

A thematic synthesis of the literature on construction accident causation analysis



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ABSTRACT

The construction industry plays a vital role in economic growth, job creation, and infrastructure development worldwide. However, it remains one of the most hazardous industries, characterized by persistently high accident rates that result in injuries and fatalities. Scholars have devoted significant efforts to undertake research in exploring the causation of construction accidents. Drawing on 78 research papers published since 1998 that focus on construction causation analysis, this review paper aims to thematically synthesize what has been achieved in the last two decades to effectively help researchers identify and recognize patterns and directions to align their work with the latest developments and to contribute to better research in construction health and safety. The synthesis is organized around five themes: research focus, research methods, accident types, key factors, and modelling approaches. It clarifies and consolidates existing knowledge by demonstrating that causal factors are the main research focus, with nearly half of the examined studies addressing it. It also offers quantitative evidence confirming that the most frequent type of accident is falls in both developed and developing countries. The review also finds that the analytical methods employed generally align with the stated research focuses. Additionally, the paper finds that the most critical category in causing construction accidents is likely to be poor safety management, rather than individual human errors, and the systemic approach has been adopted in causation analysis by more and more scholars.

1. Introduction

The construction industry is widely recognized as a major contributor to national economies in both developed and developing countries. However, its importance and continued growth are undermined by persistent health and safety challenges. Numerous studies have repeatedly demonstrated that construction remains one of the most hazardous industries, characterized by high injury and fatality rates [1–4], resulting in significant economic losses and severe humanitarian consequences.

Extensive efforts have been made by industry stakeholders to mitigate these issues. These efforts include using advanced technologies, enforcing the use of Personal Protective Equipment (PPE), performing thorough risk assessments, promoting a strong safety culture through clear communication and worker engagement, and ensuring proper housekeeping and organization on-site. Despite these initiatives, construction accidents continue to occur at alarming rates. This persistence is attributable to the high number of physical hazards, the inherent

complexity of construction projects, the involvement of multiple stakeholders, and the continuous need to comply with evolving regulations and legal obligations. At the core of it is the causation of construction accidents, which stems from the multifaceted nature of construction projects and implicates a combination of reasons, including human errors, improper equipment use, environmental hazards, poor safety procedures, and inadequate planning. Thus, it has attracted close attention from scholars worldwide. One of the earliest and most influential accident causation studies was conducted by Heinrich in 1936, who introduced the Domino Theory based on an analysis of 75,000 industrial accident reports [5]. Since then, numerous researchers have expanded the theoretical landscape of accident causation through the development of models such as Reason's omnipresent Swiss Cheese model [6], Rasmussen's risk management framework, the application of the Human Factors Analysis and Classification System (HFACS) in construction accident causation analysis, Leveson's Systems-Theoretic Accident Model [7] and Processes (STAMP) and the ConAC Model developed by Haslam et al. [8].

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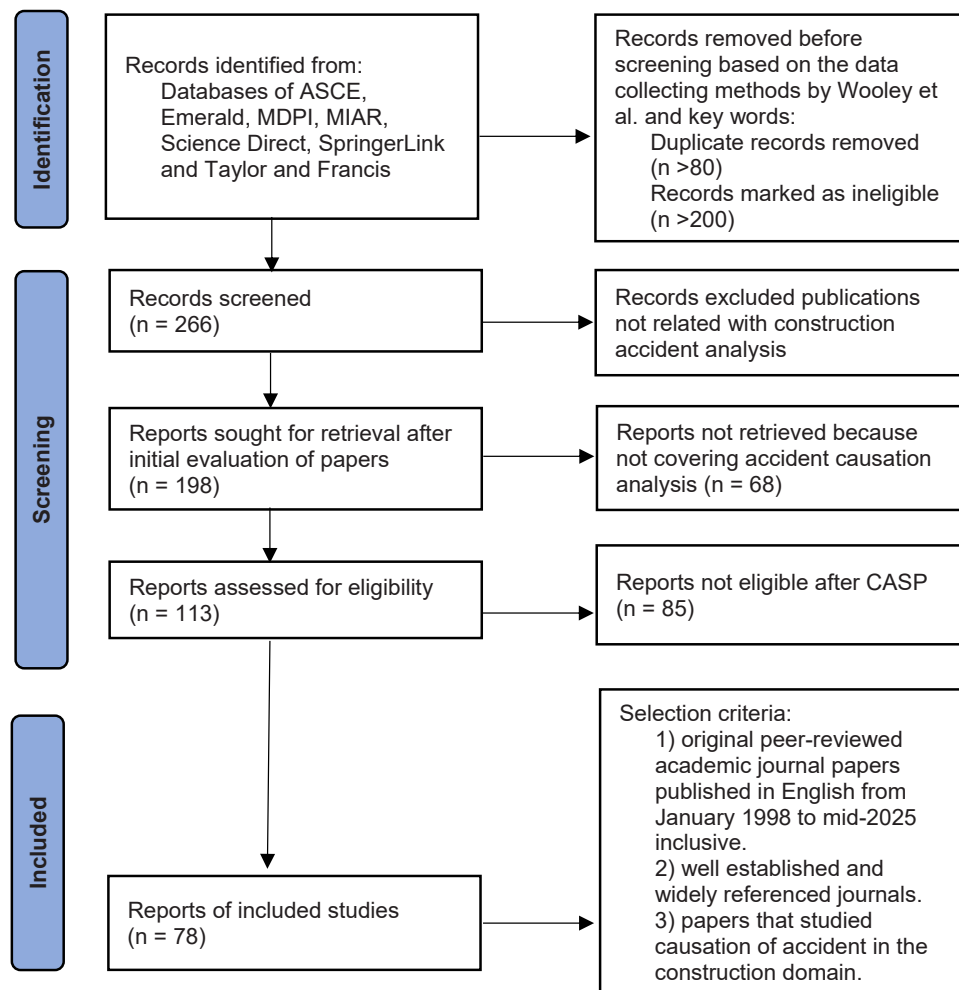


Fig. 1. A PRISMA-style process to determine the literature.

