Abstract: Hazard identification is a fundamental step in safety management that has the potential to reduce the number and severity of occupational injuries on construction sites. Researchers have identified and evaluated some of the hazards, but few have extensively discussed all of them and none have classified them by sector. The goal of this paper is to fill that research gap by considering hazard identification through an organized synthesis of the existing literature. After a comprehensive literature review, 236 publications were deemed eligible for further analysis. Eighteen safety hazards were identified and then categorized into four groups based on their physiological impacts, ranked based on frequency of citation, and classified by sector. The results revealed that falls from heights, material handling, and heavy machinery were the most frequently cited hazards and the most likely to impact all sectors. Mitigation strategies were also identified, and it was determined that most hazards can be mitigated through the use of personal protective equipment, and effective training and supervision.

Keywords: construction safety; hazard identification; occupational injuries; safety hazards; hazard management; construction management

1. Introduction

Historically, the construction industry has been viewed as particularly dangerous due to its high rates of workplace injuries and fatalities [1]. Although construction workers represent a small percentage of the United States workforce, they are the victims of 9% of all fatal occupational injuries and 20% of all non-fatal occupational injuries [2]. Despite the significant advancements made in construction safety over the years, more than 60,000 construction-related fatalities continue to be reported worldwide on an annual basis [3]. This can be largely attributed to the constant movement of and interactions between crews, materials, and equipment that take place in an ever-changing and dynamic environment, which make it easy to overlook the safety hazards that lead to preventable occupational injuries.

A hazard is defined by Vitharana et al. [4] as a potential source of harm or adverse health for an individual. The first step to controlling and managing these hazards is identifying them so that a plan can be developed to eliminate, reduce, or control them. The importance of hazard identification is often cited as the most effective safety management tool that construction managers have at their disposal [3,5], as those that are not recognized in the preconstruction phase are more likely to result in an accident on the job site [6]. Despite this knowledge, hazards continue to go unrecognized, magnifying injury severity and costing the industry billions of dollars annually [5,7]. This may be attributed to the perception that these hazards pose little risk, a lack of experience on the part of those
responsible for recognizing the need for and taking the necessary precautions, and individual risk-taking tendencies [3,8]. The dynamic nature of a construction site requires that hazards continue to be identified beyond the preconstruction phase and throughout all the project stages for effective safety planning [9]. The hazards of the four sections of the construction industry (residential, commercial, industrial, and heavy) differ widely, which makes identifying them challenging and results in workers being vulnerable to an assortment of injuries.

It is difficult for stakeholders to have a complete understanding of construction safety because of the vastness of the body of knowledge [5,9,10]—the number of studies and range of themes they address. It was, therefore, essential to conduct a thorough assessment of prior research to present an organized and comprehensive overview of the hazards. The significance of hazard identification was emphasized by Jeelani et al. [3], Goh and Chua [8], and others who, respectively, identified barriers to hazard recognition and proposed a case-based reasoning approach to identifying them. Their papers lack a comprehensive discussion of all the hazards that may be present on construction sites, however, as do multiple studies that limit their focus to one or several hazards, leaving the others unaddressed. For instance, Anantharaman et al. [11] evaluated the injury patterns and contributory factors of fall from heights, while Vukadinovic and Radosavljevic [12] explored extreme temperatures. Rafindadi et al. [13] conducted a study that identified management factors, site conditions, and workers’ behaviors that contribute to safety hazards. This paper builds on this prior research by further elaborating on those and additional hazards to ensure that all possible risks are considered.

The literature also lacks an exhaustive identification of best practices for mitigating construction hazards. Instead, studies such as the one conducted by Sanni-Anibire et al. [5] focused on developing a comprehensive list of factors contributing to different types of accidents. This review not only identifies the safety hazards and strategies to mitigate them but also ranks them within each category, based on their frequency of occurrence in the literature to highlight the perceptions and interests of researchers within the industry.

The following objectives were developed to determine the hazards that contribute to construction-related injuries: (1) develop a comprehensive list of construction-related safety hazards, (2) categorize the identified hazards according to type, (3) rank the hazards by the frequency with which they are cited in the literature, (4) classify the hazards by construction sector, and (5) identify the best practices for managing the hazards. After a thorough literature review, an extensive list of safety hazards was identified, categorized, and ranked.

This research contributes to the body of knowledge on construction safety by presenting a broad coverage of all existing construction hazards, evaluating the frequency with which they were cited in the literature, and offering a systematic review of various aspects of this subject matter. The findings of this study will assist employers with identifying all possible safety hazards on construction job sites, thus reducing the risk of their employees experiencing associated occupational accidents and injuries. Furthermore, it will support future research directions by presenting an organized synthesis of the existing literature.

2. Materials and Methods

The aim of the initial literature review was to identify all the hazards that might be present on construction sites. This was achieved by conducting a systematic literature review; compiling a database of relevant journal articles, theses, technical reports, and conference papers; and using online search engines such as Google Scholar, ASCE Library, Science Direct, and Research Gate and keywords such as construction safety, construction occupational hazards, and construction hazards. This preliminary search only considered publications that included the keywords within the title, abstract, or defined keywords of the articles selected. Articles that did not meet this requirement were eliminated.

After the initial review that resulted in a list of 18 construction hazards, an additional literature search was performed for each of the individual hazards. This secondary search
was conducted in a similar manner: the name of the hazard was entered into the topic section of the aforementioned databases. The search process was repeated for all 18 identified hazards that appeared within the title, abstract, or keywords of the article. Publications that discussed the physiological impacts of the safety hazard, both generally and with relation to the construction industry, were also considered. Figure 1 depicts the research methodology that was developed to fulfill the objectives of this study.

