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Fire Safety of Tall Buildings: Approach in Design and Prevention

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Abstract
Design of tall buildings is a multidisciplinary process and requires a wide range of measures to take to withstand in various emergencies. Fire is one of them and can cause of chaotic situations considering hundreds of users in multistorey. The measures are divided into two categories, active and passive fire protection. Architectural design and detailing are part of the passive systems. Along with the fundamental solutions in fire protection, tall buildings require more specific and often design-specific solutions. Detection and extinguishing systems are part of the active fire protection systems. The failure of the World Trade Centre pointed the vulnerability of steel structures; the fire at the Grenfell Tower pointed the significance of the enveloping materials for facades, and the fire at the One Meridian Tower pointed the significance of the active systems for every floor. The paper focuses on the fire case studies of tall buildings and follows with an assessment of the approaches in architectural design and detailing applicable from the structural design to the finishing interior detailing.
Keywords: Tall Buildings; Fire Safety; Fire Protection; Steel Structures; Fire-proof Design.

1. Introduction

Fire safety of buildings is a critical issue that either saves lives or cause deaths. In most sources, the statistics uncover the fact that smoke inhalation is the most common cause of death in most fire cases (Bush, 2015). For example, NFPA (National Fire Protection Association) in USA surveyed the fire cases between 2017 and 2019 and found that 2770 deaths were resulted only from 1900 fire cases in residential buildings, which accounted for 77% of all estimated fire fatalities. Furthermore, 37% of victims were found in fire escapes as they attempted to run away from the disaster, and 31% of victims were caught asleep. Bedrooms were, thus, reported by 50% as the place where the people caught in the first place, pointing at the night fires in buildings (National Fire Data Center, 2021). FRSs (Fire and Rescue Systems) across England examined the cases by September 2021 compared with the previous ten years. and published it on 10 February 2022. According to this fresh data, FRSs involved in 537,039 incidents including non-fire events and false fire alarms, of which 145,208 were fires. The fire cases were decreased by 5% compared with that occurred in 2020. In 2021, 243 fire-related casualties were reported, which was 231 in the previous year, 2020. Out of 145,208 fires, 26,950 were residential fires, with 73% were in houses, bungalows, converted flats etc., whereas 27% were in flats in multi storeys. Above 10 storeys, the building is considered high-rise, and 772 cases were reported in such buildings. 6468 fire cases took place in buildings with 9 or less storeys. Residential fires were decreased by 13% compared to that in 2016 and by 26% compared to that in 2011 (Home Office, 2022). According to the data of Modern Building Alliance, in United Kingdom, fire-related casualties were decreased by 56% comparing the numbers from 1982 to 2013. In France, fire-related casualties were decreased by 48% comparing the numbers from 1982 to 2012. Across the Europe countries the decrease was 65% for the past 30 years.
Building fire is often a result of human made mistake, e.g., cooking, smoking, heating etc. Other reasons include electrical problems, e.g., short circuit, old and unmaintained wires, faulty fuses and so on. To say, fire is a preventable hazard. In Table 1, there is a list of memorable fire cases from the past 50 years. Only very few of them are intentional, like Dupont Plaza Tower fire, which was an arson fire, killed 97 people. Not on the list but as a memorable one, World Trade Centre destruction in 2001 was also a terrorist attack, which killed nearly three thousand and left six thousand injured.

Table 1. The list of important fire cases in the world from 1970 to date.

Building	Height (m)	City	Country	Year	Death
New York Plaza	192	New York	USA	1970	2
Taeyongak Hotel	77	Seoul	South Korea	1971	163
Andraus Building	115	Sao Paulo	Brazil	1972	16
Joelma Building	83	Sao Paulo	Brazil	1974	179-189
MGM Grand Hotel	86	Las Vegas	USA	1980	84
Dupont Plaza Hotel		Puerto Rico	USA Territory	1986	97
Hotel International	85	Zurich	Switzerland	1988	6

One Meridian Plaza	150	Philadelphia	USA	1991	3
Garley building	53	Hong Kong	Hong Kong	1996	41
Ostankino Tower	540	Moscow	Russia	2000	3
Cook County Administration Building		Chicago	USA	2003	6
Lakanal House	47	London	UK	2009	6
Torre Ejecutiva Pemex Tower	214	Mexico City	Mexico	2013	33
Plasco Building	42	Tehran	Iran	2017	21
Grenfell Tower	80	London	UK	2017	72
Marco Polo Apartments	119	Honolulu	USA	2017	3
Wilton Paes de Almeida Building	80	Sao Paulo	Brazil	2018	7-9
FR Tower		Dhaka	Bangladesh	2019	25
Cheng Chung Cheng Building		Kaohsiung	Taiwan	2021	46
Twin Parks North West		New York	USA	2022	17