Based on the findings from 78 peer-reviewed journal papers published between 1998 and mid-2025, this paper aims to systematically review the major research focuses and key accomplishments in construction accident causation analysis, with the broader goal of supporting and guiding future research in this field. The paper adopts the thematic approach, which organizes and synthesizes the existing research by identifying and assessing recurring patterns across the literature. This method is structured around the chosen themes, rather than reviewing individual studies in isolation, to categorize the findings and discussions from various sources into coherent, meaningful subjects that directly address the research aim. The review is structured around five themes commonly employed in construction accident causation analysis: (1) research focus, (2) research methods, (3) accident types, (4) key factors, and (5) modelling approaches.

The paper is structured as follows: [Section 1](#) provides the introduction. [Section 2](#) outlines the methodology. [Section 3](#) presents the thematic synthesis, and [Section 4](#) concludes with a summary of findings and implications.

2. Methodology

Despite substantial efforts to investigate the causation of accidents in the construction industry, there are still limited publications in appraising what has been undertaken and what has been achieved in the domain. Hosseinian and Torghabeh examined prominent accident causation theories by emphasizing human factors, managerial aspects, and physical hazard characteristics [9]. Woolley et al. reviewed the extent to which construction accident analysis research has incorporated systemic

approaches focusing on causation models [10], analytical methods, and contributing factors. Their work highlighted the growing adoption of systemic perspectives in recent decades, due to their ability to holistically evaluate construction accidents by considering interrelationships and interconnectedness of different elements within a construction project, and investigating the underlying organizational and systemic factors that contribute to an accident. Khosrav et al. provided methodological and theoretical insights into empirical factors associated with unsafe behaviours and accidents on construction sites [11]. Swuste, Frijters & Guldenmund's review tried to answer the question of whether it is possible to influence safety in the sector by confining itself to the contract side, the design, and the construction of building projects [12]. Most recently, Samwinga, Zulu, and Adeyemi [13] and Owusu-Boadi et al. [14] applied bibliometric and scientometric techniques to assess research trends relating to construction workers' wellbeing and environmental health and safety (EHS), respectively.

Following the data collection procedures employed by Woolley et al. [10], we conducted a comprehensive search for relevant literature across multiple academic databases, including ASCE, Emerald, MDPI, MIAR, ScienceDirect, SpringerLink, and Taylor & Francis. Keywords and keyword combinations such as construction accident/incident, causation, analyse/examine/assess/explore/investigate, and factor/cause/model were used to identify pertinent studies. With particular attention to two databases (ScienceDirect and Taylor & Francis), the search resulted in the collection of 266 peer-reviewed journal articles.

An initial screening of the titles, abstracts, and conclusions of the retrieved papers was conducted. Additional relevant studies were

Table 1

The summary of the research focus.

Focus	Paper	Dealing with	Time of publication	Country
Cause & Factor	36	General construction project: 22 Specific building division: 9 Others: 5	1998–1999: 1 2000–2009: 6 2010–2019: 19 2020–2025: 10	Africa: 2 America: 6 Asia & Australian: 16 Europe: 9 Latin America: 1 Multinational: 2
Causation Model	17	General construction project: 14 Specific building division: 1 Others: 2	2000–2009: 4 2010–2019: 7 2020–2025: 6	America: 5 Asia & Australian: 8 Europe: 2 Multinational: 2
Accident Data	8	General construction project: 8	1998–1999: 1 2010–2019: 5 2020–2025: 2	America: 1 Asia & Australian: 4 Europe: 3
Construction worker	7	Others: 7	2010–2019: 5 2020–2025: 2	America: 1 Asia & Australian: 6
Others	10	General construction project: 2 Specific building division: 4 Others: 4	2000–2009: 2 2010–2019: 7 2020–2025: 1	America: 1 Asia & Australian: 3 Europe: 2 Not specific country: 4

Source: the papers collected.

identified by examining the reference lists of these papers, resulting in a refined set of 198 articles relevant to accident causation analysis. Employing the Qualitative Studies Checklist from the Critical Appraisal Skills Programme (CASP), we further reduced this number to 113 articles for eligibility evaluation. After applying the following inclusion criteria: 1) original peer-reviewed academic journal papers published in English from January 1998 to mid-2025; 2) papers published in well-established and widely referenced journals; 3) papers that studied the causation of accidents in the construction domain, we selected 78 papers for the final thematic analysis. The flow of literature identification, screening, and inclusion is illustrated in Fig. 1, which is presented as a PRISMA-style flow diagram. The assessment process yielded the expected results, as the process to control the quality of the literature is relatively robust, considering the short time span of the literature collecting period, the utilization of reliable databases, the Woolley methods, and CASP. More desirable products could be produced if more quality appraisal tools and better database platforms are exploited.

The primary method used to analyse the 78 selected papers is thematic analysis, which is an accessible, flexible, and increasingly

prominent method in qualitative research [15]. Five themes are identified following the six-step approach suggested by Braun and Clarke [15]. This synthesis is structured around these themes, and the subsequent discussion is organized in alignment with them.

3. The synthesis

A total of 78 papers were selected for thematic synthesis, with the analysis structured around five predefined themes. For each theme, the papers were generally categorized and coded according to the publication year, the nature of the construction work (general construction projects and specific building divisions), and the country in which the research originated.

3.1. The focus of the research

The synthesis begins with the theme “the focus of the research” in construction accident causality analysis to provide an overview of the major areas (Table 1). From the literature collected, four areas have

Table 2

The summary of methods for data collection and data analysis.