![Research methodology](image)

**Figure 1.** Research methodology.

The keyword search produced a large number of scholarly articles; therefore, a multistep methodology was formulated to refine the list of articles selected for detailed review and eliminate those not relevant to this review. The screening and exclusion process is depicted in Figure 2. Following the screening process, all pertinent literature published between 2002 and March 2023 was reviewed and analyzed to ensure that the results reflected researchers’ current interests. This two-decade restriction was established to reduce the number of publications included, due to the extensive number of publications on construction hazard safety and the fact that discussions of the hazards and mitigation strategies defined in the literature published before 2002 were also discussed in more recent studies.

![Multistep methodology](image)

**Figure 2.** Multistep methodology for review and selection of relevant literature.

### 2.1. Type of Hazard

After the safety hazards were identified, they were classified into four categories, based on their physiological impacts: primary hazards, physical hazards, chemical hazards, and ergonomic/other hazards. Figure 3 demonstrates the distribution of articles based on the type of hazard discussed. Articles that focused on topics such as construction safety, risk management, and accident rates rather than a specific type of hazard were classified as “general” and accounted for 22% of all the publications studied. The highest percentage (24%) of articles studied focused on chemical hazards; the lowest (15%) focused on physical hazards.
based on the type of hazard discussed. Articles that focused on topics such as construction safety, risk management, and accident rates rather than a specific type of hazard were classified as “general” and accounted for 22% of all the publications studied. The highest percentage (24%) of articles studied focused on chemical hazards; the lowest (15%) focused on physical hazards.

Figure 3. Distribution of articles by type of hazard.

2.2. Publication Country

The distribution of articles by country in which they were published is shown in Figure 4, which demonstrates that construction safety is a major global concern. The 236 articles reviewed were published in 41 countries, but countries such as Brazil, Singapore, and Sweden that published less than 2% and cumulatively represent 18% of all the articles are not depicted. The United States, China, and Korea published almost half (46%) of the articles, which is reflective of the higher number of occupational injuries that workers in those countries experience [10].

Figure 4. Distribution of articles by country.

3. Results and Discussions

3.1. Identification and Classification of Safety Hazards

The construction industry is widely recognized as one of the most labor-intensive industries, and protecting its workers from injuries resulting from exposure to occupational hazards is a primary concern. This study emphasizes the importance of identifying the hazards so that they can be mitigated, controlled, or even eliminated, and accomplishes its objectives by classifying and discussing those most frequently found on construction jobsites.
Construction safety hazards can be categorized according to a wide range of criteria, including frequency, severity, and risk levels [6]. Abdul Hamid et al. [14] defines two primary types of hazards present on construction sites: physical injury hazards and ill health hazards. Physical injury hazards can be fatal or non-fatal and are often attributed to construction processes and unsafe use of equipment. Ill health hazards encompass chemical, physical, and biological hazards [14] and are caused by noise, vibration, lighting conditions, radiation, and extreme temperatures. Chemical hazards occur when workers are exposed to dust, fumes, vapors, and other gases; biological hazards occur when workers are exposed to bacteria, viruses, and infectious waste [15]. Mihić [6] classified the hazards based on their source, identifying the following types: self-induced, peer-induced, and global hazards. This review classified safety hazards into the following four categories, based on their physiological impacts: primary hazards, physical hazards, chemical hazards, and ergonomic/other hazards. Classifying hazards facilitates an accurate identification process that reduces the possibility of overlooking a hazard.

The hazards were ranked within each category, based on the frequency with which they were cited in the reviewed literature. Table 1 provides a comprehensive list of safety hazards associated with construction activities, as well as their frequency of citation. The results revealed that falls from heights, material and equipment handling, heavy machinery, electrocution, and struck-by incidents were ranked highest. Three of these hazards, falls from heights, electrocution, and struck-by incidents, belong to the primary hazards category, which are those most often responsible for fatalities. Falls from heights scored the highest frequency, indicating the greatest researcher interest, which may be ascribed to the fact that approximately 35% of all construction-related fatalities result from falls from heights. The following section explores each of the safety hazards in depth as presented in the literature and discusses how each hazard might contribute to construction-related accidents.

Table 1. List of safety hazards with frequency and rank.

<table>
<thead>
<tr>
<th>Type of Hazard</th>
<th>ID</th>
<th>Safety Hazard</th>
<th>Frequency</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Hazards</td>
<td>PR.1</td>
<td>Falls from heights</td>
<td>107</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>PR.2</td>
<td>Electrocution</td>
<td>67</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>PR.3</td>
<td>Struck-by incidents</td>
<td>62</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>PR.4</td>
<td>Slips, trips, and falls at the ground level</td>
<td>60</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>PR.5</td>
<td>Caught-in-between incidents</td>
<td>47</td>
<td>5</td>
</tr>
<tr>
<td>Physical Hazards</td>
<td>PH.1</td>
<td>Noise</td>
<td>49</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>PH.2</td>
<td>Extreme temperatures</td>
<td>39</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>PH.3</td>
<td>Lighting and visibility</td>
<td>37</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>PH.4</td>
<td>Fire</td>
<td>36</td>
<td>4</td>
</tr>
<tr>
<td>Chemical Hazards</td>
<td>CH.1</td>
<td>Hazardous materials</td>
<td>53</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>CH.2</td>
<td>Airborne materials</td>
<td>32</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>CH.3</td>
<td>Thermal and chemical burns</td>
<td>26</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>CH.4</td>
<td>Asbestos</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>Ergonomic and Other Hazards</td>
<td>EO.1</td>
<td>Material and equipment handling</td>
<td>76</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>EO.2</td>
<td>Heavy machinery</td>
<td>68</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>EO.3</td>
<td>Trench collapse</td>
<td>31</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EO.4</td>
<td>Scaffold collapse</td>
<td>29</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>EO.5</td>
<td>Vibration</td>
<td>28</td>
<td>5</td>
</tr>
</tbody>
</table>

