fire

Review

Review of Structural Fire Hazards, Challenges, and Prevention Strategies

Chenting Zhang

Maanshan Teacher's College, Maanshan 243041, China; zctntc@163.com

Abstract: Reducing the occurrence of structural fires is the common goal of all countries. However, the development level of different countries determines the degree of perfection of local fire management regulations. Developed countries have a more rational urban layout, sufficient firefighting resources, and the ability to guarantee fire safety. In contrast, haphazardly built residential areas in developing and underdeveloped countries have more safety hazards, which increases the challenges of local fire management. This study provides an overview of the causes and impacts of fires in different countries and identifies gaps in fire safety between developed and developing countries, as well as corresponding strategies to deal with fires. It is worth mentioning that the development and evolution of artificial intelligence (AI) has made it possible to predict fires, thereby greatly reducing damage and losses caused by fires. In addition, the development of new fire-resistant building materials, etc., provides more means to reduce the possibility of fire.

Keywords: structural fires; fire management; fire education; fire mitigation

check for updates

Citation: Zhang, C. Review of Structural Fire Hazards, Challenges, and Prevention Strategies. *Fire* **2023**, *6*, 137. https://doi.org/10.3390/fire6040137

Academic Editors: Yongzheng Yao, Jinlong Zhao, Qiang Wang and Zihe Gao

Received: 26 February 2023
Revised: 26 March 2023
Accepted: 28 March 2023
Published: 29 March 2023

1. Introduction

Structural fires have been a major global issue in both developed and underdeveloped countries [1,2]. The chances of a fire in structures can be drastically reduced by integrating fire safety measures during the structural design process [3,4]. Structures made from wood are more prone to fire outbreaks owing to the low fire performance; however, building materials such as concrete, bricks, etc., also lose their structural integrity when exposed to higher temperatures [5]. Structural fires resulted in approximately 401,000 deaths per year on a global scale from 1993 to 2020 [6,7]. Due to this, the growing concern towards the improvement of fire safety in structures has become critical over the recent decades. This is also a result of the increase in the occurrence of fire hazards globally. The global increase in fire risks can be attributed to urbanization and congestion [8–10], the drastic increase in construction activities [11], and the lack of implementation of safety rules and regulations, as well as carelessness from individuals [12]. Fires are a threat to life and livelihood. In fact, statistics on fire hazards in China have shown that in 2021 approximately 249,000 people died from fire outbreaks, which also resulted in approximately USD 620 million in direct property loss [13].

Several structural fires have been witnessed in both residential and industrial buildings globally. On 16 September last year, a fire outbreak occurred in a 42-storey China telecom building in Changsha, Hunan province. Reports show that the façade cladding of the 218 m tall building caught fire, hence, 36 fire engines and 280 firefighters were dispatched to extinguish the fire. Another serious fire occurred on June 18th at a chemical plant in Shanghai. According to witnesses, huge plumes of smoke filled the air and over 500 firefighters worked tirelessly to put out the fire. The main causes of these fires have still not been identified. Other notable fires such as the Grenfell tower fire in the United Kingdom [14] and the apartment fire in the Bronx [15], USA, etc., caused death, injuries, and property loss.

Over the years, fire protection systems have been put in place to detect fires in their early stages and to minimize flame spread [16]. Devices such as sprinklers, fire and smoke alarms, fire extinguishers, etc., as well as fire doors and flame-resistant coatings applied to building materials provide protection against fire hazards [16–19]. Although these systems are effective and have minimized the likelihood of fires and subsequent damage from fires, an advancement is needed for further mitigation [20]. Fire management involves ensuring that fire safety measures are implemented and that all devices are in good working condition and can work properly to assist residents to safety [21]. It should be noted that different fire management strategies are adopted in different regions, depending on the level of development. Firefighting in underdeveloped or developing countries poses a greater challenge compared to developed countries [22].

While there are systems in place to counteract hazards in developed countries, developing countries such as Pakistan and some African countries do not take fire as a critical threat, therefore, investing in fire safety is considered a waste of resources [23,24]. A study conducted by Farooq et al. [24] in three cities in Pakistan showed that, on average, three fires occur in these cities each day. However, a survey in some buildings showed no installed fire safety devices or fire safety code compliance. Without these systems, there is no means of reducing ignition likelihood or suppressing fires when they occur, which has resulted in the high records of structural fires [25]. In South Africa, Ghana, Nigeria, etc., the growth in population and industrialization have tremendously increased the risk of fire [26]. The research of Walls et al. [27] showed the inadequate resources, training, and education on fire safety in these parts of the world. Nonetheless, very few organizations show interest in bridging the fire safety gap in these areas.

In this review article, the major causes and impacts of fire outbreaks in residential structures are discussed with references to recent publications. The fire management systems in developed and developing nations are assessed to reveal the gaps in the systems. Based on the assessment, the study gives recommendations for bridging the fire safety gaps between these countries. Lastly, strategies for minimizing the likelihood of structural fires are discussed with recommendations for future application. Factors such as the integration of technology-based education in fire safety training and research and investing in the development of fire-resistant building materials whilst improving the operation and sensitivity of temperature sensors and fire and smoke alarms that will help in reducing the death records and predict impending fires have been discussed. This review article will help identify the critical sources of ignition in structures and put into perspective fire safety measures in buildings.

2. Causes of Fire in Structures

Any item in a structure that can bring about ignition, increase the fuel load in a building, or cause a possible flame spread or propagation can be the source of a fire. As stated in reports from the national fire protection association (NFPA), the leading causes of fires are human factors. With this, the five main activities that cause fires in buildings have been identified as cooking, heating, smoking, electrical applications such as lighting, and arson.

Compared to other rooms in a building, kitchen fires are more prevalent due to the thermal radiation from cooking stoves to the users [28]. In addition, most kitchens are set up such that the cooking areas are usually close to the exits or escape points, preventing a smooth escape in the event of fire [29]. Spearpoint et al. [30] identified the use of cooking oil for deep or shallow frying in the kitchen as one of the major causes of house fires (80% of reported kitchen fires). The authors showed that factors such as the frying frequency and volume of oil contribute significantly to the severity of the fire risk. Hence, to minimize this risk, the authors proposed a volume of oil of 2.5 L for deep frying and 150 mL for shallow frying. In addition, they noted that the frequency of frying should be reduced from 17 times per month to 11 times.

To estimate the severity of cooking oil fires, authors [31,32] have considered the type of pan and its dimensions, the type of cooking oil and the volume used, the heating source, and ventilation in the kitchen. These factors directly influence the heat release rate (HRR) from the fire, the height of the flame, and how long the fire lasts. It was observed in the work of Chen et al. [33] that with the same size and type of pan, increasing the amount of oil, which acts as the fuel, can cause a 3.1 times increase in HRR and a 1.6 times increase in flame height.

Ouache et al. [34] developed an artificial neural network (ANN) model to identify the potential fire origins and factors that enhance the risk in smart green multi-unit residential structures in Canada. The models employed the Lavenberg–Marquardt, Scaled Conjugate Gradient, and Bayesian Regularization backpropagation algorithms to compare prediction accuracy. In this work, the authors grouped fire risks under eight categories: cooking equipment, heating equipment, appliances and equipment, electrical distribution equipment, electrical equipment, smoker's material, open flame exposure, and miscellaneous. The most critical factors out of these eight were used as the standard for the prediction of ignition source factors and fire impacts. The input data consisted of the fire incidents and risk factors of some major cities in Canada. The results from the prediction showed that cooking equipment and smoking materials pose significant fire risks in buildings. In addition, 65% of the data analyzed showed fires occurring in the kitchen.