Data Collection				Data Analysis
Method	Source	Case & Participant	Duration (years)	Method
Secondary	Government department or designated institution	Fatal incident only: 26–2348 All incidents: 100–1163178	Fatal incident only: 2–10 All incidents: 1–27	Natural Language Processing Data mining technology Storybuilder
Interview & Focus group	Experienced experts, academics, managers, on-site workers, regulators	Interviewees: 7–78	N/A	4 M analysis method
Case study	Investigation report	1–10	N/A	Big Data analysis technology
Questionnaire	Builders, engineers, architects, surveyors, government officials	Respondents: 200–425	N/A	Statistical analytical methods
Observation	One construction project	To test the model developed	N/A	Grounded Theory Construction accident causation models Frequency analysis Delphi method Social network analysis Coupling risk assessment method

Source: the papers reviewed.

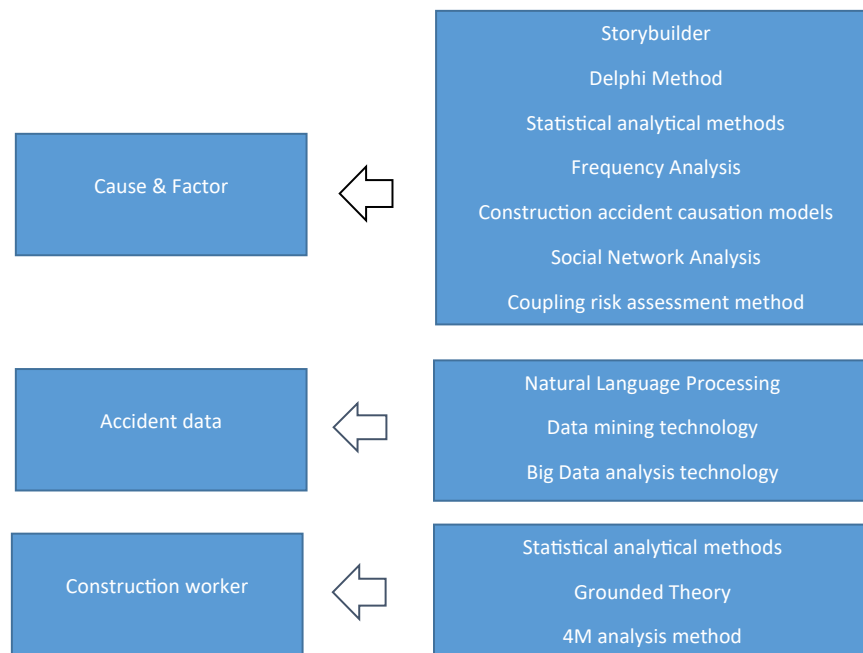


Fig. 2. Data analysis methods and the research focus.

emerged as the main focuses of the research concerning accident causality. Out of the 78 papers, 36 are devoted to “Cause and Factor”—to identify and analyse root causes and key factors that lead to construction accidents. Representative works include Kartam & Bouz [16], Behm [17], Swuste [18], Winge, Albrechtsen & Mostue [19], Cao [20]. 17 to “Causation Model”—to develop a model elaborating the mechanism of construction accidents. Examples include Arboleda & Abraham [1]; Manu et al. [21]; Mohandes et al. [22]; Yoo et al. [23]. 8 to “Accident Data”—to process the data collection more efficiently by using various technologies such as Big Data analytics and Artificial Intelligence (AI). Notable contributions include Cheng, Lin & Leu [24]; Kim & Chi [25], and 7 to “Construction Worker”—to specifically investigate how construction workers play the roles in construction accidents. Examples include Chan [26], Mohajeri et al. [27], and Yoon et al. [4]. The remaining 10 papers address diverse topics, including identifying the most frequent accident types [28], exploring temporal patterns of fatal accidents [29], and literature reviews such as Hu et al. [30] and Grant et al. [31].

Despite the broad range of research focuses, it is evident that the study of cause and factor has attracted the most attention. This emphasis is justified, as understanding the complex network of interacting causal elements is essential for establishing a scientific framework for analysing construction accidents. Undoubtedly, the solidity of research on accident causes and contributing factors depends heavily on the availability and quality of accident data. Benefiting from the rapid development of new technologies, research in this field is expected to be expedited.

In the “Dealing with” column of Table 1, three indicators are used to compare the four research focuses: general construction project, referring to the whole project; specific building division, referring to part of the project, such as crane, design, tool, and equipment; and others. It is evident that research analysing construction accident causality are mostly based on the entire construction project, e.g., Mitropoulos, Abdelhamid & Howell [32], Arquillos, Romero & Gibb [33], and Cabello et al. [34], likely due to greater data availability. The notable exception is research focusing on “Construction Workers”, such as Chi, Han & Kim [5] and Jiang, Fang & Zhang [35], and Yoon et al. [4], which does not neatly fall into either the general project or specific division categories.

Table 1 also reports the number of papers published in different time periods, allowing examination of temporal trends in research

focus. Regarding Causes & Factors, the most prominent focus area, scholarly attention has steadily increased: 19 publications in the 2010s, tripling the number of 2000s, and there were already 10 papers published in less than five years in the 2020s. The second major focus was “analysing model” which saw an increase from 4 papers in the 2000s to 7 in the 2010s. The fact that 6 have been published so far indicates the sustained enthusiasm in this area. The remaining two subjects, however, were less explored, and the patterns show no significant changes.

The last column of Table 1 shows the geographic distribution of the studies, indicating the countries or regions from which the construction accident data were derived. It proves that three regions, i.e., Asia and Australia, Europe, and America, account for the majority of publications, with Asia and Australia contributing the largest share (e.g., 16 in Cause & Factor, 8 in Causation Model), which is different from what Hu et al. [30] had found. The differences stem from different study aims, data collection, industry sector, and time period. However, a notable emerging trend is the increasing scholarly output from mainland China, which helps to address the issue of under-representation of the Global South.