3.1.1. Primary Hazards

Construction sites are always in a state of flux due to the constant movement of people and equipment. Machinery and scaffolding are continually assembled, relocated, or modified [16], which combined with the human factor results in a hazardous working environment. Primary hazards are those that most commonly result in fatalities or serious injuries. As demonstrated in Table 1, five primary hazards were identified: (1) falls from
The greatest number of construction accidents, some of which are fatal, are fall-related and occur both at the ground level (falls into holes and excavation pits) and from heights (falls from scaffolding, roofs, ladders, and cranes) [11]. Falls from heights are the primary cause of construction-related injuries in many countries, including the United States, Singapore, New Zealand, Hong Kong, Taiwan, and Kuwait [17], and much of the danger from them stems from the fact that rather than free-falling, workers encounter scaffolding or other objects during the fall, modifying the mechanism of landing and resulting in a variety of bodily injuries [11]. An analysis of fatal construction falls from heights in Hong Kong revealed that the primary causes of falls are loss of balance, a lack of adequate fall protection devices, malfunction or collapse of platforms, and a direct encounter with another object [18]. A study by Anantharaman et al. [11] highlighted human-related issues associated with the lack of effective safety measures to prevent falls and protect workers against fall hazards. Through the assessment of injury patterns associated with falls from heights, the study revealed that more than 80% of those injured from falling from scaffolding or a ladder reported the absence or incorrect usage of a safety harness or helmet [11]. Immersive virtual reality may be utilized as a training tool to enhance safety training, illustrate the dangers of hazardous behavior, and reinforce the importance of safety measures without risking injuries [19].

While both falls from heights and slips, trips, and falls at the ground level are common occurrences on construction sites, the latter often result in serious musculoskeletal injuries but are rarely fatal. Slips occur when there is insufficient frictional resistance between the foot and the walking or working surface, whereas trips occur when the foot unexpectedly encounters an obstruction on the walking surface [20]. Slips and trips cause a loss of balance, often resulting in a fall to the same level. In the instances where they do not result in a fall, indirect injuries can occur from the individual attempting to regain their footing [21]. The risk factors contributing to slips, trips, and falls at the same level are either environmental, system-related, or human, with the primary factor being low friction between the foot and the walking surface [22]. Other contributing factors include unstable or uneven surfaces, the presence of contaminants on the walking surface due to poor housekeeping, inadequate illumination, inappropriate footwear, and failure to visually detect the hazard [5].

After falls, caught-in-between incidents, which occur when a worker is caught in or trapped between moving or stationary equipment or objects, constitute the most fatal accidents. Construction machinery and heavy equipment play significant roles in construction processes and increase the likelihood of caught-in-between accidents. Other sources contributing to this type of accident are material handling equipment, motor vehicles, powered hand tools, cranes, trench collapses, and solid materials or equipment [23]. To minimize the occurrence of this type of accident, construction supervisors should emphasize the dangers of working around heavy equipment; increase the frequency and quality of training; minimize access to moving machinery parts; secure guards on all equipment; and ensure that workers are familiar with the locations of pinch, shear, wrap, and crush points [23].

Struck-by injuries are caused by falling objects, collisions between heavy equipment, or collisions between machinery and construction workers [24] that originate from construction activities and the movement of people and equipment. The nature of the incidents varies, depending on the jobsite and tasks at hand [25], but they predominantly involve equipment collisions, motorized vehicles, falling materials, and collapse of trenches [24]. Although it may be hard to predict the likelihood of struck-by accidents, a study in Malaysia identified the factors that increase the risk of these incidents: a lack of safety training, inadequate supervision, poor housekeeping practices, a lack of situational awareness, defective equipment, and poor visibility [26]. Poor visibility is the leading cause of struck-by fatalities, as equipment or vehicle operators may be unable to see workers when they are in a blind spot or in an area with inadequate lighting [27]. Adverse weather also increases
the likelihood of a struck-by incident. For instance, construction workers are at greater risk of being hit by falling objects in windy conditions where equipment placed at higher levels can be blown over, striking those below [26]. An incident in Johor, Malaysia, in which a construction worker suffered a fatal head injury after being struck by a falling brick, highlights the danger of falling equipment [26].

Electrocution, another primary hazard identified in Table 1, can result in burns, damage to internal organs, and/or cardiac arrest and can be fatal. Electricity travels in a closed circuit through a conductor, and the human body, when exposed to electric flow, becomes part of the circuit and acts as a conductor. The electric sources on construction sites include equipment, power lines, transformers, switches, and fuses [28], and electrocution can occur by direct contact with the electricity source or by indirect contact with an intermediary conductive medium. Construction workers are at highest risk of electrocution when they work on live lines, weld, or operate construction vehicles such as hoists and mobile cranes [29], but injuries and fatalities can be prevented when effective safety precautions are in place. A study of fatalities resulting from electrocution in Taiwan’s construction industry revealed that the primary causes were improper use of personal protective equipment, a lack of grounding, failure to maintain a safe distance from electrical hazards, defective insulation, a lack of hazard awareness, and failure to de-energize [28]. Workers were found to be commonly electrocuted by backfeed voltage from household generators due to a lack of de-energizing and proper grounding of power lines [28], but these fatalities are preventable when effective safety precautions are in place. The importance of safety measures was demonstrated in a recount of an unexpected energization of a power line that electrocuted and killed a worker who had taken many of the necessary safety precautions but failed to wear any personal protective equipment [30].

3.1.2. Physical Hazards

Physical hazards encompass different forms of energy that may negatively affect the physical health of workers, either instantaneously or over a prolonged period of exposure. The four physical hazards presented in Table 1 have been identified on construction projects and can magnify the impacts of other hazards, thus making construction workers more vulnerable.