In our modern world today, most people live in multi storey buildings as the cities are densely populated urban areas. Tall buildings shape the cityscapes in many metropolitan areas. This also raises the question of how we can make tall buildings safe in terms of fire safety. Almost every country has their own fire safety codes, and this issue requires specialisation both at architectural and engineering level in the construction industry. Ensuring the fire safety can be provided based on the verification that the fire resistance of the structure is greater than the fire severity. Fire resistance measures the ability of the structure to resist the collapse, and the fire severity measures the destructive impact of the fire as such constantly increasing fire loading cause failure in the building. The relation between them can be seen in Table 2.

Table 2: The relation between the fire resistance and fire severity (Buchanan and Abu, 2017).

Domain	**Units**	Fire resistance	≥	**Fire severity**
Time	Minutes or hours	Time to failure	≥	Fire duration as calculated or specified by code
Temperature	C	Temperature to cause failure	≥	Maximum temperature reached during the fire
Strength	kN or kNm	Load capacity at elevated temperature	≥	Applied load during the fire

Modern fire safety measures are divided into two categories: active fire protection systems and passive active fire protection systems (Purkiss, 2007, p:13), as explained below:

Active fire protection systems include:

- Alarm systems,
- Smoke control and detection systems,
- Fire control systems,
- Access of external firefighting,
- Fire management system.

Passive fire protection systems include:

- Appropriate compartmentation,
- Control of flammability of the structure fabric,
- Plan of escape routes,
- Ensuring adequate structural performance.

Ensuring fire safety in design cannot only rely on fulfilling the code requirements but should demonstrate the results of various worst-case scenarios. Each scenario should study the likely spread path and smoke movement, considering the human behavioural features for a safe evacuation. Fire spread begins within the room, room of origin, may spread the adjacent rooms through open doors, windows or even through pipe and wire gaps in the walls. And this follows the spread to other floors eventually. One of the worst cases is the fire jumps to the adjacent building. While the horizontal spread is more likely to happen on a street with full of building with similar height, if a tall building exists nearby a shorter building, then the fire can easily jump to the façade of the tall building and then spread continues if the fire resistance was not fully provided (Buchanan and Abu, 2017).

2. Fire Vulnerability of Tall Buildings

On 14th June 2017 in London, UK, a fire started on the 4th floor of a 23-storey building namely Grenfell Tower, which was a social housing block. The fire began because of a malfunctioned fridge-freezer in a flat located on the east side of the block and the spread continued from the south side. The fire rapidly wrapped the building in less than half an hour (Figure 1) and killed 72 people. The building was constructed between 1972 and 1974 and refurbished in 2016, including the new façade cladding material, windows renewal, and replacement of common heating system. However, the main responsible of the rapid spread was found the cladding material, which was aluminium panel with flammable core, laterally continued all four sides of the building and above and below the windows on each storey. The infill material of the façade was polyethylene polymer, which increased the fire temperature. Post-fire refurbishment was planned to begin in January 2020 (BBC, 2019).

Figure 1. Grenfell Tower plan, burnt enveloping façade on the North, West and South (Source: https://www.bbc.com/news/uk-40301289)

Another deadly disaster took place on 9th January 2022, a fire wrapped a 19-storey building in Bronx, New York. 19 people were killed, including 9 children, and 44 were injured, including 13 in serious condition. The fire started because of a space heater malfunctioned on the 3rd floor and the fire door was not in closed situation, the dense smoke was able to flee to upper floors through the stairwell shaft of the building. The building was built in 1972 and had no fire escapes and no sprinklers. The fire doors were reported failed in the inspections in 2013 and 2019 as 'not-self closing' (Anderson et al., 2022). This case was announced as the second most deadly residential fire in the past 40 years (Westhoff, 2022). The building (Figure 2) was a part of affordable housing block that was built for low- and moderate-income families. The building had another fire case in 1986 as the garbage compactor between the 12th and 13th floor sparkled, with no death or injury reports (Fitz-Gibbon, 2022).