3.2. Research methodology

Having outlined the collective research focuses in the domain, we now turn to the critical issue of research methodology. Methodological choices provide the structured foundation for any research, ensuring that data collection is reliable and valid, thereby enabling credible findings and meaningful contributions to knowledge. This is particularly important in construction accident causation analysis, where appropriate methodological approaches are essential for untangling the complexity and interrelatedness of causal factors. The seventy-eight papers were divided into four groups, i.e., the papers dealing with general construction project [4,16,36–38], with specific building division [39–41], with accident analysis model [42–44] and with other aspects of construction accident, such as construction project features [21], fall from height [45] and heat illness [46]. Table 2 summarizes the methods used for data collection and data analysis across these four groups.

3.2.1. Data collection

Given the nature of the construction causation research, official records of construction incidents at the city, region, or national level are generally accessible in both developed and developing nations

Table 3
The official construction accident types from HSE and CPWR.

	Fatal Injuries	Nonfatal Injuries
HSE	Falls from a height Trapped by something, collapsing, overturning Struck by moving, including flying/falling object Struck by moving vehicle Contact with electricity or electrical discharge	Slips, trips or falls on same level Injured while handling, lifting or carrying Falls from a height Struck by moving, including flying/falling object
CPWR	Falls, slips, trips Transportation incidents Contact with objects and equipment Exposure to harmful Substances/Environments Violence and other injuries by Persons/Animals	Contact with objects and equipment Overexertion and bodily reaction Falls, slips, trips Exposure to harmful substances or environments Transportation incidents

Source: the official websites of HSE (2022) and CPWR (2022).

because it is usually a legal requirement to report construction accidents to the authorities. It is therefore common for researchers to employ such data in their studies. This is true for all four groups. However, primary data collection methods, including interviews (and focus groups) and questionnaires, are widely employed. For general construction projects, examples include Haslam et al. [8] and Ijaola et al. [47]; for specific building divisions [40,48], for accident analysis models [17,49], and for other aspects of construction accidents [26]. Another notable trend is the frequent use of mixed data collection methods. Studies often combine secondary data with interviews [8,41], with questionnaires [27,48], or with both interviews and surveys [46]. In general, combining secondary data with interviews and surveys is advantageous for construction accident causation research, as this mixed-methods approach enables cross-validation of findings across data types, leading to more robust and reliable conclusions.

Regarding data sources, nearly all secondary data originate from databases managed by government agencies or designated institutions (the most famous are OSHA in the USA and HSE in the UK), which are legally mandated to collect information on construction incidents. Following major accidents, official investigations are conducted, and reports are published, making these investigation reports readily accessible for research purposes [50,51]. A good number of interviews (including focus groups) were also used in collecting primary data, which, as expected for such a method, involved specialists and professionals who possessed in-depth knowledge in the related construction area [41,52]. Few studies employed questionnaires, which were distributed to construction workers or individuals affiliated with construction-related entities [27,36].

As suggested above, the secondary data used in these studies generally consist of comprehensive records of construction accidents over a period of time for a city, a region, or a country. Therefore, the number of cases in secondary data studies is understandably large, especially those examining general construction projects. Table 2 divides the papers that utilize

Table 4.1.1
Construction accident categories and their rates in different countries - General construction building projects.

Author	Category	Rate
Zhang, W, et al., (2020) [62]	Fall from height	36 %
	Collapse	24 %
	Object strike	10 %
	Lifting injury	9 %
	Electric shock	7 %
	Poisoning	6 %
	Vehicle injury	3 %
	Mechanical injury	2 %
	Drowning	1 %
	Explosion	1 %
	Fire	1 %
Note	1. Country: China. 2. Injury types of 571 accidents from 2005 to 2016	

Source: the papers collected.

Table 4.1.2
Construction accident categories and their rates in different countries - General construction building projects.

Author	Category	Rate
Ale, B., et al. (2008)	Fall from height (roof/floor/platform)	24 %
	Contact with falling/collapsing object	19 %
	Fall from height ladder	17 %
	Fall from height scaffold	14 %
	Contact with moving parts of a machine	13 %
	Fall from moveable platform	4 %
	Contact with hanging or swinging objects	3 %
	Struck by moving vehicle	2 %
	Trapped between/against	2 %
	Contact with object ejected from machine	2 %
Note	1. Country: Dutch. 2. Most frequent accident type (Bow-Tie) for construction BIK 45 (1998–2003).	

Source: the papers collected.

secondary data into two groups. The number of fatal incidents reported varies widely, ranging from 26 to 2348 cases, which is more likely associated with the nature of the construction market (the size, the growth, etc.) in a country and less likely with the time length (if the data availability and accessibility are presumed). For example, Shao et al. [29] reported 2348 fatal incidents in China over a 5-year period, whereas comparable studies in the USA documented only several hundred fatal cases over 5–6 years [53,54]. When considering all incidents, the variation is even greater in terms of both the number of cases and time, which is influenced by multiple factors, among which the research focus plays a key role. For example, when the research dealt with a general project, the case number easily reached several thousand (9082 cases in 6 years [55]; 9358 cases in 9 years [56]; 4263 cases in 27 years [25]). Official secondary data are generally considered reliable. However, in developing countries, data quality can be variable. Issues like inconsistent data collection, limited availability, and differing methodologies may affect the accuracy and completeness of the data, which can lead to it being defective for certain analyses.

3.2.2. Data analysis

Table 2 summarizes twelve data analysis methods identified in the reviewed studies, most of which are qualitative in nature. It appears that the selection of the method is influenced by the main research focuses, as outlined in Table 1. The connection is illustrated in Fig. 2, which connects three research focuses, i.e., Cause and Factor, Accident Data, and Construction Worker, with specified analysis methods.

Of the twelve methods, seven are used in the analysis of “cause and factor”, which is unsurprising given that this is the most extensively

Table 4.1.3

Construction accident categories and their rates in different countries - General construction building projects.