Noise pollution is a common side effect of construction, and while there is usually a greater focus on the impact of noise on residents surrounding construction sites, construction workers are the group most negatively affected. Construction noise, which is characterized by sudden, irregular, high-intensity, and difficult-to-control bursts of sound [31], stems primarily from machines that produce impacts such as pile drivers, earth augers, and combustion engines [32]. Noise-induced hearing loss, which can be so severe that it impairs an individual’s ability to conduct day-to-day activities, is one of the most common occupational illnesses in the United States, and construction workers are the second most impacted group [33]. Prolonged noise exposure can also be manifested in other health issues [32] and can lead to an increased likelihood of other hazards, e.g., occupational noise can overpower speech and auditory safety cues, leading to ineffective communication and a lack situational awareness. Dynamic models tailored to the topography of the site and the noise levels of the equipment can significantly reduce prolonged noise exposure and effectively manage its impact [32,34].

Extreme temperatures can also cause reduced cognitive ability, minimizing workers’ ability to recognize hazardous situations and making them more vulnerable to accidents [35]. In most construction projects, work must proceed regardless of the weather conditions. Consequently, workers are often faced with extreme hot or cold temperatures that make them more vulnerable to injuries because of their physical or physiological reactions to their working environment [12]. A study in Italy revealed a positive correlation between work-related injuries and occupational exposure to adverse weather conditions, emphasizing the need for employers to implement controls to protect workers from the effects of extreme temperatures [36]. The human body is sensitive to variations in external
temperatures and responds by attempting to maintain a constant internal temperature. Exposure to extreme weather disrupts the body’s core temperature, making individuals vulnerable to the effects of cold and heat stress.

The inability to see clearly also magnifies the impact of other hazards and frequently results in struck-by and heavy-equipment-related incidents [37]. Lighting conditions and other visual factors are essential components of construction safety that are often neglected [38] but have a significant impact on workers’ safety, comfort, visual acuity, and productivity levels [39]. Most construction-vehicle-related incidents are the result of impaired visibility and take place on highway projects, either because of collisions with oncoming traffic or on-site equipment [37]. Proper illumination of work areas enhances the ability of workers to perform their tasks safely [40]; poorly lit areas reduce visibility and increase the potential for accidents.

Fires are another of the four physical hazards that are a very real threat to the safety of on-site construction workers and deserve the rapt attention of those responsible for employee safety [41]. Buildings under construction are temporary facilities that are rarely equipped with a fully functioning fire protection system [42]. They are instead protected by firewalls that are positioned to prevent a fire’s spread [43] but are rarely sufficient to protect the workers so that they can safely evacuate the compromised premises [41]. Falling objects, explosions, and exposure to flammable substances that can be easily ignited increase the number of injuries and extend the amount of damage to buildings and individuals beyond the construction site [42]. As construction sites are vulnerable to the threat of fire due to their inadequate fire safety systems, it is essential to enhance the safety awareness of construction crews and ensure that they recognize the associated risks and consequences. Care should also be taken to store combustible materials appropriately, install and enforce no-smoking signs, and train employees to safely operate electrical equipment and machinery [13]. The vulnerability of construction sites can be reduced through the simulation of fires, promoting safety awareness and mitigating fire hazards [34].

3.1.3. Chemical Hazards

Chemical hazards comprise respiratory sensitizers, skin irritants, and carcinogens and include a wide variety of gases, vapors, dusts, and fumes, exposure to which can negatively impact the health of workers immediately upon contact or over a prolonged period of time. A wide range of hazardous materials that can cause occupational health hazards upon exposure, including lead-based paint, mercury, synthetic or human-made mineral fibers, and treated timber [44], are often overlooked on construction sites. Emissions of substances such as volatile organic compounds are especially dangerous as exposure can occur through inhalation, ingestion, and dermal contact [45]. Volatile substances encompass a wide variety of materials, including pesticides, formaldehydes, paints, and thinners [44], and inhaling these toxic substances increases the likelihood of developing respiratory health issues. Similarly, prolonged inhalation and exposure to radon, a radioactive gas that is found on construction sites in the form of concrete, gypsum boards, and bricks [44] can cause deterioration of the lungs and may result in lung cancers or other respiratory disorders. Biological hazards such as mold and fungi thrive in moist conditions and are another potential danger for construction workers. To reduce the risk of exposure to these hazards, the materials need to be clearly identified prior to the start of construction activities. When possible, employers should aim to reduce their use of hazardous materials through substitution, but if that is not feasible, they should be vigilant about increasing their employees’ awareness of the potential dangers and ensure that they utilize the appropriate personal protective equipment when handling the materials [13].

As shown in Table 1, airborne materials were identified as a chemical safety hazard, and as the construction industry causes approximately 75% of fine dust pollution [46], workers are at a high risk of inhaling the polluted air and developing critical associated health problems. The dust is generated as a by-product of on-site activities and can be exacerbated by weather conditions, dry climates, wind, mechanical disturbances, and the
presence of silt [47]. Inhaling airborne particulate matter can have both short-term and prolonged adverse health effects, as it can easily penetrate the respiratory tract and lungs, causing respiratory, kidney, and cardiovascular diseases [48].

Exposure to asbestos, a mineral that is easily inhaled through the respiratory system and migrates to the lungs [49], is another chemical hazard presented in Table 1. Prior to being identified as a carcinogen in the 1960s, asbestos was commonly utilized in pipes, roof coverings, ventilation ducts, and flooring and as a fireproofing material [50]. Although its use has since been prohibited, the risk of exposure remains, as construction activities such as maintenance and demolition of structures containing asbestos remain a potential hazard [51]. Exposure to asbestos has been linked to fatal respiratory diseases and to benign asbestos-related disorders that prevent the lungs from functioning correctly and cause breathing difficulties. Globally, occupational asbestos exposure causes more than 100,000 deaths annually, impacting construction workers and manufacturers [52].