Heating equipment such as central heating systems, fireplaces, water heaters, and space heaters have been ranked the second leading source of residential fires. In homes, heating equipment is usually placed close to flammable materials, such as curtains, carpets, beds, etc., which easily ignite, for instance, in the case of a power surge or if the heater malfunctions. Data from NFPA has shown that space heaters caused approximately two-fifth of structural fires, leading to 81% and 80% of deaths and injuries, respectively.

According to David Baker [35], there are approximately 5.5 million unvented kerosene heaters currently being used in homes. These heaters pose a significant fire risk when left unattended or operated improperly. Concerns regarding refueling these heaters, using unrecommended fuels such as gasoline, and storage of the fuels have been raised in an attempt to make their usage fire safe. The authors, therefore, outlined some safety guidelines for the operation of such heaters.

Cigarettes and other smoking materials are major causes of structural fires [36]. Statistics have shown that over 5.2 trillion cigarettes were consumed in 2020, all of which must be well extinguished to prevent fires [37]. Globally, 5% of structural fires are started by smoking materials, causing 23% of the total fire deaths and 10% of injuries per annum.

Anderson et al. [38] compared the fatalities and damages caused by fires from smoking materials in the United Kingdom, America, Finland, and Japan for a ten year period. The authors also carried out an analysis to determine the contribution of lighters, candles, matches, and space heaters against cigars, pipes, etc., to ignition and fire spread. It was seen in the analysis that all the countries had higher smoking material fires compared to fire caused by low energy materials. In addition, the introduction of reduced ignition propensity cigarettes in these countries did not have any significant impact on the fires caused by smoking and low-energy materials. The results also showed that fires from smoking materials were more severe than those of low energy materials, showing that they caused more deaths and injuries. To differentiate between the fire fatalities from smoking materials and low energy materials, variables such as age, item first ignited, race, and season of the year were considered.

It has been established that the probability of households with smokers experiencing fire injuries is five times more than non-smoking households [39]. In the work of Leistikow et al. [40], the economic loss from smoking related fires was estimated for some cities in the U.S. The authors also estimated how often adults and children are exposed to ignitions from lighters and matches as well as the subsequent fires, burns, and deaths. The research showed that cigarette lighters alone have caused over 100,000 fires in the U.S and one million fires involving children globally. In addition, on a global scale, smoking has led to approximately 10% of fire deaths, with an economic loss of USD 27.2 billion. With these statistics, the authors proposed that smoking be reduced substantially to minimize fire risks. They also suggested that smokers must have smoke detectors, apps that detect fire alarms, and other important mobile safety equipment to reduce fire losses. Smoking should not be done in a bedroom or living room but on a balcony or an open porch area where there are fewer flammable materials and enough ventilation.

Electrical fires as defined by Babrauskas [41] are a result of the ignition of items by current or static electricity in electrical distribution, appliances, etc. Furthermore, if a piece of non-heating electrical equipment provides heat for ignition and subsequent fire, it can be termed as an electrical fire. There are various phenomena that cause electrical fires: poor electrical connections, overloading, hot particle ejection, excessive thermal insulation, etc. For developed countries, the number of fires caused by electric fires remains high. For example, the total number of fires caused by electric fires in Spain ranks second [42]. In addition, developing countries are also suffering from electrical fire damage; for example, China has experienced several electrical fires over the decades [43,44]. John Shea [45] conducted a study to identify the root causes of electrical fires in residences. The authors gave a thorough description of the failure modes that occur in arc faults and the response of circuit breakers. It was observed that current flowing through unintended lines can produce heat that can cause flammable items to burn. Another observation made in the research was that wire insulation is usually the first item that burns up during electrical fires. The effect of factors such as thermal aging, lose or glowing connections, broken wires, wires under mats, etc., on the intensity of the fires was also explored. The effects of thermal aging on the properties of electrical wire insulation, such as hardness and cracking, were assessed. It was seen that bundles of wires and glowing connections can cause overheating, leading to fires. Wires become brittle due to thermal aging, which exposes them to arcing faults. Owing to this, it is advised to practice careful wiring procedures that do not expose wires to temperatures above the rating limits of the insulation. Figure 1 shows images of the various causes of fires discussed in this section.

Figure 1. Causes of fires in structures: (**a**) cooking equipment fires, (**b**) glowing electrical wire connections, (**c**) space heater fires, (**d**) fire from a cigarettes.

There are other causes of fire in buildings, such as vandalism, fireworks, failure to maintain fire protection systems in buildings, etc. All these factors can either cause the fire or increase its intensity and hinder the activities of firefighters in buildings.

3. Impact of Structural Fires

It has been established that structural fire is dangerous. It costs lives and causes property damage. In general, structural fires occur most frequently in residential, commercial, or community-based buildings. However, the rate of fire depends on a variety of factors, including building type, building material, and the degree of flame and/or radiant heat generation. These factors must be considered prior to building design in order to avoid or mitigate fire damage. According to the National Fire Protection Association's "Home Structure Fires—2021" report, nearly 26% of fire accidents on home structures were reported between 2015 and 2019, resulting in the deaths of 75% civilians, and 72% suffered various fire injuries [34]. The causes of these fires could include explosions caused by gas leaks, unintended/uncontrolled chemical reactions in an industrial plant, or a malicious act. According to an investigation by Kim et al. [46], the primary causes of fire accidents on construction sites are violations of fire safety regulations and a lack of inspections. The fire explosion generates high pressure waves and intense heat, causing severe structural damage to buildings. Furthermore, fires in buildings can result in secondary accidents, such as fire spread and explosion. According to the Zebra survey report "House Fire Statistics in 2022" [47], 50% of fires in residential buildings were caused by cooking accidents, 12.5% by heating equipment, and 6.3% by electrical failure. The type of material used in the building can help explain the fire characteristics of structures. Concrete, steel, wood, brick, and mortar are common building materials. Concrete and steel do not spread fire, so flame behavior is limited; however, brick, mortar, and wood can burn and spread fire. The temperature can reach 1000 °C during the fully developed stage of fire. At this temperature, the strength and stiffness of structural materials such as reinforced concrete will be significantly reduced, and in turn they will lose the ability to withstand the designed structural loads, which will eventually lead to the collapse of the house [48]. Another important concern regarding structural fires is the loss of property [49]. Fire damage to structural buildings causes both direct and indirect monetary loss. It is critical to investigate the fire characteristics of structures in conjunction with structural and material science, because structural design and structural material characteristics influence fire behavior. The progression of fire has several stages, each of which poses a significant risk to human life.

In a fire accident, in addition to the need to prevent heat burns, extra attention needs to be paid to the effects of smoke production. When a fire breaks out, there is a large amount of smoke, which can cause a significant loss of visibility, making it impossible for people to identify their direction, making it impossible for them to recognize their otherwise very familiar surroundings. It is also important to note that the minimum visibility required for people to get out of danger is 5 m, but under the influence of smoke, the visibility may be less than 3 m, which makes it more and more difficult to get out of the fire. People who stay in the smoke surrounding too long will experience a sense of fear, which may bring inconvenience to the rescue work [50]. Toxic gases such as carbon monoxide (produced by incomplete combustion), hydrogen cyanide (produced by burning plastics), and phosgene gas (produced by burning vinyl-based household materials) are produced during the pre- and post-flashover stages, posing serious health risks to humans upon inhalation. Additionally, the soot and toxic vapor can cause allergic reactions such as eye irritation and stomach upset. Overall, the gas oxygen, essential for humans, is reduced, causing suffocation.