Figure 2. Twin Park North West blocks, Bronx, New York.

These residential and non-luxury tall buildings encountered such deadly fire cases. Apparently, tall buildings become vulnerable in fire cases, particularly when the fire cannot be taken under control. Fire vulnerability of tall buildings can be examined in two-folds. One is the performance of users' evacuation, e.g., egress strategy, and the other one is the building performance, which also can be examined in two-folds: structural performance and resistance to fire spread (Cowlard et al., 2013). The latter is the concern of architects and engineers and considering the technological advances and material varieties in the sector, fire safety requires expertise in the field.

3. Research Aspects and Methods

The paper, accordingly, focuses on the fire safety approaches primarily concerning architects. At the design stage, it is the responsibility of the architect to ensure the safety at some level through design, though material selection and finishing details. Thus, the paper explores the fire cases regarding the cause of fire, the established safety methods for the problem and enriches with the scientific outcomes of the literature review. It is expected to highlight the fire safety measures with cases and refer to the current knowledge for architects.

4. Safety Measures in Tall Buildings

Fire safety of tall buildings is more complicated than the safety of low-rise buildings. It often requires the passive protection systems unique in design and full consideration of active protection systems. Although fire codes in many countries outlines the requirements in plan layout and in selection of material, not every architect is familiar with it. The following titles analyses the safety measures to ensure in design, in detail, in structure and the elements of active protection systems. Successful examples along with the failed examples highlight the significance of the safety measures.

4.1 Safety Measures in Design

Fire safety in tall buildings can be ensured from the beginning of the design. Compartmentation is the most well-known approach. Compartments can be designed vertically, horizontally and in combination of both. A compartment volume helps to limit the spread of fire and smoke inhalation of users, which can give them space to evacuate the building (Purkiss, 2007). It can be planned as seen in Figure 3. For tall building, generally every floor is designated to be a compartment with fire resistance of one hour. Additionally, if the building has basement floors, used as parking, technical rooms etc., the ground floor can be fully designated as compartmented from the basement, so the upper floors would not be affected by the fire. In hotel floors, for example, it is necessary to design the doorways as fire resistant at least 90-120 minutes to ensure the fire safety. In Scotland, Fire Act guidance specifies that in care homes, where the residents depend on the assistance to flee, the floor area should be divided into two compartments with a self-closing fire door. Accurately, if the floor area exceeds 1500 sqm, the area to be sub-divided in two parts, each part not exceeding 1500 sqm. All the floor material, door and wall covering will be at least one hour resistant.

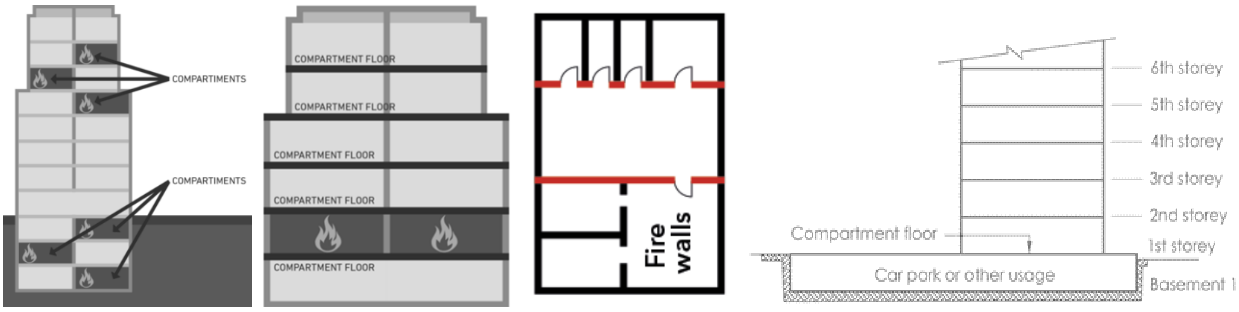

Figure 3. Design of compartmentation in various conditions.

Atrium is also highly preferred in architectural design, but it comes with a cost of increasing the risk of fire vulnerability. Atrium void causes a stack effect and draws the fire smoke and temperature move upwards rapidly. Hence, the top of the atrium fills with dense smoke and high temperature, while it also helps the invasion of the upper floors. Accordingly, in design, the spaces directed to the atrium must be separated with fire resistant wall, can be fire-proof glass or solid wall material. This way, if there are exhaust fans installed on the roof, then the smoke and temperature find a way to escape without causing any severe damage (Figure 4).