The construction industry has one of the highest rates of occupational burns, which are caused by exposure to heat sources, electrical currents, chemical agents, and radiation [5] (see Table 1). Thermal burns occur when the skin encounters tar, hot fluids, hot surfaces, or steam or is exposed to the sun for a prolonged period of time. These burns have varying degrees of consequences on the body, depending on the nature of the burn and the duration of exposure. Electrical burns are another form of thermal burns that occur when an individual contacts a large amount of electrical current. These accidents usually involve mobile vertical scaffolding or cranes and power lines [5]. Chemical burns occur upon exposure to agents such as acids and alkalis, and in the construction industry, they are largely attributed to exposure to wet cement [53]. Wetting cement with water causes the solution to become alkaline, and prolonged contact can cause severe and deep burns [53]. These burns commonly occur when workers stand or kneel in freshly poured cement for a prolonged period [54]. Chemical burns represent a small portion of burn injuries, but they are arguably more hazardous than thermal burns and their dangers are largely underestimated. They can also cause irreversible damage to the eyes and impair visual function [55]. The construction sector does not have the highest frequency of ocular chemical burns to the eye, but it does have the most damaging incidents.

3.1.4. Ergonomic and Other Hazards

The final category includes five additional safety hazards on construction sites: ergonomic hazards and the collapse of temporary structures. Ergonomic hazards are associated with repetitive motions, such as material and equipment handling, which increase the likelihood of developing musculoskeletal disorders. This section also discusses scaffold collapse and the dangers associated with excavation.

Construction equipment and material handling are one of the ergonomic hazards identified in Table 1 and encompass the movement of materials manually or mechanically through lifting, lowering, pushing, pulling, holding, and carrying [56]. Equipment handling also includes on-site assembly and dismantling of heavy machinery. Improper handling of equipment and materials increases the likelihood of occupational injuries [57], as workers are at risk of developing musculoskeletal disorders that are inflammatory and progressive in nature and have the ability to impair day-to-day activities. Ergonomic risk factors such as unhealthy postures, heavy loads, repetitive motions, and overexertion increase the likelihood that a construction worker will develop a musculoskeletal disorder or injury [58,59]. The provision of surface electromyogram-based sensors that measure electrical impulses during the manual movement of materials may be a useful tool for reducing unergonomic postures and actions, consequently reducing the risk of occupational musculoskeletal disorders [60]. The presence of construction equipment on site presents an additional safety hazard, as each of the wide variety of machines mandates a different safety procedure and operating technique [58]. Unsafe practices are generally avoidable, however, as they are often due to human factors, such as ineffective site safety management, irregular maintenance, and failure to operate machinery properly [61].
Operating heavy machinery can result in fatal or non-fatal injuries if performed incorrectly, presenting another safety hazard. Tower cranes are a type of heavy machinery commonly utilized on construction sites to transport materials vertically and horizontally [62]. They play an indispensable role in the construction process due to their load lifting capacity and large coverage area [63], but despite their benefits, their presence on a construction site introduces additional risks to workers, machinery, equipment, surrounding buildings, and individuals beyond the construction site [64]. The factors contributing to safe operations of tower crane construction can be categorized as human, environmental, management, and material factors. Of these categories, a Hong Kong study identified human factors as having the most significant impact on safety outcomes. The major human factors affecting unsafe tower crane operation include lack of or low-quality safety training, prioritizing time over safety, ineffective communication, and inadequate supervision [63]. An analysis of OSHA data on fatal crane incidents between 1997 and 2003 revealed that while cranes present a safety hazard, a fatal outcome is often the result of proximal causes such as struck-by loads, electrocution, crushing during installation or disassembly, or failure of the crane boom or cable [65].

Constant vibration to the hand, arm, or even the entire body is an often-overlooked hazard that construction workers face and is a safety hazard associated with equipment handling. Hand–arm vibration occurs when workers use vibrating hand-held or hand-guided tools. Although occasional exposure to hand-transmitted vibrations is unlikely to cause any health issues, prolonged vibration presents the risk of developing hand–arm vibration syndrome and continued exposure causes the condition to worsen [66]. Hand–arm vibration syndrome is a condition that impacts the neurological, vascular, and musculoskeletal systems, resulting in symptoms such as reduced senses in the hands, reduced manual dexterity, and weakened grip strength. Operators of vehicles and construction equipment are the most impacted by whole body vibration, which occurs when mechanical energy oscillations are transmitted from the machinery to the operator’s body through the seat [67]. Operators of older equipment tend to be exposed to a greater frequency of whole-body vibration, emphasizing the need for constant maintenance and lifecycle assessments of equipment. Construction workers exposed to vibrations are also often susceptible to musculoskeletal disorders due to the presence of other occupational hazards such as noise exposure, overexertion due to manual material handling, and awkward posture [68].

Scaffolds and temporary work platforms are a leading cause of falls from heights, a primary hazard previously discussed. Scaffolds are designed for lighter loads than those prescribed for permanent structures [69], and their presence greatly impacts the safety of construction workers. The type of scaffolding, its assembly and erection, and its operating environment [70] affect its safety, as does the behavior of the scaffolders. A behavioral study discerned that Chinese scaffolders choose not to utilize safety harnesses due to the inconvenience and discomfort they present [71]. Similarly, a study in Singapore analyzed the behavior of scaffolders and observed that because of their poor attitudes and despite adequate safety training, it was common for them to fail to anchor the safety harness [17]. In addition to falls, scaffolds on construction sites sometimes collapse, either as a result of inadequate design or improper construction techniques [71].

