanka. He has published books, journal and conference papers. His research interest include information technology law, dispute resolution, environmental law, and health and safety welfare.