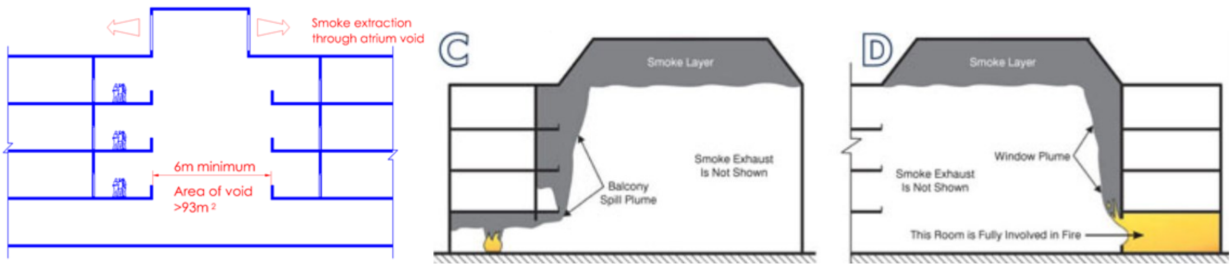

Figure 4. Design of atrium space according to the movement of the smoke and fire (Klote, 2012).

Additionally, for tall buildings refuge area is a requirement. This idea was firstly introduced in Asian towers, almost 40 years ago. The idea of refuge area came from the fact that not every user in a tall building necessarily evacuates the building but should wait in safe until the emergency is taken under control. Secondly, a refuge area is similar to compartmentation as it must be fire resistant and contains inflammable material and has its separate ventilation system. In Jin Mao Tower, completed in 1999, there are refuge floors designated on the 15th and 30th floors for office users (Weismantle and Antell, 2019). With a height of 828 meters, Burj Khalifa is the tallest structure in the world. It also has refuge areas on 42nd, 75th, 111th and 138th floors, counting it has 160 floors. The refuge areas are located as seen in Figure 5. The construction of this area is at least two hours fire resistant (Prasad, 2016). Besides, in Burj Khalifa there are three separate emergency elevators designated for the use of firefighters only. Two of them reach at the 111th floors, and the third reaches at 160th floor (Kinateder et al., 2014). In Shanghai World Financial Centre, with a height of 492 meters, total evacuation time was decreased by 40% with also using double-deck emergency elevators. Soltanzadeh et al. (2018) studied the significance of refuge area in combination with other emergency evacuation routes, e.g., fire escapes and emergency elevators. They analysed on a 40-storeys building scenario and found that to design a refuge area on 20th or 21st floor working together with 6 evacuation elevators and 3 staircases was the most optimal evacuation design, rather than increasing the number of the refuge areas, which resulted surprisingly slower evacuation time.

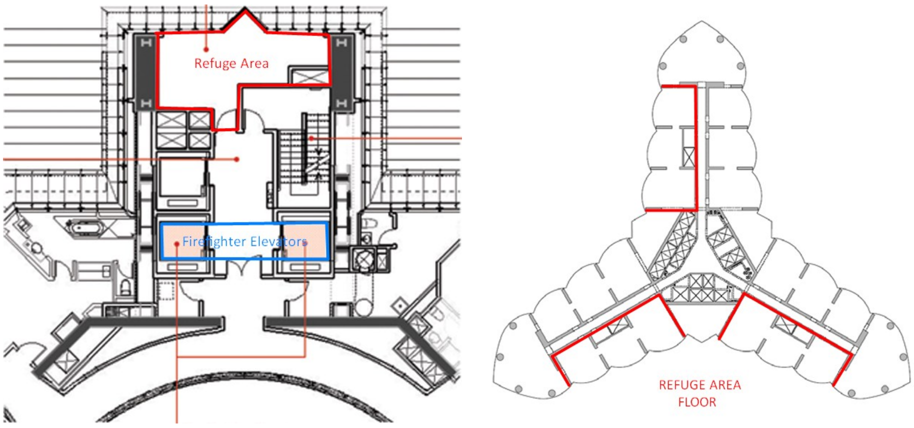

Figure 5. Refuge areas in Jin Mao Tower (on the left) and Burj Khalifa (on the right).