Excavation work is a fundamental step in infrastructure development that involves the removal of soil or rock from the Earth to form an open face [72]. It introduces a multitude of workplace hazards, including trench collapse, falls into the excavation area, flooding or water accumulation, confined spaces, equipment or other material falling on the workers, oxygen deficiency, and exposure to toxic gases [72]. The number of construction industry fatalities due to cave-ins and trench collapses, which is the leading cause of both fatal and non-fatal accidents in excavation work [71], is alarming. The work is fraught with danger, as the excavated soil at the edge of the trench increases the pressure on the trench walls, and the pressure is further exacerbated by surrounding work and environmental conditions. Collapsing soil weighs more than one ton per cubic yard and trench cave-ins often occur in multiples, suffocating and crushing workers beneath tons of soil [73]. The nature of the
work is inherently dangerous, but despite the dangers associated with cave-ins, the risks are often underestimated.

3.2. Construction Safety Hazards by Sector

Table 2 depicts a list of 18 safety hazards, which vary with the type of project and the unique nature of each venture, and shows the construction sectors (commercial, heavy, industrial, and residential) commonly affected by them. The table was designed to simplify the hazard identification process by providing a guideline of potential hazards on construction sites and shows that the hazards, including falls from heights, electrocution, vibration, and hazardous materials, are likely to be present on most of them. Other hazards, such as heavy machinery and material handling, are associated with indispensable construction processes and activities, and also impact all sectors [58,61,74]. Such guidelines are not only beneficial to employers, who are responsible for implementing hazard mitigation strategies, but can also improve hazard awareness amongst construction employees.

Table 2. Safety hazards by construction sector.

<table>
<thead>
<tr>
<th>ID</th>
<th>Safety Hazard</th>
<th>Commercial Sector</th>
<th>Heavy/Highway Sector</th>
<th>Industrial Sector</th>
<th>Residential Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR.1</td>
<td>Falls from heights</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PR.2</td>
<td>Electrocution</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PR.3</td>
<td>Struck-by incidents</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PR.4</td>
<td>Slips, trips, and falls at the ground level</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PR.5</td>
<td>Caught-in-between incidents</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PH.1</td>
<td>Noise</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PH.2</td>
<td>Extreme temperatures</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PH.3</td>
<td>Lighting and visibility</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PH.4</td>
<td>Fire</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH.1</td>
<td>Hazardous materials</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>CH.2</td>
<td>Airborne materials</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>CH.3</td>
<td>Thermal and chemical burns</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH.4</td>
<td>Asbestos</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>EO.1</td>
<td>Material and equipment handling</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>EO.2</td>
<td>Heavy machinery</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>EO.3</td>
<td>Trench collapse</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>EO.4</td>
<td>Scaffold collapse</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>EO.5</td>
<td>Vibration</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Some hazards may impact only one type of sector. For instance, lighting and visibility hazards primarily impact highway projects, as they can cause motorists to drive into work zones, colliding with workers or construction equipment. During evening hours, limited visibility due to inadequate lighting is a primary concern, as reflected by the increased number of fatalities in highway work zones at night [37]. Similarly, asbestos is most likely to impact the residential sector, specifically in the maintenance and demolition of old homes where it was commonly utilized as a construction material prior to its use being regulated in the 1960s [50,51].

3.3. Mitigation Strategies

Identifying the hazards on construction sites is fundamental to safety management as controls can only be implemented after the hazard has been recognized. The two aspects of the control and management of construction hazards are prevention and precautionary measures. Prevention aims to reduce the probability that a hazardous event will occur; precautionary measures acknowledge the unlikelihood of preventing the hazardous event and aim instead to reduce its severity [7]. The hierarchy of controls applies to both methods. From most-to-least effective, the hierarchy of controls proposes hazard elimination, substi-
tution, engineering controls, administrative controls, and the use of personal protective equipment (PPE). Since elimination or substitution of the hazard is often not feasible, the following table considers the application of engineering controls, administrative controls, and personal protective equipment as measures that can be taken to mitigate the risks. The table is not a comprehensive list of all mitigation strategies but serves as examples that were identified from the literature, encompassing traditional and modern approaches. Although previous studies discussed these measures, they did not classify them by the type of measure or discuss the related safety hazards. As illustrated in Table 3, there are various methods to control a single hazard. The suitability of the control measure is dependent on a multitude of factors, including the project sector and complexity [75].