Author	Category	Rate
Haslam, R. et al. (2005)	Falls	24 %
	Struck by moving object/vehicle	24 %
	Injured while handling, lifting or carrying	19 %
	Strike against something fixed or stationary	9 %
	Trapped by something collapsing or overturning	7 %
	Contact with/by moving machinery	5 %
	Contact with electricity or electrical discharge	2 %
	Other accident event types	10 %
Note	1. Country: UK.	
	2. Study sample compared with reportable injuries to construction industry workers (1996–2000)	

Source: the papers collected.

Table 4.1.4

Construction accident categories and their rates in different countries - General construction building projects.

Author	Category	Rate
Ahmad, S. et al. (2016)	Fall	23 %
	Throwing objects	23 %
	Slipping	22 %
	Collision and crash	17 %
	Abrasion	15 %
	Manual Handling	15 %
	Electrical shock	10 %
	Chemical	7 %
Note	1. Country: Iran.	
	2. Accident type factors (2009–2013).	

Source: the papers collected.

Table 4.1.5

Construction accident categories and their rates in different countries - General construction building projects.

Author	Category	Rate
Chi, S., Han, S. & Kim, D., (2013)	Falls (elevation/same level)	44 %
	Struck-by/against	26 %
	Caught in/Between	10 %
	Electrical shock	6 %
	Inhalation, inhalation, ingestion or absorption	3 %
	Cardiothoracic, vascular or respiratory failure	2 %
	Others	10 %
Note	1. Country: USA.	
	2. Degree of injuries by accident types (2002–2011)	

Source: the papers collected.

Table 4.1.6

Construction accident categories and their rates in different countries - General construction building projects.

Author	Category	Rate
Winge, S., & Albrechtsen, E., (2018)	Fall	48 %
	Hit by object	24 %
	Cut by sharp object	13 %
	Squeezed, caught	6 %
	Electricity	4 %
Note	1. Country: Norway.	
	2. Top five accident types for different samples (2015).	

Source: the papers collected.

explored focus. Among these seven methods, Storybuilder [55], Social Network Analysis [54,57], Delphi Method [37], Frequency Analysis [5,29], and Coupling risk assessment method [20] are utilized

Table 4.2.1

Fatal accident.

Author	Category	Rate
Eteifa, S. & and El-adaway, I. (2018)	Fall	47 %
	Struck by	24 %
	Caught in between	11 %
	Electrocution	8 %
	Burn/Explosion	4 %
	Asphyxia	4 %
	Health related	3 %
Note	1. Country: USA.	
	2. Direct causes of the investigated fatalities (2006–2010).	

Source: the papers collected.

Table 4.2.2

Fatal accident.

Author	Category	Rate
Shao, B. et al. (2019)	Fall	55 %
	Struck by object	13 %
	Collapse	11 %
	Hoisting damage	9 %
Note	1. Country: China.	
	2. Top four types of accident (2012–2016).	

Source: the paper collected.

Table 4.2.3

Fatal accident.

Author	Category	Rate
Hinze, J. et al. (1998)	Falls	34 %
	Struck by	20 %
	Caught in/between	17 %
	Electric shock	19 %
	Others	12 %
Note	1. Country: USA.	
	2. Distribution of Fatalities by Causes (average of two periods of 1985–1989 and 1994–1995).	

Source: the paper collected.

relatively infrequently. The most commonly employed method is modelling (such as Suraji [44], Winge, Albrechtsen & Mostue [19]), either by leveraging existing models to identify key causes and factors or by developing new models tailored to a specific study. The second most prevalent method is regression analysis, which is particularly suitable for general construction projects where causal factors can be treated as independent variables. Various regression techniques have been applied, such as Logistic Regression by Park et al. [37], One-way ANOVA by Ahmad et al. [58], multiple linear regression by Chen & Cao [59], and Bayesian network analysis by Yang & Xiang [60].

Table 5.1

The summary of the top seven types of construction accidents for general construction projects.

Developed economies		Undeveloped economies	
Category	Rate	Category	Rate
Falls (elevation/same level)	43.8 %	Falls (elevation/same level)	40.5 %
Contact with falling /collapsing/moving object	22.0 %	Contact with falling /collapsing/moving object	20.5 %
Struck by/strike against moving vehicle/object	21.50 %	Struck by/strike against moving vehicle/object	16.50 %
Injured while handling, lifting or carrying	16.0 %	Injured while handling, lifting or carrying	14.5 %
Trapped between/against	6.3 %	Trapped between/against	-
Chemical injuries	5.0 %	Chemical injuries	6.5 %
Electrical injuries	5.0 %	Electrical injuries	8.5 %

Source: the authors' summary of the papers collected.

Table 5.2

The summary of the top four types of construction accidents for fatal injuries.

USA		China	
Category	Rate	Category	Rate
Falls	40.5 %	Falls	55 %
Struck by	22.0 %	Struck by	13 %
Caught in/between and collapse	14.0 %	Caught in/between and collapse	11 %
Electrocution	13.5 %	Electrocution	-

Source: the authors' summary of the papers collected.

The volume of construction accident reports is monumental, with most accident cases documented as unstructured text. Significant time and effort are thus required to retrieve and analyse this information. In addition, the contributing factors to construction accidents are numerous and complex. To address these challenges, researchers have explored emerging analytical techniques. Two methods have proven particularly advantageous: Natural Language Processing (e.g., Kim & Chi [25]) and Data Mining (e.g. Xu et al. [38]). By extracting meaningful information from historical data of construction accidents, the data mining technique “can further help identify and provide frequent conditions that can be prevented in the future and enable potential cause-and-effect relationships to be determined among the many factors that play a role in the accidents” [24,34]. Building on rapid technological advancements, more recent research has also applied Big Data analysis and AI [61], which results in more efficient processes for data extraction and use.