Chow and Chow (2010) found that in an 800-meter-tall building air movement through leakages in upper floors can be 1,2 times faster than a room at ground level, which creates stack effect. Abu-Zidan et al. (2022) simulated the effect of wind speed and direction on an external fire for a tall building. They tested a similar material to what was used in Grenfell Tower, aluminium composite panel with thickness of 3mm and insulation layer from PIR (polyisocyanurate). They concluded that the building geometry and the wind flow patterns shall bear in mind in modelling for possible façade fires. Wind speed and its direction have significant effect on the fire spread. Although, in their study, the case of no wind scenario had the most rapid vertical spread over the façade, whereas the horizontal spread was the smallest, which shows the vulnerability of such material use. They found side and diagonal wind most hazardous in spread for a rectangular shaped building.

4.2 Safety Measures in Detail

Architectural details in design of tall buildings plays a significant role in the fire safety of the building. The case of Grenfell Tower in 2017 became a disaster largely because of wrong material selection and detailing on the façade cladding. The panels were preferred aluminium instead of zinc panels, which had more resistant insulation core in honeycomb shape, only because of economic benefits. Additionally, the cladding system preferred was installed with a detail to hide fixings. The system was tested in 2005 for the first time and failed. The tests were reapplied in 2011, 2014 and 2015, and eventually failed every time and classified E. The lowest fire resistance of European classification is F. However, the same façade material and system had another installation with a detail without hiding fixings and passed the tests rather successfully with classification C (Figure 6). The fire code applied in UK requires to use materials in quality of European Class B for buildings taller than 18 meters, and in quality of European Class C for shorter buildings (Symonds, 2021). Besides, the material chosen to fill around the new windows was combustible, whereas the code strictly specified the use of rockwool material as it is non-combustible.

Figure 6. Grenfell Tower façade cladding system with hidden fixings (Symonds, 2021), the burnt cladding and the triangular shaped niches on the facades that pulled the smoke and heat almost like a chimney to the upper floors.

The fire case in TVCC (Television Cultural Center) on 9th February 2009 was similar to that in Grenfell tower in terms of the exterior cladding material (Figure 7). The tower had 32 storeys and a height of 159 meters. A high atrium existed between floors numbered 5th and 26th, in use as hotel and restaurant. The tower had a rectangular shape in plan and two facades with metal cladding and strips, two other facades with only glass covering. As the fire started because of fireworks flames landed on the roof, it melted the metal panels, which was titanium-zinc alloy, and walked through the insulation layer inside the panels, which was Extruded Polystyrene (XPS) foam. Mainly because of such façade material, the fire was able to cover all the building in nearly 20 minutes. The building was not completed by then, so through the window openings, the smoke and heat moved inside the building. The atrium made a stack effect, making it easier to move upwards and downwards inside. One firefighter died and seven workers injured in this case (Peng et al., 2013).

Figure 7. TVCC Tower after and before fire (Terri Meyer Boake via CTBUH)

Colic and Pecur (2020) examined the metal facades with combustible and non-combustible insulation layer and the effect of vertical and horizontal fire barriers. They concluded that the number of fire barriers were the actual fire retarders in cladding. with the combustible cladding material, they reached easily above the 900C temperature. The façade with combustible insulation was successful under fire loading only in the sample that had four horizontal barriers, which resulted in temperatures similar to the cladding with non-combustible insulation. However, the cladding sample with non-combustible insulation layer and with two horizontal fire barriers resulted nearly one this of the temperature of the cladding with combustible insulation and with four horizontal fire barriers. This proves how significant to prefer non-combustible materials in building. Pershakov et al. (2016) also highlighted the absence of horizontal barriers in the façade of a tall building could lead the fire spread to the entire façade in 15-20 minutes through window openings, balconies etc.
Another earlier fire disaster in UK caused a serious change in the fire code. Shirley Towers in Southampton was on fire on 6th April 2010. Two firefighters died in the case, as the reports stated they had entangled in the cables fell

from the ceiling that were supported by plastic cable trunks, which deformed and melted under the high temperature and eventually fell on the stairs and corridors that hampered the progress in the fighting. The case was in 2010, but the investigation over the death of the firefighters was completed in 2013. Thus, the related part of the code was updated by stating clearly that electrical installations of the buildings to be fixed in metal trunks instead of plastic (Hampshire Fire and Rescue Service, 2013).