In the following, a few fire accidents that happened globally are addressed. On 27 August 2022, a fire broke out in a residential building in Liaoning Province, China. According to reports, the cause of the fire was a poor connection between the power cord plug of an electric balance car charger and the socket [51]. The accident resulted in no fatalities, but the fire severely damaged the building. Figure 2 shows the charred building structure after the fire.

Figure 2. Before and after fire effect in residential building, Liaoning Province, China.

In addition, a fire broke out at a 40-year-old building structure in the southern Taiwanese city of Kaohsiung, killing 46 people and injuring 41 more [52]. The fire started on the first floor of the building and spread to the sixth. The fire was then extinguished with the deployment of 75 fire trucks and 160 fireman. This incident is important in understanding the typical effects of fire on structures. The burned-out building was investigated, and it was determined that it was structurally weak and should be demolished.

On 16 July 2004, fire from a school's kitchen killed 94 children at the Sri Krishna School and Saraswathi Nursery School complex in Kumbakonam, India [53]. One of the main causes of the fire was the school's poor design. The lack of firefighting mechanisms, emergency exit plans, and the congested area of the school building were the main reason for this incident. Another fire accident on March 2010 in Kolkata, India, killed 42 people and injured many [54]. The fire broke out at the historic Stephen Court building on Park Street, Kolkata. The main reason for the fire was a short circuit in the lift. The lack of proper fire exits and high floors exacerbated the situation for fire fighters. The fire that engulfed Ulsan's commercial and residential buildings on 8 October 2020 injured 93 people, including a firefighter, but no fatalities were reported [55]. It took nearly 13 h to put out the flames. The fire at the tower block in Sao Paulo, Brazil, on the 1 May 2018 completely collapsed the building [56]. This incident illustrates structural failure during a fire. These accidents serve as a reminder of the importance of structural fire safety in creating safe environments.

4. Gaps in Fire Management between Developed and Developing Countries

In developed countries such as the United States of America, European countries, etc., the cities are well planned, with accessible social amenities. It is understood that human mobility is inevitable due to climate change, hence, planned relocation is implemented to avoid crisis and environmental hazards [57]. Permissions and certifications from the government are required before and during construction works [58]. Existing structures are regularly checked to ensure the owners are adhering to the fire safety policies in the region for the safety of occupants. Advanced fire safety equipment is used in new buildings, and the already installed safety devices are regularly examined within specific time periods to assess their operational conditions. Smart devices such as smart sprinklers that can identify the specific directions of smoke and flames are being used to put out fires. Fire safety engineering is being taught as a program in many colleges, which increases the awareness of fire hazards and the mitigation strategies. In these countries, fire incidents are studied in a systematic way by using statistical data from past events, codes and standards are regularly updated to suit the current technological advancement, and consequences of outbreaks are highlighted to inform society about the risks [59]. Firefighters in developed countries have the required infrastructure for efficient work. Due to this, response time to the site of fires is kept at a minimum. Transportation in planned cities facilitate movement, hence, it is easy to find the actual geographical location of a particular building. All these factors aid in controlling the damage from fires [60].

With the economic development of developing countries, the causes of fire in better areas have changed. In China, for example, as of 2016, electrical faults have become the culprit for more than 30% of fatal fires. Fires in China occur mainly in summer, but it should be noted in particular that major fires mostly occur in winter. According to statistics, 787 periods of larger and extraordinarily major fires occurred from 2008 to 2017, 277 of which occurred in winter. The causes of fires are mostly various electrical problems, such as overheated electrical equipment in living rooms, aging wiring, and overloaded running machines, while careless fire use by residents is the second most common cause [61].

However, some developing countries are less developed, and informal settlements are often used. Fire is recognized as a major risk in informal settlements, but it is frequently overshadowed by the emphasis on formal built settlements. Because of the spatial layout of informal settlements, fire resilience is a major issue.

According to the related information, accidental fire death is high in southeast Asia and causes twice as many deaths in women as in men. An extraordinary 80% of global fire deaths among adult women occurred in southeast Asia. Many fire accidents are probably caused by cooking, but it is not the only cause [62]. It should be noted that nearly 2000 fire accidents in informal settlements were recorded in Cape Town, South Africa, between the years 2016 and 2017 [63]. Several other fire outbreaks have been recorded in various African and Asian countries. On August 16, 2019, fire broke out in an informal settlement in Dhaka, Bangladesh, destroying thousands of homes and displacing nearly 50,000 people [64]. The Imizamo Yethu informal settlement in Cape Town, South Africa, was completely destroyed by a large fire on 11 March 2017, killing four people. Over 9700 people were relocated, and 2194 homes were completely destroyed [65]. It is quite challenging to implement fire safety principles in these communities because the regulations are irrelevant. It has been reported that 40% of the fire causes for accidents in informal settlements were unknown [66]. A post-fire investigation is critical to determining the cause of the fire; however, the inherent nature of these settlements complicates the investigation and leads to failure in determining the fire cause. Residents in these settlements cook over open fires, and the lack of electricity forces them to rely on candles and lambs at night. It should also be noted that the settlements were constructed using flammable materials rather than less flammable building materials. Furthermore, these settlements are dense, allowing fire to spread quickly. A sudden fire in an informal settlement can cause severe destruction because the flashover can occur in a matter of minutes [65] and there is no time to save any household goods during the fire. Walls et al. [67] investigated informal settlements in the South African region for fire safety. The authors conducted research in three areas to mitigate the fire: ignition risk management, active fire protection interventions, and passive fire protection interventions. The investigation's findings summarized a few strategies for preventing fires. The authors, however, stated that the implementation of these strategies is not successful in all settlements due to factors such as social dynamics, leadership structures, settlement topography and layouts, access to electricity, and other factors. In another study, Walls et al. [27] stated that there are a few challenges, such as the inherently uncontrolled, variable, and complex nature of dwellings; fire loads; social behavior; and infrastructure, to be considered during the development of fire safety solutions. Furthermore, these factors make identifying the problems and causes of fire difficult.

The aforementioned discussion shows that there exists a wide gap between fire management in developed and developing countries. This could mainly be due to lack of planning in the cities and inadequate resources. Nevertheless, more attention should be paid to these developing countries to bridge the fire safety gap.

5. Strategies for Minimizing Building Fires—Mitigation

Building fires have deleterious effects on residents and the environment. Aside from the loss of lives and livelihoods, economic loss, etc., burning items release carcinogens that can cause diseases such as cancer. Although it is quite imperative to train personnel for effective firefighting and post-disaster recovery, it is also of utmost importance to direct some resources to minimize the occurrence of fires in general [68]. Hence, this section discusses some strategies for mitigating building fires to create a fire-safe environment.

5.1. The Popularization of Fire Safety

Most structural fires occur as a result of negligence on the part of the residents, for example leaving hot surfaces, cooking items unattended, and smoking in undesignated areas. Hence, education on the factors that lead to the occurrence of fires, the risks involved, and the prevention methods, emergency actions, evacuation procedures, etc., will help minimize the hazards.