Construction workers play a critical role in the analysis of construction accidents because they represent a major causal factor themselves [35] and many accident-related factors are closely linked to the activities performed by workers on site [5,26]. Research examining the relationship between construction workers and construction accidents generally follows two lines of inquiry. One is the behaviours or actions of workers on site [5], and the other is the internal factors, such as fatigue [26] and external factors, such as heat waves [46] that negatively influence workers. The analytical methods employed in this area are predominantly statistical, while some studies adopt qualitative approaches suited to the nature of the data, such as Grounded Theory [46].

Table 6

The differences of incidents involved in analysing the key causes or factors.

Project	All incidents	All fatal incidents	All falls	Fatal falls	Heat illness & Others
General construction projects	✓	✓	✓	✓	✓
Specific building division	✓	✓			

Source: the papers collected.

3.3. Types of accident

In the previous sections, we appraised what has been achieved in the field in terms of the focus and the methods. The next three themes are more specific to the analysis of construction accident causation. Their selection is justified both by the availability of existing research and by the importance of these subjects. We begin by examining accident types to better understand the mechanism of accidents in construction activities, identify recurring patterns, and ultimately contribute to uncovering underlying causes.

In developed economies, systems for classifying, reporting, and recording construction incidents are well established and have been in operation for decades. For example, in the UK, the Health and Safety Executive (HSE) is the government agency responsible for managing workplace health, safety, and welfare across all industries, including construction. According to the statistics published by HSE (Construction statistics in Great Britain, 2022), five types (“causes” in HSE’s term) are identified for fatal construction incidents, and four types account for 10 % or more of nonfatal injuries. In the USA, the situation is more complicated. There are two parallel systems. One is the Occupational Safety and Health Administration (OSHA), under the Department of Labour, and the other involves a chain of agencies: the Department of Health and Human Services > Centres for Disease Control and Prevention > National Institute for Occupational Safety and Health > Centre for Construction Research and Training (CPWR). In 2017, OSHA and CPWR formed an alliance to strengthen efforts in construction safety. The statistical data published by CPWR (Fatal and Nonfatal Injuries in Construction, 2022) classify construction incidents into five categories for fatal injuries and five for nonfatal injuries. Table 3 catalogues the official construction accident types used by HSE and CPWR.

The above categories, derived from the two organizations, are mainly designed for reporting and recording purposes, enabling the public to access and interpret construction safety data. In contrast, the types of construction accidents outlined in the following tables are extracted from academic studies specifically investigating construction accidents across different regions of the world. These studies rely on the data obtained from official records, supplemented in some cases by interviews and questionnaires, most of which do not explicitly distinguish between fatal and nonfatal injuries. The papers

Table 7

The summary of the factor categories referring to general construction projects.

General construction project	
Category	Application
Human factors (Hazardous behaviours; Activities during incident; unsafe actions; Worker and work team; unsafe behaviour)	OSHA; HSE;
Work-place factors (Hazardous Conditions; unsafe conditions; Site factors; Materials and equipment; workplace conditions; work organization; workplace design; work method; unsafe machines & tools)	HFACS; others
Environment factors (safety, economy and labour force...)	
Direct causes	Traditional research
Root causes	ConAC Model
Immediate causes	
Shaping factors	
Originating influences	
Proximal Factors	Early research
Distal factors	Individual research
Contributing factors	

Source: the papers collected.

Table 8

Summary of factor categories for specific building divisions.

Specific building division	
Category	Application
Human factors	OSHA;
Work-place factors (Material/ equipment; Safety protection device; PPE; Site layout/ space)	HSE; HFACS; others
Safety management factors	
Environment factors	
External causes	Traditional research
Internal causes (direct causes, indirect causes, radical causes and root causes)	
Immediate causes	ConAC Model
Shaping factors	
Originating influences	
Contributing factors	Individual research
Underlying causes	

Source: the papers collected

were selected based on the considerations that they explore the categories of accidents purposely, and quantitative data is available for these categories.

The following tables [1] are structured in a way that conforms to what the papers deal with, i.e., general construction projects (Tables 4.1.1–4.1.6) and fatal accidents (Tables 4.2.1–4.2.3) [2]. The accident types included represent the most frequently occurring events on construction sites, those formally reported and registered, and those resulting in minor injuries, severe injuries, or fatalities among workers. Incidents that did not directly cause physical harm to workers, such as near-misses or adverse conditions, are excluded.

Compared with the accident categories listed in Table 3, several similarities and differences can be observed. For fatal and nonfatal injuries, four categories align with those used by CPWR, and three align with HSE. However, when considering the full sets of items reported by each organization, the differences become more pronounced. These discrepancies may result from the markedly different nature and environment of the construction industries in the two countries. Referring to the categorization systems established by HSE and CPWR, we conducted a stratified analysis of the data presented in Tables 4.1.1–4.1.6 and 4.2.1–4.2.3. The results are presented in Tables 5.1 and 5.2, which rank the top seven types of construction accidents for “general construction project” and the top four for “fatal injuries”. The aim of this analysis is not to calculate the total number of accident categories identified across the studies. Rather, we are more interested in finding

out what the top types of construction accidents are, which might be more useful for future research.

The categories of accident presented in Tables 5.1 and 5.2 [3] were derived from Tables 4.1.1–4.1.6 and 4.2.1–4.2.3 and subsequently consolidated with reference to those utilized by HSE and CPWR. This process is inherently challenging because the categories in each country are defined and categorized by its regulators, and thus, the same category may contain dissimilar content. These discrepancies also impact the ranking of categories, complicating matters further as the studies included in this review do not report a uniform number of categories. Notwithstanding, we endeavoured to group comparable categories and establish a ranking [4] based on the consideration of the characteristics of construction.