Exterior façade is often the way the fire finds channel to spread. Windows are critical in this regard. An indoor fire can quickly reach up to 600 to 1000C and this can cause the windows to crack and burst. This way, fire spreads directly to the upper floors. Façade windows are often selected by architects based on the energy saving concerns, but also fire -proof of glass for windows must be bear in mind. Fire-proof glass can be categorised into three. The first one is tempered glass, or fire-rated glass. This can be high borosilicate fire-resistant glass, which can resist to temperatures from 520C to 850C. Either, it can be monolithic potassium cesium fire-resistant glass, which can resist fire up to one hour. The other category is laminated glass. PVB laminated glass (Polyvinyl butyral) and SGP interlayer glass (Sentryglas Plus) are two products in use. Both are fire-resistant type of glass, but SGP performs better, which comes with a cost. For façade enveloping such fire-proof glass material must be chosen. Zhou (2014) pointed at two fire cases in China. In Shenyang, a hotel building with two blocks, Tower A and B. Fireworks flames started a fire on the Tower B, which had ordinary glass and windows. But the fire spread to the façade of Tower A, which was built with fire-proof monolithic caesium and potassium glass. Eventually, the façade did not get as damaged seriously as Tower B, which had severe exterior and interior damage.

4.3 Safety Measures in Structure

Fire safety measures are crucial for the structural elements of the building. The interior and exterior finishing materials are significant in the prevention of fire spread. However, if the fire spreads rapidly and the temperature increases to the level that can damage the columns and beams of a frame structure, then the whole building can collapse, which is the worst-case scenario for the users and firefighters. The structural safety is crucial to ensure the users to flee the building on time and to enable the building to continue its function after plausible post-fire renovation and refurbishment. There are deadly fire cases that ended up with total structural collapse. Plasco Building in Tehran, Iran, is one of them. On 19th January 2017, a fire began on the 10th floor of the 17-storey steel frame building, which was the first tall steel building of the city, constructed as a landmark in 1960s (Weinberg, 2018, Aziz Amen & Nia, 2017). When the building was constructed, there was no fire code to fulfil. Thus, the building was lack of fire escapes, sprinklers, and additional coating for steel structural elements. Rectangular columns of the building were only protected with gypsum boards and light concrete. Suspended ceiling was applied obviously without fire leak details. There was only some type of water hosing system on each floor but malfunctioned in the case when firefighters wanted to activate. As the fire load increased over time, the structure weakened, and the partial collapse began. The first collapse took place on the 10th and 11th floors as the fire started here. Following this, 12th and 13th floors also collapsed. This affected the structural stability of the building as the fire load kept increasing. Therefore, nearly 3,5 hours of fire was enough the building's steel to lose its resistance and eventually 16 firefighters and 6 users lost their lives due to the total collapse of the building as seen in Figure 8 (Ahmadi, et al. 2019).

Figure 8. Plasco Tower structural steel plan, the damaged rectangular columns, and the view after the total collapse (Ahmadi, et al. 2019; Macguire, 2017).

Steel and concrete structural combination advances the construction technology for tall and supertall buildings. However, steel is known with its low capacity of resistance under fire loading. The collapse of Plasco Tower represents an example to the fact. Therefore, fire load is another dynamic stress on tall structures and can cause to total collapse. A fire loading simulation was studied for Shanghai Tower by Jiang et al. (2015) and they found that the structure of the building has a three hours of fire resistance before progressive collapse. The concrete beam and core had a deformation ranged from 15 to 25 mm under six hours of loading. However, steel belt truss had a deformation of 90 mm under five hours of fire loading. As seen, steel structures need particular attention in the fire protection. The methods are generally applicable in the design and detailing stage, such as wrapping the steel columns with fire-proof boards materials and encasement in poured concrete. Board materials can be made from calcium silicate or gypsum plaster. Spraying fire-proof material is deemed the easiest way. The fire-proof material can be glass or cellulosic fibrous usually mixed with cement. However, not usually preferred by architects since it displays non-decorative finishing (Buchanan and Abu, 2017). Detailing of board wrapping can be seen in Figure9.