Drotárová et al. [69] explored the use of hybrid learning (both e-learning and traditional methods) in fire safety education. It was established that while fire drills and other intensive fire prevention activities require face-to face-learning, the basic theoretical studies can be carried out via the internet or can be digitalized to create awareness and heighten the interest of participants. There should be online courses available for residents in the community to take, if possible, for free, to make them safety conscious. Fire safety education should be integrated into the curriculum of children to adequately prepare them. Community planners can take advantage of virtual reality (VR) technology to develop an interactive and practical platform for fire safety education. VR-based fire safety programs for military fire training and a training simulator involving smoke assessment have been developed by researchers [70,71]. Zhang et al. [72] enhanced fire safety education on campuses by developing a VR-based system with fire education theories accessed through an HTC VIVE helmet. To make it more interesting and efficient, the new system was designed in the form of a game, with rewards for participation. The prototype was tested by 60 random students for 60 min, and the students were able to master the fire safety skills and protocols. Such platforms can be implemented in residential areas to bolster fire protection.

5.2. The Use of Active and Passive Fire Safety Systems

Fire protection systems protect both people and infrastructure from fire hazards [73,74]. They detect fires by the heat transfer of thermal radiation, smoke release, or flames. Active fire protection systems are activated for early detection of fire; they stop fires and allow for the evacuation of occupants. These include fire alarm systems, smoke detectors, sprinklers, automatic vents, emergency escape lights, fire extinguishers, etc.

Passive fire protection systems are both structural and non-structural systems that prevent ignition in the initial stages, and fire spread, and help maintain structural stability [75,76]. Fire doors, curtains, fire and smoke dampers, fire-resistant building materials, etc., are examples of passive systems. These preventive fire safety measures have saved lives and property globally. An analysis of the effectiveness of the introduction of smoke alarms in buildings in Germany conducted by Festag [77] showed a drastic improvement in the their fire fatality risk. Over the decades, several technological advancements that improve operation and maintenance have been made in these systems. Qiu et al. [78] developed a novel video-based fire detection system that can effectively detect initial fire signs. The novel flame recognition algorithm used in this study had high illumination and could significantly minimize image blurring and flame-like interference during image recognition. Images obtained from camera feeds were processed with a smoothing algorithm to distinguish objects with real flaming attributes and those mimicking them. The smoothing process produces real images from fires, and an emission spectrometer attached to the system identifies carbon and hydroxyl radicals in the burning objects.

Kuznetsov et al. [79] conducted an investigation into the operation of fire protection systems, such as sensors in automated fire suppression systems. The authors determined the combination of active fire protection systems that can collectively enhance and optimize early fire detection and subsequent suppression, as well as minimize combustion and smoldering in buildings. They also looked at the minimum amount of water or extinguishing liquid required to suppress fires. The use of feedback loops to obtain information on the progress of the fire suppression was also addressed. The research showed that the minimum flame height for flame detectors within a distance of 2 m to 5 m ranges from 0.02 m to 0.15 m. For heat detectors, a temperature of 55 °C and above, growing at a rate of 1 °C/s, is the minimum threshold. In addition, pyrolysates detected by smoke detectors vary with the type of fuel load (material being burnt). For linoleum, wood, and paper, the thresholds are 2, 24, and 34 g/m^3, respectively. From a gas analysis system, the minimum concentrations of oxygen, carbon dioxide, and carbon monoxide concentrations after ignition are 20.5–18.5%, 0.5–2%, and 0.15–0.5%, respectively. The amounts of gases and level of heat detected by the gas analysis system and heat detectors can provide information on the burning stage and fire suppression. These thresholds and recommendations are important for managing fires.

5.3. Building Fire Design and Fire Safety Codes

As we know, different countries/cities have different rules and standards for fire safety in buildings [80]. For example, China's fire protection standards point out that building fire protection refers to the fire prevention measures taken in the process of building design and construction to prevent fires and reduce fire hazards to life and property. Generally, building fire protection measures include passive fire protection and active fire protection. Passive fire protection measures mainly include building fire protection distance, building fire resistance level, building fire protection structure, building fire compartment separation, building safety evacuation facilities, etc. [81].

According to Buchanan et al. [82], the safety of residents of a building, their escape in the event of a fire, and the ability of firefighters to gain access to the building depend on the design and construction of the building, as well as the fire resistance of the structural elements. The inclusion of fire safety requirements in building codes helps to reduce the probability of the occurrence of fires [75] and also to ensure that the structural integrity of the building is preserved. Building fire designs give specifications of acceptable fire-resistant materials for construction and explain the purposes of structural elements in case of a fire. It specifies the fuel load acceptable in buildings, the dimensional limits of structural members, fire ratings, and evacuation protocols [83]. There has been a shift from prescriptive and functional-based design to performance-based designs. In addition, residential buildings are evolving in height [84]. Recent forensic analyses on fire outbreaks in tall buildings have revealed that the advancement in modern structures does not comply with the current fire safety codes and standards [85]. According to Cowlard et al. [86], due to the drastic evolution of modern buildings, the current fire safety codes no longer satisfy the fire safety needs. There is, therefore, the need to update the codes with stringent fire safety requirements to suit the new construction methods. Qianli et al. [87] noticed that high-rise residential buildings in China faced several safety risks during fires. In their research, the authors identified four major risks that increased the complexity of firefighting in these buildings. It was observed that the rate at which fire and smoke spread in these high-rise buildings through the stairway and elevator shafts was very high. In addition, building facades are combustible, and hence increase flame spread vertically at a drastic rate. In addition, both firefighting and evacuation in high-rise residential buildings are difficult due to the high number of occupants compared to low buildings. Upgraded equipment is therefore required for effective firefighting. The authors also identified residential buildings that suspend in midair, such that the staircases and elevators do not reach the ground floor. In such cases, fire lifts and firefighters do not have easy access to such spaces [88]. The authors, therefore, provided a new design with transfer floors and passageways as well as emergency exits for easy access to the outside. Maluk et al. [89] emphasized the need to integrate fire safety designs into the building design process. The authors stated that fire safety engineers are not usually involved in the building design process until the structure is constructed and approval is needed. This majorly affects the implementation of fire safety protocols and tends to increase fire risks. Because the individual building elements in the building design are required to comply with an acceptable rating, integrating fire safety at the early stages of design could help minimize the occurrence of fires.

5.4. Development of Fire-Safe Building Materials

Although the source of a fire may be cooking equipment, electrical failure, cigarettes, etc., flame spread depends on the fuel load in the building. Any combustible material in a building that increases the intensity of a fire and promotes flame spread can be classified as a fuel load. The advancement in building technology and the quest for light-weight structures have brought about the utilization of flammable materials such as light-weight plastic and engineered wood in buildings. During a fire, these materials lose their structural integrity within approximately four to eight minutes. Additionally, to supplement energy usage in buildings for heating, cooking, etc., building insulation materials such as expanded polystyrene are used as the thermal envelope for buildings [90]. These materials, according to flammability assessments [91], possess a low fire performance and have the ability to cause fires and flame spread. The extensive use of these insulation materials without the necessary fire protection can cause fire outbreaks, as was seen in the Grenfell tower fire [92] and several other fires from façade claddings [93]. In a review of exterior wall claddings in China, Peng et al. [94] proposed the installation of a fire-resistant protective layer on the surfaces of insulation materials to enhance fire safety in buildings. In addition, fire retardants that are both sustainable and innocuous towards the environment, such as phytic acid based ones, can be used as treatment before installation [95]. Several fire-resistant building materials are being developed; however, these materials are still in the research stage and have not been commercialized.