Tables 5.1 and 5.2 display the results of the stratification of Tables 4.1.1–4.1.6 and 4.2.1–4.2.3 according to economic status and geographical region. The most important seven incident types were extracted and synthesized from Table 4.1 for “general construction building project”. These seven categories generally appear in descending order for both developed and developing economies, suggesting a degree of global consistency. “Falls” ranks unequivocally at the top, which is not a surprising outcome. It is ranked the highest in all six studies reviewed in both economic groups, with reported proportions ranging from 24 % to 59 %, manifesting both the magnitude and severity of this issue. With rates of 43.8 % and 40.5 % in developed and developing countries, respectively, falls occur at more than twice the rate of the second-ranked category, which further proves the multiplicity and commonality of the issue.

Four accident types dominate the table, which warrants close attention for all stakeholders. A number of studies, such as Chi, Lin, and Dewi [63]; Wong et al. [45]; Mohajeri et al. [27], have focused explicitly on “falls”, and relevant review papers have also examined this issue, such as Hu et al. [30]; Nadhim et al. [64]. Greater research effort is needed, especially for the other three major categories. The comparatively high rates of chemical and electrical injuries are also notable, as these areas appear to be under-examined, especially the latter.

Given their severe consequences, the top four incident types for “fatal injuries” were identified and ranked, as shown in Table 5.2. Constrained by the availability of the research, this ranking reflects data from only two countries, i.e. USA and China, the biggest construction markets in the world. Consistent with the findings for general construction projects, “falls” ranks undisputably first, followed by “struck by” and “caught in/between”. Conspicuously, “electrocution” shows a high average rate of 13.5 % in the USA, with one study reporting a staggering 19 % frequency among “fatal injuries”.

3.4. The key factors

The second theme specific to construction-accident-causation analysis concerns the key factors that lead to the occurrence of construction accidents. Although there is no universally accepted distinction between types and factors in construction accident analysis, this review adopts the following differentiation: the *type* of an accident (the *what*) refers to its category or nature, such as a “fall” or an “electrocution”, whereas the *factors* (the *why*) refer to the specific conditions, influences, or events that increase the likelihood of that accident occurring, such as human error or poor management.

As demonstrated in Table 1, causes and contributing factors have been the primary focus of research around the globe, especially in recent times. However, significant disparities remain in the findings and results of existing studies. So, it may be arbitrary to proclaim that “the results of existing research on accidents in the construction industry show that the factors that influence the incidences are similar in many different countries” [34]. In the following section, we appraise studies that investigate key causes/factors in terms of incident, categorization of factors, source of factors/causes, and key factors. As in previous appraisals, the projects covered in the reviewed papers are categorized into two groups, i.e., general construction projects and specific building divisions.

Table 9

The top factors* and rankings** for the four Categories.

Sum of Ranking	Column Labels					
Row Labels	1	2	3	4	5	Grand Total
Human error	6	10	9	4	5	34
Bodily action				4		4
Careless walking on workplace	1					1
Failure to recognize danger or carelessness on the part of the employees					5	5
Improper usage of equipment		2				2
Improper use of PPE	1					1
Inappropriate construction operation	1					1
Inappropriate operative action		2				2
Insufficient safety awareness			3			3
Unable to understand and perceive risks			3			3
Uncertainty of hazards	1					1
User Ability Failure		2				2
Violation of work procedure	1					1
Worker & Work Team - worker actions/behavior		2				2
Worker actions and behaviors		2				2
Worker capabilities, including knowledge and skill			3			3
Worker turnover and false acts	1					1
Inappropriate workplaces	4	8	18	12	20	62
Defective material/equipment	1					1
Fall arrest failure			3			3
Improper cleaning and unusable materials			3			3
Inappropriate site condition					5	5
Instability of the foundation pit support system	1					1
Lack of overall protection systems to prevent falls		2				2
Lack of safety equipment	1					1
Local hazards				4		4
Materials - condition of materials					5	5
No fall arrest system, guardrails, or safety nets		2				2
No PPE			3			3
Roof edge protection failure	1					1
Roof/floor deficiency					5	5
Site congestion			3			3
Tools and Equipment - suitability of tools/equipment			3			3
Unguarded opening		2				2
Unsafe ladder					5	5
Unstable work area/platforms		2				2
Weak roofing (supporting) structure			3			3
Working area not intended to support exerted weight				4		4
Workplace - housekeeping				4		4
Poor safety management	5	14	21	20	20	80
Construction operations against the rules				4		4
Deficient enforcement of safety			3			3
Difficulty in traffic (i.e. vehicle and pedestrian) control around site vicinity					5	5
Disordered field management		2				2
Inadequate safety procedures		2				2
Inadequate work method	1					1
Inappropriate construction control				4		4
Inappropriate construction planning			3			3
Insufficient allocation of safety budget and safety incentives by the client		2				2
Insufficient provision of safety training and resources by the contractor			3			3
Insufficient safety procedure		2				2
Intense work pressure					5	5
Lack of general health and safety training				4		4
Lack of inspection			3			3
Lack of proper supervision			3			3
Lack of proper training		2				2
Lack of specific on-the-job training	1					1
No feedback from the system			3			3
No jobsite inspection					5	5
No PPE and improper arrangement of workplace			3			3
Originating Influences - risk management	1					1
Poor supervision		2				2
Project management					5	5
Risk management	1					1
The demands of the job are not familiar (e.g. inexperienced operators)	1					1
Time-pressure				4		4
Violations of safety rules				4		4
Working at height		2				2
Unfavorable environment	1			4		5
Poor enforcement of safety rules and regulations by the Government agencies	1					1
Welding/hot works				4		4
Grand Total	16	32	48	40	45	181

Source: the papers collected.

* top 3–5 factors from the 16 papers.

** the ranking by the original research.

3.4.1. Incident

As discussed in the previous section, the types of accidents have been reviewed, and the most prominent categories have been summarized (Table 5.1 and Table 5.2). An examination of the studies addressing the critical causes/factors of construction accidents reveals differences in the types of accidents examined across the two categories of project (Table 6). Clearly, the research comprising general construction projects is more inclusive (5 vs 2).