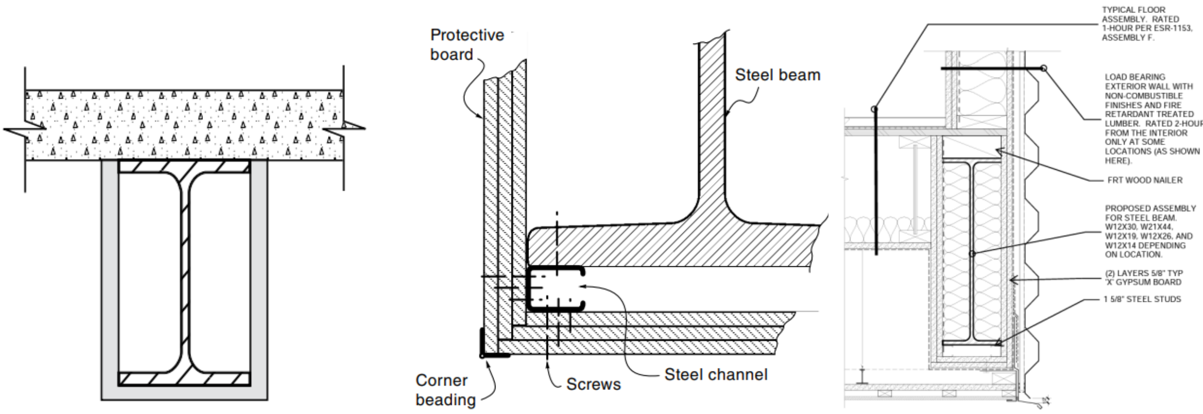

Figure 9. Board wrapping for fire protection of steel H columns with at least two layers of gypsum boards (Buchanan and Abu, 2017; Code Unlimited LLC, 2015).

4.4 Safety Elements for Active Protection

On 23rd February 1991, a fire took place in One Meridian Plaza Tower in Philadelphia, USA. The building had 38 storeys and the fire started on the 22nd floor and lasted 19 hours. The fire fully destroyed eight floors. It took more than 300 firefighters' effort and three firefighters lost their lives during the intervention. The building was completed in 1972, when there were no specific requirements for tall buildings. A requirement of installation of automatic sprinkler system was enforced with the adoption of new code in 1984, in which a specification was made for the tall new buildings, leaving the existing tall buildings out of the code. Despite the fact, the builders decided to retrofit the building with sprinkler systems on some floors; four floors were fully, and three floors were partially installed in the entire building. On the disaster day, the fire reached at the 30th floor and the floor was one of the fully installed with automatic sprinklers, which extensively helped the fight to end the fire. The case was a big lesson for the city and was a proof how the active systems were significant for the fire safety, not only for the residents but also for the fighters. A new code was enforced by the end of the year, in December 1991, which clearly stated to retrofit the existing non-residential buildings taller than 75 feet (22.86 meters) by the end of 1997 (Ellis, 2021; Hensler, 2022). The Grenfell Tower was completed in 1974, when no strict fire code enforced to the construction companies. The building had no sprinkler to extinguish and no centralised smoke alarming.

The active extinguishing systems are crucial for a successful firefighting. Similar to sprinkler system, water-mist system also preferable for special buildings as well as tall buildings. Water-mist system uses 90% less water than conventional sprinkler system and prevents the temperature rise and decreases the risk of flammability of the materials around the fire source. In Elbphilharmonie Concert Building, water-mist system was preferred (Figure 10). The whole building has 108 meters of height, and the main concert hall has a ceiling height of 25 meters. While the rest of the building was actively protected by sprinkler systems, the main concert area was installed with high pressure water-mist systems as a deliberate choice regarding the architectural details inside. The simulations of the area pointed the possible fire load on the floor and the seating area around the stage. Accordingly, in contrast to the conventional sprinkler system, high pressure water-mist system was installed under the floor (Kopp, 2021).

Water-mist system gained popularity over the years, although it has been the technology in use for the past two decades, and today some fire codes and regulations cover the guidance. For example, Welsh Government published a guidance in August 2021 for "Automatic water mist systems for domestic and residential premises", which refers to new buildings and conversion for existing buildings.