Caetano et al. [96] developed fire resistant gypsum and cement-based mortars capable of enhancing the stability of steel members during fire exposure. They also evaluated the effect of the size of aggregates as well as the addition of silica particles on the thermal properties of the concrete. The authors found that the use of gypsum as a binder and the addition of silica micro- and nano-particles to mortars increased the insulating capacity. The research showed that a 10 mm thick gypsum mortar was enough to produce a thermal barrier that shielded steel columns from approximately 70% of the temperature from an oven.

Several other composite materials, such as fiber reinforced polymers, etc., are available on the market for architectural applications. Although they have very high aesthetic value, flammability assessments should be conducted on a large scale to critically evaluate their fire performance [97–99]. Such analysis can eliminate vertical flame spread from insulation materials in high rise buildings and flame spread through floorboards and cracks so as to maintain the integrity of building components.

5.5. Integration of Artificial Intelligence (AI) to Predict Impending Fires

AI predictive models have been used in several research areas with a high level of accuracy [99–103]. Through the independent learning and inference of a large amount of experimental data, and improving the algorithm model, the function of accurate prediction is obtained [102–105]. The development of AI prediction in the field of firefighting is relatively new and is still in the early stage of study. Some researchers [106–108] have used artificial neural network models to predict the heat release properties of polymers; however, this analysis only gives an idea of the materials' fire behavior. It is worth noting that researchers from the national institute of standards and technology (NIST) have developed an artificial intelligence model, FlashNet, that can accurately (92%) predict the time to flashover of fires [109]. This model can inform firefighters on the time to enter or leave a burning building to save occupants, as well as the resources needed to put out a fire.

Andre Ostrak [110] used the database of the Estonian Rescue Board to develop a machine learning model to predict house fires in Estonia. To achieve this, the author used the location and time data from past fires, the building database, and the weather forecasts. The weighted XGBoost prediction algorithm was selected to train the model owing to its ability to handle data imbalance. The model accurately predicted 79% of the past fires in Estonia and wrongly classified 21% of the fires.

So far, being able to develop full AI models to predict impending fires remains a long-term goal. It is anticipated that using the rate of temperature rise from temperature sensors and data from smoke sensors and camera feeds, it will be possible to develop an artificial neural network model that can predict fires minutes before they occur. Such models can help reduce the occurrence of fires, not only in residential buildings, but also in commercial buildings, as well as for forest fires.

6. Summary and Conclusions

Fire safety in structures is crucial in this modern age due to the gravitation towards light-weight and aesthetically pleasing building materials. The frequency of occurrence of fires in structures is increasing drastically globally. One way to assess this global rise is to review the fire incidents, identify the gaps in fire safety, and propose mitigation measures, which is the focus of this review article.

Developed countries have systematically planned cities with available infrastructure and social amenities that make fire management more effective. On the other hand, developing and underdeveloped nations lack fire protection resources, fire-safe building materials, and education on fire hazards. Over the decades, this has increased the number of fires in these settlements.

To minimize the occurrence of fires, more fire safety training programs should be introduced in schools and communities by employing both electronic and face-to-face learning approaches. The responsible authorities should ensure the safe operation of fire protection devices. More funding should be directed towards the development of fire-safe building materials that can reduce flame spread in buildings. In addition, developing new models that can accurately predict impending fires in buildings could drastically enhance fire safety in structures.

These factors will not only bridge the fire safety gap but will also improve the resistance to fire in structures.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study can be found in the cited references.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Manzello, S.L.; Blanchi, R.; Gollner, M.J.; Gorham, D.; McAllister, S.; Pastor, E.; Planas, E.; Reszka, P.; Suzuki, S. Summary of workshop large outdoor fires and the built environment. *Fire Saf. J.* **2018**, *100*, 76–92. [CrossRef]
2. Galiana-Martín, L. Spatial Planning Experiences for Vulnerability Reduction in the Wildland-Urban Interface in Mediterranean European Countries. *Eur. Countrys.* **2017**, *9*, 577–593. [CrossRef]
3. Bartlett, A.I.; Hadden, R.M.; Bisby, L.A. A Review of Factors Affecting the Burning Behaviour of Wood for Application to Tall Timber Construction. *Fire Technol.* **2019**, *55*, 1–49. [CrossRef]
4. Östman, B.; Brandon, D.; Frantzich, H. Fire safety engineering in timber buildings. *Fire Saf. J.* **2017**, *91*, 11–20. [CrossRef]
5. Bwalya, A. An Overview of Design Fires for Building Compartments. *Fire Technol.* **2008**, *44*, 167–184. [CrossRef]
6. Murray, C.J.L.; Lopez, A.D. *Global Health Statistics: A Compendium of Incidence, Prevalence and Mortality Estimates for over 200 Conditions*; Harvard School of Public Health on behalf of the World Health Organization and the World Bank: Cambridge, MA, USA, 1996; Volume 2, Available online: https://apps.who.int/iris/handle/10665/41848 (accessed on 13 November 2022).
7. Brushlinsky, N.; Sokolov, S.; Wagner, P. Center of Fire Statistics World Fire Statistics. 2022. Available online: https://www.ctif.org/sites/default/files/2022-08/CTIF_Report27_ESG.pdf (accessed on 5 January 2023).