### Table 3. Preventative measures for construction safety hazards.

<table>
<thead>
<tr>
<th>No.</th>
<th>Preventative Measure</th>
<th>Type</th>
<th>Safety Hazard</th>
<th>Previous Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Provision of suitable working platforms</td>
<td>Engineering control</td>
<td>PR.1, EO.4</td>
<td>[16]</td>
</tr>
<tr>
<td>2</td>
<td>Safety training to increase hazard awareness</td>
<td>Administrative control</td>
<td>PR.1 to 5, PH.1 to 4, CH.1 to 4, EO.1 to 5</td>
<td>[76]</td>
</tr>
<tr>
<td>3</td>
<td>Effective on-site safety information and supervision</td>
<td>Administrative control</td>
<td>PR.1 to 4, PH.1 to 4, CH.1 to 4, EO.1 to 5</td>
<td>[74]</td>
</tr>
<tr>
<td>4</td>
<td>Provision of exoskeletons for material handling</td>
<td>Administrative control</td>
<td>EO.1</td>
<td>[77]</td>
</tr>
<tr>
<td>5</td>
<td>Appropriate use of equipment and machinery</td>
<td>Administrative control</td>
<td>PR.2, PR.3, PR.5, EO.1, EO.2, EO.5</td>
<td>[61]</td>
</tr>
<tr>
<td>6</td>
<td>De-energization of power lines</td>
<td>Engineering control</td>
<td>PR.2, CH.3</td>
<td>[78]</td>
</tr>
<tr>
<td>7</td>
<td>Back-up alarms on moving equipment</td>
<td>Engineering control</td>
<td>PR.3</td>
<td>[25,27]</td>
</tr>
<tr>
<td>8</td>
<td>Environment acclimatization</td>
<td>Administrative control</td>
<td>PH.2</td>
<td>[79]</td>
</tr>
<tr>
<td>9</td>
<td>Effective workplace illumination</td>
<td>Engineering control</td>
<td>PH.3</td>
<td>[5]</td>
</tr>
<tr>
<td>10</td>
<td>Provision of fire control for temporary facilities</td>
<td>Engineering control</td>
<td>PH.4, CH.3</td>
<td>[43]</td>
</tr>
<tr>
<td>11</td>
<td>Execution of a vibration reduction strategy</td>
<td>Administrative control</td>
<td>EO.5</td>
<td>[80]</td>
</tr>
<tr>
<td>12</td>
<td>Utilization of water suppression and local exhaust ventilation</td>
<td>Administrative control</td>
<td>CH.1 to 4</td>
<td>[13,81]</td>
</tr>
<tr>
<td>13</td>
<td>Installation of trench wall protective systems</td>
<td>Engineering control</td>
<td>CH.1, CH.2</td>
<td>[46,47]</td>
</tr>
<tr>
<td>14</td>
<td>Continuous inspection of equipment</td>
<td>Administrative control</td>
<td>EO.2, EO.5</td>
<td>[74]</td>
</tr>
<tr>
<td>15</td>
<td>Provision of wearable light systems</td>
<td>PPE</td>
<td>PH.1</td>
<td>[38]</td>
</tr>
<tr>
<td>16</td>
<td>Provision of appropriate footwear</td>
<td>PPE</td>
<td>PR.1, PH.2, CH.1, CH.3</td>
<td>[83,84]</td>
</tr>
<tr>
<td>17</td>
<td>The use of hearing protection devices</td>
<td>PPE</td>
<td>PH.1</td>
<td>[33]</td>
</tr>
<tr>
<td>18</td>
<td>Utilization of protective gloves or finger guards</td>
<td>PPE</td>
<td>PR.2, PH.2, CH.1, CH.3</td>
<td>[83,85]</td>
</tr>
<tr>
<td>19</td>
<td>Monitoring of particulate matter or hazardous material concentrations</td>
<td>Engineering control</td>
<td>CH.1, CH.2, CH.4</td>
<td>[46]</td>
</tr>
<tr>
<td>20</td>
<td>The use of unmanned aerial systems or drones</td>
<td>Engineering control</td>
<td>PR.1, PR.3, PR.5, PH.3, CH.1, EO.3</td>
<td>[86]</td>
</tr>
<tr>
<td>21</td>
<td>Optimization of site layouts through modeling</td>
<td>Engineering control</td>
<td>PH.1, CH.2</td>
<td>[32,87]</td>
</tr>
<tr>
<td>22</td>
<td>Adoption of virtual reality for training</td>
<td>Administrative control</td>
<td>PR.1 to 5, PH.1 to 4, CH.1 to 4, EO.1 to 5</td>
<td>[88]</td>
</tr>
<tr>
<td>23</td>
<td>Utilizing eye tracking technology to improve hazard recognition</td>
<td>Administrative control</td>
<td>PR.1 to 5, PH.1 to 4, CH.1 to 4, EO.1 to 5</td>
<td>[89]</td>
</tr>
<tr>
<td>24</td>
<td>Provision of Building Information Modeling (BIM) for hazard identification</td>
<td>Administrative control</td>
<td>PR.1, EO.4</td>
<td>[90]</td>
</tr>
<tr>
<td>25</td>
<td>Monitoring of proper use of fall protection devices using Bluetooth Low Energy</td>
<td>Engineering control</td>
<td>PR.1, EO.4</td>
<td>[91]</td>
</tr>
<tr>
<td>26</td>
<td>Utilization of wearable sensors for ergonomic assessment</td>
<td>Engineering control</td>
<td>EO.1</td>
<td>[60]</td>
</tr>
<tr>
<td>27</td>
<td>Identification of vulnerable areas on site using heat map generation</td>
<td>Administrative control</td>
<td>PR.3, PH.3, EO.2</td>
<td>[27]</td>
</tr>
<tr>
<td>28</td>
<td>Application of real-time fire detection model</td>
<td>Administrative control</td>
<td>PH.4, CH.3</td>
<td>[41]</td>
</tr>
<tr>
<td>29</td>
<td>Utilization of automated PPE–tool pair checking system</td>
<td>PPE</td>
<td>PR.1 to 5, PH.1 to 4, CH.1 to 4, EO.1 to 5</td>
<td>[83]</td>
</tr>
</tbody>
</table>

An emphasis on safety training and thorough inspections of the site and equipment prior to the start of construction operations are the most effective ways to mitigate safety hazards on construction sites and reduce the likelihood of accidents [74]. Table 3 shows that safety training and effective on-site supervision are preventative measures that are applicable to all the identified construction hazards. Construction jobsites are dangerous by nature, and the danger is magnified by unsafe human behavior. Individual risk-taking
tendencies may influence a construction worker to minimize the safety hazard and neglect protocol, increasing the likelihood of an accident [92]. Thus, adequate safety training should focus on enhancing hazard cognition and increasing the workers’ awareness of potential hazards [28,82]. The vigorous nature of construction sites requires individuals to maintain situational awareness to detect and effectively respond to the presence of hazards and their evolving surroundings [76]. The lack of effective safety training can cause workers to underestimate the dangers and increase the likelihood that they will engage in risky behaviors that make them more vulnerable to occupational incidents.

Modeling and advanced technologies can be utilized to detect hazards and prevent accidents, and hazards can be identified by using virtual reality, BIM, and other software for virtual design construction. Virtual reality simulations can be especially beneficial for safety training, as employees experience immersive and practical training through an exact replica of the construction site [88,93]. BIM-based modeling is another useful site safety management tool that can recognize construction hazards virtually, as well as manage the risks associated with overlapping construction activities [90,94]. BIM-based safety planning has various applications, including the simulation and assessment of fires on construction sites, the detection of potential fall hazards, and the reduction in dust pollution through the simulation of various site layouts [83,88,92]. The optimization of site layouts is especially useful for predictive analysis and hazard mitigation. The modeling of noise maps, for instance, is a useful tool for the management of noise pollution and can be utilized to assess the effectiveness of planned mitigation efforts, such as the locations of mobile noise barriers [32].