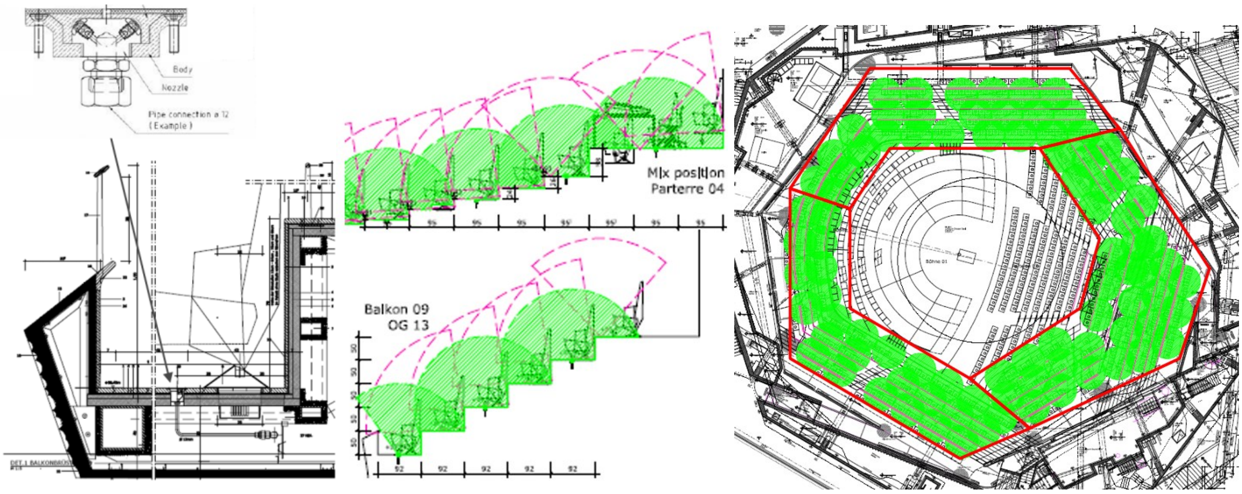

Figure 10. Elbphilharmonie Concert Building, the water-mist system installed on the floor and technical detailing (Kopp, 2021).

As a part of active fire protection systems, fire curtains or smoke curtains are applicable in many projects including large span and tall buildings. Fire/smoke curtains are part of fire management systems. In hotel buildings, they are widely applied to the lobbies, indoor pools, and atriums as well. Atriums or smaller voids in floor are preferable for natural lighting and ventilating. But, as explained earlier, these areas can contribute the fire to spread. To prevent the spread and to make it easier for firefighters to intervene, fire curtains can cover such areas as seen in Figure 11. It helps to block the smoke and temperature in a volume. The system can be established vertically, e.g., for stairwells and mezzanine spaces. Horizontal systems can be installed for shopping mall atriums and galleries, and small lighting atriums in libraries and office buildings. To give another example, the curtain system is effective for multipurpose halls as well. It can be installed vertically above the stage to separate the seating area and the stage, including screen and lighting electrical equipment. So, if the fire begins from the stage area, it will remain blocked as the curtains shut the area.

Figure 11. Fire curtains horizontally applies, and vertically applied.

5. Discussion

Modern tall buildings are more likely to have fire protection systems that makes them safe on one hand. On the other hand, there are more occupants and there is often a longer route to exit the building. The evacuation route of a 30-storey building and 150-strorey building cannot be the same. So, they must have different fire safety measures to adopt in the plan and the section. The measures start at the design stage as the passive fire protection systems and the architectural process is completed with the active fire protection systems in mechanical terms. The examples of fire cases proved that particularly existing old tall buildings pose a great danger in fire as they mostly were built with a lack of fire protection systems, i.e., with single common-use stairwell, no evacuation elevator and so on. Moreover, today we use more synthetic and polyester-based materials in the construction sector that increases the risk of fire. Preferring the appropriate material is the key to fire safety, particularly for the exterior fire spread. When doing the selection of the façade cladding material, an architect must check the fire performance classification of the material and make sure to fulfil with the fire code requirement. If the design includes steel structural elements, then necessary safety measures must be taken to ensure the structural safety of the building.

Active fire protection systems are complementary part of the fire safety and plays a significant role in the firefighting as the real cases proved. It must be consulted with an expert to discuss the most suitable system based on the function of the building.

6. Conclusions

The paper aimed to explore the fire cases and their causes through the discussion of the fire protection systems for tall buildings. This type of structures requires particular attention in design, in material selection and the utilization of active systems. The fire case studies explored included Grenfell Tower, Twin Park North West, Plasco Tower, One Meridian Plaza, Shirley Tower and TVCC. Fire safety measures are outlined as safety measures in design, in detailing, in structure and active protection. It is hoped that the paper successfully shed light on the issue of fire safety of tall building from the architectural perspective.

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Conflict of Interests

The authors declare no conflict of interest.

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