8. Rahman, M.S.; Islam, B.; Ahmed, B. *An Overview on Rapid Urbanization and Induced Disaster Risk Factors in Bangladesh. World Town Planning Day*; Bangladesh Institute of Planners: Dhaka, Bangladesh, 2012; pp. 56–64. [CrossRef]
9. Aliyu, A.A.; Amadu, L. Urbanization, cities, and health: The challenges to Nigeria—A review. *Ann. Afr. Med.* **2017**, *16*, 149. Available online: https://www.annalsafrmed.org/text.asp?2017/16/4/149/216708 (accessed on 16 December 2022). [CrossRef]
10. Liu, D.; Xu, Z.; Wang, Z.; Zhou, Y.; Fan, C. Estimation of effective coverage rate of fire station services based on real-time travel times. *Fire Saf. J.* **2021**, *120*, 103021. [CrossRef]
11. Sanni-Anibire, M.O.; Mahmoud, A.S.; Hassanain, M.A.; Salami, B.A. A risk assessment approach for enhancing construction safety performance. *Saf. Sci.* **2020**, *121*, 15–29. [CrossRef]
12. Kodur, V.K.R.; Naser, M.Z. Designing steel bridges for fire safety. *J. Constr. Steel Res.* **2019**, *156*, 46–53. [CrossRef]
13. China Sees 13.6% Drop in Deaths from Fire in 2020. 2021. Available online: http://english.www.gov.cn/statecouncil/ministries/202101/22/content_WS600ac5b3c6d0f725769445a9.html (accessed on 16 December 2022).
14. McKee, M. Grenfell Tower fire: Why we cannot ignore the political determinants of health. *BMJ* **2017**, *357*, j2966. [CrossRef]
15. Ansfield, B. The Broken Windows of the Bronx: Putting the Theory in Its Place. *Am. Q.* **2020**, *72*, 103–127. [CrossRef]
16. Ramachandran, G. *The Economics of Fire Protection*; Routledge: Oxford, UK, 2002. [CrossRef]
17. Durai, J.S.; Vigneshwaran, R. Fire System Analysis and Optimization of Suitable Fire Control System. *Environ. Sci. Eng.* **2022**, *1*, 14–16. [CrossRef]
18. Zheng, A.; Garis, L.; Pike, I. Fire Severity Outcome Comparison of Apartment Buildings Constructed from Combustible and Non-Combustible Construction Materials. *Fire Technol.* **2022**, *58*, 1815–1825. [CrossRef]
19. Ivanov, M.L.; Chow, W.-K. Fire safety in modern indoor and built environment. *Indoor Built Environ.* **2023**, *32*, 3–8. [CrossRef]
20. Bullock, J.A.; Haddow, G.D.; Coppola, D.P. Mitigation, Prevention, and Preparedness. In *Introduction to Homeland Security*; Elsevier: Amsterdam, The Netherlands, 2013; pp. 435–494. [CrossRef]
21. Billington, M.J.; Copping, A.; Ferguson, A.G. *Means of Escape from Fire*; John Wiley & Sons: Hoboken, NJ, USA, 2008.
22. Kiggundu, M.N. Integrating strategic management tasks into implementing agencies: From firefighting to prevention. *World Dev.* **1996**, *24*, 1417–1430. [CrossRef]
23. Walls, R.S.; Cicione, A.; Messerschmidt, B.; Almand, K. Africa: Taking fire safety forwards. *Fire Mater.* **2021**, *45*, 999–1007. [CrossRef]
24. Farooq, S.H.; Maqbool, S.; Haseeb, S. Structural Fire Safety Measures in Developing Countries: Pakistan—A Case Study. *Int. J. Eng. Adv. Technol.* **2014**, *1*, 2249–8958.
25. Rahardjo, H.A.; Prihanton, M. The most critical issues and challenges of fire safety for building sustainability in Jakarta. *J. Build. Eng.* **2020**, *29*, 101133. [CrossRef]
26. Addai, E.K.; Tulashie, S.K.; Annan, J.-S.; Yeboah, I. Trend of Fire Outbreaks in Ghana and Ways to Prevent These Incidents. *Saf. Health Work.* **2016**, *7*, 284–292. [CrossRef]
27. Walls, R.; Olivier, G.; Eksteen, R. Informal settlement fires in South Africa: Fire engineering overview and full-scale tests on "shacks". *Fire Saf. J.* **2017**, *91*, 997–1006. [CrossRef]
28. Robbins, A.P.; Wade, C. Residential New Zealand Fire Statistics: Part 1 Initial Analysis. BRANZ Study Report. 2010, p. 222. Available online: https://d39d3mj7qio96p.cloudfront.net/media/documents/SR222_Residential_New_Zealand_fire_statistics_-_part_1_-_initial_analysis.pdf (accessed on 16 December 2022).
29. Ahrens, M.; Maheshwari, R. *Home Structure Fires*; Fire Analysis and Research Division: Quincy, MA, USA, 2013.
30. Spearpoint, M.; Hopkin, C. Household cooking oil use and its bearing on fire safety. *J. Fire Sci.* **2021**, *39*, 265–284. [CrossRef]
31. Spearpoint, M.; Hopkin, C.; Hopkin, D. Modelling the thermal radiation from kitchen hob fires. *J. Fire Sci.* **2020**, *38*, 377–394. [CrossRef]
32. Hu, Y.; Chen, J.; Bundy, M.; Hamins, A. The character of residential cooktop fires. *J. Fire Sci.* **2021**, *39*, 142–163. [CrossRef]
33. Chen, J.; Hu, Y.; Wang, Z.; Lee, K.Y.; Kim, S.C.; Bundy, M.; Fernandez, M.; Hamins, A. Why are cooktop fires so hazardous? *Fire Saf. J.* **2021**, *120*, 103070. [CrossRef]
34. Ouache, R.; Chhipi-Shrestha, G.; Hewage, K.; Sadiq, R. An integrated risk assessment and prediction framework for fire ignition sources in smart-green multi-unit residential buildings. *Int. J. Syst. Assur. Eng. Manag.* **2021**, *12*, 1262–1295. [CrossRef]
35. Baker, D.E. Unvented Portable Kerosene Heaters—Safety Considerations. 2022. Available online: https://hdl.handle.net/10355/91186 (accessed on 15 January 2023).
36. Ahrens, M. Smoking and fire. *Am. J. Public Health* **2004**, *94*, 1076–1077. [CrossRef]
37. Statista Research Department. World Consumption of Cigarettes 1880–2020. 2022. Available online: https://www.statista.com/statistics/279577/global-consumption-of-cigarettes-since-1880/ (accessed on 30 November 2022).
38. Anderson, A.; Janssens, M. A Multi-national Survey of Low-Energy and Smoking Materials Ignition Fires. *Fire Technol.* **2016**, *52*, 1709–1735. [CrossRef]
39. Warda, L.; Tenenbein, M.; Moffatt, M.E.K. House fire injury prevention update. Part I. A review of risk factors for fatal and non-fatal house fire injury. *Inj. Prev.* **1999**, *5*, 145–150. [CrossRef]
40. Leistikow, B.N.; Martin, D.C.; Milano, C.E. Fire Injuries, Disasters, and Costs from Cigarettes and Cigarette Lights: A Global Overview. *Prev. Med.* **2000**, *31*, 91–99. [CrossRef] [PubMed]
41. Babrauskas, V. Research on Electrical Fires: The State of the Art. *Fire Saf. Sci.* **2008**, *9*, 3–18. [CrossRef]