Safety practices can also be modernized through the provision of wearable technology. In combination with machine learning algorithms, wearable sensors may be utilized to recognize ergonomically hazardous body postures associated with material handling [60]. Exoskeletons are another promising technology for the management of material handling, in which the wearable robot enhances workers’ physical abilities and decreases muscle fatigue [77]. Such technologies may also be utilized to promote and monitor the proper use of PPE either with Bluetooth Low Energy sensor devices or an automated PPE pair checking system, using the internet of things [91,95]. Additionally, real-time monitoring systems can be integrated into hazard management through the provision of unmanned aerial systems or the generation of heat maps [27,83].

4. Conclusions

Unrecognized hazards are unmanageable risks; therefore, hazard identification is crucial for effective site safety management, and the dynamic nature of construction projects requires that it begin at the design stage and continue throughout all project phases to ensure that no hazard is overlooked. The objective of this paper was to contribute to the construction safety body of knowledge by identifying, classifying, and categorizing safety hazards by construction sector and then ranking them based on frequency of citation in the literature. Although previous studies discussed safety hazards in construction projects through archival data, this review considers hazard identification through a comprehensive synthesis of the existing studies to highlight the perceptions and interests of researchers within the industry.

The 18 safety hazards that were determined to be present on construction sites were sorted into four categories (primary, physical, chemical, and ergonomic/other hazards), based on their physiological impacts. Because construction crews are exposed to a wide variety of hazards, which correlate with the type of project they are working on, the hazards were also classified by construction sector. Falls from heights, heavy machinery, material and equipment handling, and struck-by incidents, however, were found to impact all types of projects. Within each category, the hazards were ranked, based on the frequency with which they were cited in the reviewed literature, to determine the perceptions of researchers in the construction industry. The findings showed that falls from heights, material and equipment handling, heavy machinery, electrocution, and struck-by incidents
were the most frequently cited hazards. Of these, falls from heights, electrocution, and struck-by incidents belong to the primary hazards category, which are those with the most fatal outcomes.

After safety hazards are identified, mitigation plans can be implemented to prevent or control them through prevention or precautionary measures. Examples of control measures were identified for all 18 hazards through the literature review, and it was clear that most hazards can be mitigated through the appropriate use of personal protective equipment, hazard awareness safety training, and effective on-site safety information and supervision. Hazard identification and management can also be enhanced through the utilization of advanced technologies, BIM modeling, and wearable technology. The utilization of appropriate risk mitigation strategies can reduce the impact of construction safety hazards, thereby minimizing the number of fatal and non-fatal injuries. The findings of this study will assist employers in identifying all possible safety hazards on construction job sites so that they can develop and implement mitigation strategies to manage them, thus reducing the risk of their employees being victims of associated occupational accidents.

5. Future Directions

The impetus for this research study was the high number of accidents that befall workers in the construction industry. A systematic literature review was conducted to identify and categorize all the potential safety hazards on job sites, as well as to provide mitigation tools that would minimize their impact. Due to the extensive amount of literature available on this topic, future research may benefit from a scientometric review to identify the patterns in publication.

The current literature discusses these hazards and emphasizes the importance of hazard recognition; however, few studies consider the mitigation strategies that could be utilized to eliminate or minimize their impact. The existing body of knowledge could be enhanced by identifying preventive measures through focus group discussions, interviews, or surveys and assessing the most appropriate preventive measures for each hazard, according to the affected construction sector.

While this study discussed the utilization of technology for site safety management and the mitigation of hazards, a deeper exploration of the role of emerging technologies may be helpful. Future studies could evaluate the feasibility and effectiveness of integrating advanced technologies for site safety management and compare standardized safety protocols and technology-based mitigation strategies to determine their effectiveness. The application of a blockchain-based framework for accident information management in construction and its capability to identify the incident’s root cause are other suggestions for additional research.

This study found that the dangers associated with safety hazards were often magnified by construction workers’ unsafe actions. Thus, this paper also puts forth the suggestion of conducting psychological evaluations on the behavior of construction workers, specifically the risk-taking tendencies that could cause them to disregard dangers that hazards present. Lastly, additional studies may be performed to assess the impact of safety hazards on the mental health of construction personnel and to determine the relationship between these two factors.

Author Contributions: Conceptualization, S.K., A.P., K.L. and Z.Y.; methodology, D.A.; design and development of data analysis, D.A., S.K. and A.P.; data collection, D.A.; analysis and interpretation of results, D.A.; writing—original draft preparation, D.A.; writing—review and editing, D.A., S.K., A.P., K.L. and Z.Y.; supervision, S.K. and K.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflicts of interest.
References


34. Sivakumar, C.; Malathy, R.; Sivaprakash, P. A study on fire safety on residential and commercial construction sites. Saf. Sci. 2020, 130, 104865. [CrossRef]


77. Zhu, Z.; Dutta, A.; Dai, F. Exoskeletons for manual material handling–A review and implication for construction applications. *Autom. Constr.* 2021, 122, 103493. [CrossRef]


83. Yang, X.; Yu, Y.; Shirowzhan, S.; Li, H. Automated PPE-Tool Pair Check System for construction safety using smart IOT. *J. Build. Eng.* 2020, 32, 101721. [CrossRef]


87. Tao, G.; Feng, J.; Feng, H.; Feng, H.; Zhang, K. Reducing construction dust pollution by planning construction site layout. *Build. 2022*, 12, 531. [CrossRef]


**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.