42. Fernández-Vigil, M.; Echeverría, T.B. Elderly at Home: A Case for the Systematic Collection and Analysis of Fire Statistics in Spain. *Fire Technol.* **2019**, *55*, 2215–2244. [CrossRef]
43. Lu, S.; Liang, C.; Song, W.; Zhang, H. Frequency-size distribution and time-scaling property of high-casualty fires in China: Analysis and comparison. *Saf. Sci.* **2013**, *51*, 209–216. [CrossRef]
44. Matsui, H.; Oniki, A. *Risk Management of Electrical Fires in China*; Easy Chair: Manchester, UK, 2019.
45. Shea, J.J. Identifying causes for certain types of electrically initiated fires in residential circuits. *Fire Mater.* **2011**, *35*, 19–42. [CrossRef]
46. Kim, J.; Youm, S.; Shan, Y.; Kim, J. Analysis of Fire Accident Factors on Construction Sites Using Web Crawling and Deep Learning Approach. *Sustainability* **2021**, *13*, 11694. [CrossRef]
47. House Fire Statistics. The Zebra. 2023. Available online: https://www.thezebra.com/resources/research/house-fire-statistics/ (accessed on 10 February 2023).
48. Kodur, V.; Kumar, P.; Rafi, M.M. Fire hazard in buildings: Review, assessment and strategies for improving fire safety. *PSU Res. Rev.* **2019**, *4*, 1–23. [CrossRef]
49. Kumar, P.; Kodur, V. Modeling the behavior of load bearing concrete walls under fire exposure. *Constr. Build. Mater.* **2017**, *154*, 993–1003. [CrossRef]
50. Gao, Y. Research on monitoring method of smoke particles diffusion path in high—Rise building fire. *Environ. Sci. Manag.* **2020**, *45*, 131–135. (In Chinese)
51. The Cause of the Fire in a High-Rise Building in Dalian Has Been Identified—Seetao. 2019. Available online: https://www.seetao.com/details/112114.html (accessed on 15 September 2021).
52. Hsueh-kuang, H.; Wang, K. Death Toll in Kaohsiung Fire Climbs to 46; Injuries Reach 41. Available online: https://archive.ph/20211014104204/https://focustaiwan.tw/society/202110140015 (accessed on 14 October 2021).
53. Nadu, T. HomeTamil Nadu13 Years after 94 Children Died in Tamil Nadu Fire, All Convicts Freed This Article Is from Aug 11, 2017 13 Years after 94 Children Died in Tamil Nadu Fire, All Convicts Freed. 2017. Available online: https://www.ndtv.com/tamil-nadu-news/kumbakonam-fire-mishap-madras-high-court-suspends-conviction-sentence-of-7-1736263 (accessed on 1 October 2020).
54. Dutta, A. Stephen Court Fire Toll Rises to 43. India. 2021. Available online: https://www.thehindu.com/news/national/Stephen-Court-fire-toll-rises-to-43/article16627837.ece (accessed on 4 November 2020).
55. Fire at South Korea 33-Level Tower Block Brought under Control. Ulsan. 2020. Available online: https://www.bbc.com/news/world-asia-54470378 (accessed on 10 October 2020).
56. High-Rise in Brazil Collapses after Massive Fire. The Two-Way. 2018. Available online: https://www.npr.org/sections/thetwo-way/2018/05/01/607313901/high-rise-in-brazil-collapses-after-massive-fire (accessed on 30 November 2022).
57. Garimella, P.P. Planned relocation: An unusual case for developed countries. *Curr. Res. Environ. Sustain.* **2022**, *4*, 100177. [CrossRef]
58. Meijer, F.; Visscher, H. Measuring the Evolution of Online Handling of Building Permits in Europe. RCIS COBRA 2009. The Construction and Building Research Conference of the Royal Institution of Chartered Surveyors. 2009, pp. 1328–1338. Available online: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=5e828b299dccbde187ad804ae7cc566e9c80e634 (accessed on 30 November 2022).
59. Babrauskas, V.V. Some Neglected Areas in Fire Safety Engineering. *Fire Sci. Technol.* **2013**, *32*, 35–48. [CrossRef]
60. Challands, N. The Relationships Between Fire Service Response Time and Fire Outcomes. *Fire Technol.* **2010**, *46*, 665–676. [CrossRef]
61. National Ten-Year Fire Data Warning. Xinhua Network. 2021. Available online: http://www.news.cn/datanews/20211015/C99905849A6000016872423D822F8320/c.html (accessed on 29 November 2022).
62. Mathers, C.D.; Boerma, T.; Fat, D.M. Global and regional causes of death. *Br. Med. Bull.* **2009**, *92*, 7–32. [CrossRef] [PubMed]
63. Wang, Y.; Beshir, M.; Hadden, R.; Cicione, A.; Krajcovic, M.; Gibson, L.; Rush, D. Laboratory experiment of fire spread between two informal settlement dwellings. *Int. J. Therm. Sci.* **2022**, *171*, 107195. [CrossRef]
64. Bangladesh Fire: Thousands of Shacks Destroyed in Dhaka Slum. 2019. Available online: https://www.bbc.com/news/world-asia-49382682 (accessed on 30 November 2022).
65. Kahanji, C.; Walls, R.S.; Cicione, A. Fire spread analysis for the 2017 Imizamo Yethu informal settlement conflagration in South Africa. *Int. J. Disaster Risk Reduct.* **2019**, *39*, 101146. [CrossRef]
66. Quiroz, N.F.; Walls, R.; Cicione, A. Developing a framework for fire investigations in informal settlements. *Fire Saf. J.* **2021**, *120*, 103046. [CrossRef]
67. Walls, R.S.; Eksteen, R.; Kahanji, C.; Cicione, A. Appraisal of fire safety interventions and strategies for informal settlements in South Africa. *Disaster Prev. Manag. Int. J.* **2019**, *28*, 343–358. [CrossRef]
68. Marrion, C.E. More effectively addressing fire/disaster challenges to protect our cultural heritage. *J. Cult. Herit.* **2016**, *20*, 746–749. [CrossRef]
69. Drotárová, J.; Kačíková, D.; Kelemen, M.; Bodor, M. The possibilities of using blended learning in fire safety education. *CBU Int. Conf. Proc.* **2016**, *4*, 283–286. [CrossRef]
70. Bhagat, K.K.; Liou, W.-K.; Chang, C.-Y. A cost-effective interactive 3D virtual reality system applied to military live firing training. *Virtual Real.* **2016**, *20*, 127–140. [CrossRef]

71. Xu, Z.; Lu, X.Z.; Guan, H.; Chen, C.; Ren, A.Z. A virtual reality based fire training simulator with smoke hazard assessment capacity. *Adv. Eng. Softw.* **2014**, *68*, 1–8. [CrossRef]
72. Zhang, K.; Suo, J.; Chen, J.; Liu, X.; Gao, L. Design and Implementation of Fire Safety Education System on Campus based on Virtual Reality Technology. In Proceedings of the 2017 Federated Conference on Computer Science and Information Systems (FedCSIS), Prague, Czech Republic, 3–6 September 2017; pp. 1297–1300.
73. Burke, R. *Fire Protection: Systems and Response*; CRC Press: Boca Raton, FL, USA, 2007.
74. Guo, T.-N.; Fu, Z.-M. The fire situation and progress in fire safety science and technology in China. *Fire Saf. J.* **2007**, *42*, 171–182. [CrossRef]
75. Lim, J.; Baalisampang, T.; Garaniya, V.; Abbassi, R.; Khan, F.; Ji, J. Numerical analysis of performances of passive fire protections in processing facilities. *J. Loss. Prevent. Proc.* **2019**, *62*, 103970. [CrossRef]
76. Mróz, K.; Hager, I.; Korniejenko, K. Material Solutions for Passive Fire Protection of Buildings and Structures and Their Performances Testing. *Procedia Eng.* **2016**, *151*, 284–291. [CrossRef]
77. Festag, S. Analysis of the effectiveness of the smoke alarm obligation—Experiences from practice. *Fire Saf. J.* **2021**, *119*, 103263. [CrossRef]
78. Qiu, X.; Xi, T.; Sun, D.; Zhang, E.; Li, C.; Peng, Y.; Wei, J.; Wang, G. Fire Detection Algorithm Combined with Image Processing and Flame Emission Spectroscopy. *Fire Technol.* **2018**, *54*, 1249–1263. [CrossRef]
79. Kuznetsov, G.; Zhdanova, A.; Volkov, R.; Strizhak, P. Optimizing firefighting agent consumption and fire suppression time in buildings by forming a fire feedback loop. *Process. Saf. Environ. Protect.* **2022**, *165*, 754–775. [CrossRef]
80. Rodrigues, E.E.C.; Rodrigues, J.P.C.; Filho, L.C.P.d.S. Comparative study of building fire safety regulations in different Brazilian states. *J. Build. Eng.* **2017**, *10*, 102–108. [CrossRef]
81. Sun, X.; Cai, N.; Zhang, W. Discussing the development of domestic and foreign fire protection technical regulation and fire protection technical standard systems. *J. Saf. Sci. Resil.* **2022**, *4*, 26–29. [CrossRef]
82. Buchanan, A.H.; Abu, A.K. *Structural Design for Fire Safety*, 2nd ed.; John Wiley & Sons: Hoboken, NJ, USA, 2017; ISBN 978-0-470-97289-2.
83. Chu, G.; Sun, J. Decision analysis on fire safety design based on evaluating building fire risk to life. *Saf. Sci.* **2008**, *46*, 1125–1136. [CrossRef]
84. The Skyscraper Centre. The Global Tall Building Database of the CTBUH. Available online: http://skyscrapercenter.com/ (accessed on 10 December 2022).
85. Fletcher, I.A. Tall Concrete Buildings Subject to Vertically Moving Fires: A Case Study Approach. 2009. Available online: http://hdl.handle.net/1842/3199 (accessed on 10 December 2022).
86. Cowlard, A.; Bittern, A.; Abecassis-Empis, C.; Torero, J. Fire Safety Design for Tall Buildings. *Procedia Eng.* **2013**, *62*, 169–181. [CrossRef]
87. Ma, Q.; Guo, W. Discussion on the Fire Safety Design of a High-Rise Building. *Procedia Eng.* **2012**, *45*, 685–689. [CrossRef]
88. Kathar, A.; Barhate, Y.; Chakhale, J.; Thakur, P.D.K. Fabrication of Fire Fighting System for High Rise Building. *Int. J. Res. Publ. Rev.* **2022**, *3*, 684–687.
89. Maluk, C.; Woodrow, M.; Torero, J.L. The potential of integrating fire safety in modern building design. *Fire Saf. J.* **2017**, *88*, 104–112. [CrossRef]
90. Aditya, L.; Mahlia, T.; Rismanchi, B.; Ng, H.; Hasan, M.; Metselaar, H.; Muraza, O.; Aditiya, H. A review on insulation materials for energy conservation in buildings. *Renew. Sustain. Energy Rev.* **2017**, *73*, 1352–1365. [CrossRef]
91. Mensah, R.A.; Xu, Q.; Asante-Okyere, S.; Jin, C.; Bentum-Micah, G. Correlation analysis of cone calorimetry and microscale combustion calorimetry experiments. *J. Therm. Anal. Calorim.* **2019**, *136*, 589–599. [CrossRef]
92. McKenna, S.T.; Jones, N.; Peck, G.; Dickens, K.; Pawelec, W.; Oradei, S.; Harris, S.; Stec, A.A.; Hull, T.R. Fire behaviour of modern façade materials—Understanding the Grenfell Tower fire. *J. Hazard. Mater.* **2019**, *368*, 115–123. [CrossRef]
93. McLaggan, M.; Hidalgo, J.; Osorio, A.; Heitzmann, M.; Carrascal, J.; Lange, D.; Maluk, C.; Torero, J. Towards a better understanding of fire performance assessment of façade systems: Current situation and a proposed new assessment framework. *Constr. Build. Mater.* **2021**, *300*, 124301. [CrossRef]
94. Peng, L.; Ni, Z.; Huang, X. Review on the Fire Safety of Exterior Wall Claddings in High-rise Buildings in China. *Procedia Eng.* **2013**, *62*, 663–670. [CrossRef]
95. Mensah, R.A.; Shanmugam, V.; Narayanan, S.; Renner, J.S.; Babu, K.; Neisiany, R.E.; Försth, M.; Sas, G.; Das, O. A review of sustainable and environment-friendly flame retardants used in plastics. *Polym. Test.* **2022**, *108*, 107511. [CrossRef]
96. Caetano, H.; Laím, L.; Santiago, A.; Durães, L.; Shahbazian, A. Development of Passive Fire Protection Mortars. *Appl. Sci.* **2022**, *12*, 2093. [CrossRef]
97. Charbonnet, J.A.; Weber, R.; Blum, A. Flammability standards for furniture, building insulation and electronics: Benefit and risk. *Emerg. Contam.* **2020**, *6*, 432–441. [CrossRef]
98. Banu, D.; Feldman, D.; Haghighat, F.; Paris, J. Energy-Storing Wallboard: Flammability Tests. *J. Mater. Civ. Eng.* **1998**, *10*, 98–105. [CrossRef]
99. Kererekes, Z.; Lublóy, É.; Elek, B.; Restás, Á. Standard fire testing of chimney linings from composite materials. *J. Build. Eng.* **2018**, *19*, 530–538. [CrossRef]

100. He, D.; Wang, Z.; Liu, J. A Survey to Predict the Trend of AI-able Server Evolution in the Cloud. *IEEE Access* **2018**, *6*, 10591–10602. [CrossRef]
101. Krittanawong, C.; Bomback, A.S.; Baber, U.; Bangalore, S.; Messerli, F.H.; Tang, W.H.W. Future Direction for Using Artificial Intelligence to Predict and Manage Hypertension. *Curr. Hypertens. Rep.* **2018**, *20*, 75. [CrossRef] [PubMed]
102. Wang, Z.; Srinivasan, R.S. A review of artificial intelligence based building energy use prediction: Contrasting the capabilities of single and ensemble prediction models. *Renew. Sustain. Energy Rev.* **2017**, *75*, 796–808. [CrossRef]
103. Agrawal, A.; Gans, J.S.; Goldfarb, A. Artificial Intelligence: The Ambiguous Labor Market Impact of Automating Prediction. *J. Econ. Perspect.* **2019**, *33*, 31–50. [CrossRef]
104. Manu, D.S.; Thalla, A.K. Artificial intelligence models for predicting the performance of biological wastewater treatment plant in the removal of Kjeldahl Nitrogen from wastewater. *Appl. Water Sci.* **2017**, *7*, 3783–3791. [CrossRef]
105. Anderson, J.; Rainie, L. Artificial Intelligence and the Future of Humans. 2018, Volume 10. Available online: https://www.pewresearch.org/internet/2018/12/10/artificial-intelligence-and-the-future-of-humans/ (accessed on 10 December 2022).
106. Asante-Okyere, S.; Xu, Q.; Mensah, R.A.; Jin, C.; Ziggah, Y.Y. Generalized regression and feed forward back propagation neural networks in modelling flammability characteristics of polymethyl methacrylate (PMMA). *Thermochim. Acta* **2018**, *667*, 79–92. [CrossRef]
107. Jiang, L.; Mensah, R.A.; Asante-Okyere, S.; Försth, M.; Xu, Q.; Ziggah, Y.Y.; Restás, Á.; Berto, F.; Das, O. Developing an artificial intelligent model for predicting combustion and flammability properties. *Fire Mater.* **2021**, *46*, 830–842. [CrossRef]
108. Mensah, R.A.; Jiang, L.; Asante-Okyere, S.; Xu, Q.; Jin, C. Comparative evaluation of the predictability of neural network methods on the flammability characteristics of extruded polystyrene from microscale combustion calorimetry. *J. Therm. Anal. Calorim.* **2019**, *138*, 3055–3064. [CrossRef]
109. Tam, W.C.; Fu, E.Y.; Li, J.; Huang, X.; Chen, J.; Huang, M.X. A spatial temporal graph neural network model for predicting flashover in arbitrary building floorplans. *Eng. Appl. Artif. Intell.* **2022**, *115*, 105258. [CrossRef]
110. Ostrak, A. Predicting House Fires with Machine Learning. 2020. Available online: https://cyber.ee/resources/news/predicting-house-fires-with-machine-learning/ (accessed on 11 December 2022).