Most studies embrace all construction incidents or all fatal incidents when exploring key causes or contributing factors, particularly those focusing on specific building divisions [21,38,42,54,59]. This tendency may stem from ease of data access or limitations in data availability. Studies that address general construction projects also commonly examine all fall-related incidents and fatal falls, which is reasonable because it has been proven that falls (including falls from height and falls from level) are the most frequent type of incident [45,55,63]. Only a small number of papers focus on other types of incidents, such as heat-related illness or fatigue [26,46].

3.4.2. Categorization of factors

The factors contributing to construction accidents are grouped into bands for both general construction projects (Table 7), which have five bands, and specific building divisions (Table 8), which have four. The most important band (Band 1) comprises human factors, workplace factors, and environment factors for general construction projects and human factors, workplace factors, safety management, and environment factors for specific building divisions. In compiling these categories, we define human factors as errors committed by individuals on site (thus put all factors that are consistent with the definition in this group — in brackets), workplace factors as physical elements on site that result in accidents, safety management factors [5] as non-physical aspects associated with project management or site workers that influence accident occurrence, and environmental factors as external conditions beyond the site that may result in accidents. The remaining bands are largely self-explanatory.

The second column in Tables 7 and 8 is “Application”, which indicates how these factors are applied, used, or sourced. The first band can be found in research using data from official sources such as OSHA [56,65] and HSE [40]. The HFACS, originally developed for analysing aviation incidents, has also been applied in construction accident analysis. For example, Hale et al. [66] used a modified HFACS framework to analyse underlying causes of fatal construction accidents. The study’s effectiveness could be enhanced with larger sample sizes, longer study periods, and an HFACS model incorporating additional construction-specific characteristics. A few scholars adopt alternative terminologies, such as direct versus root causes, external versus internal causes, or contributing factors, while others prefer the distinction between

proximal factors and distal factors [18,67]. These approaches later informed the building of the ConAC Model (Construction Accident Causation Model). The group of immediate causes, shaping factors, and originating influences originates exclusively from the ConAC Model, which has attracted attention in construction accident causation analysis since its introduction by Haslam et al. in 2005.

3.4.3. Source of factor/cause

It is well established that construction accidents result from multiple contributing factors. One of the most vital tasks for researchers is to find the key factors underlying these incidents. This pursuit resembles the process of refining, from a large amount to a small amount, from crudity to purity, and the output of the product depends on the input; hence, the importance of the sources of factors.

The exploration of the research aiming to uncover the key factors and causes of construction accidents produces a comparatively straightforward picture regarding the sources of these factors for both general construction projects and specific building divisions. Three primary sources are commonly identified: 1) Past literature, 2) Survey, and 3) Standardized Official Accident Reports.

All three sources are frequently cited by researchers. While a few studies refer to only one or two previous papers [52], most synthesize factors from multiple previous studies to compile their own lists and identify the most critical ones [49,53]. Surveys also vary in method, with researchers employing questionnaires, interviews, and focus groups to collect relevant factors [41,42]. The third source (official reports) is extensively used by scholars [55,56,68] as the accident reporting is required to follow the official procedure, and the standardized reports are published in official channels. Notably, many studies combine multiple sources rather than relying on a single source, enhancing the robustness of their analyses.

3.4.4. Key factors

The key factors identified across previous studies are diverse, since the research is based on different projects at different times and in different countries. After extracting the top-ranked factors (excluding root causes) from 16 studies that provided rankings, and classifying them according to the first-band categories presented in Tables 7 and 8, a Vote Count Analysis (MS PivotTable) was conducted to summarize the rankings for the four categories (Table 9), which is subsequently visualized in Fig. 3.

Table 9 groups the ranked factors into four major clusters: Human Error, Inappropriate Workplaces, Poor Safety Management, and Unfavourable Environment. Together, these clusters encompass sixty-seven specific factors. Under the Row Labels of ranking (1, 2, 3, 4, 5), the sums

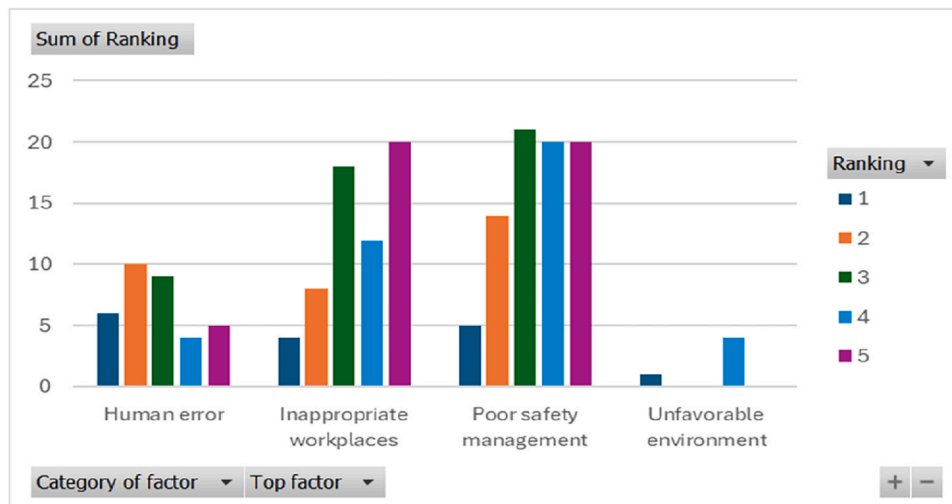


Fig. 3. Visualization of the summary of rankings for the four Categories.

Table 10

Statistical summary of the first band of factors.

	Human error	Inappropriate work places	Poor safety management	Unfavourable environment	Total
NO. of top factor	16	21	28	2	67
Percentage of top factor	24 %	32 %	42 %	2 %	100 %
NO. of ranked 1st	6	4	5	1	16
NO. of ranked 2nd	5	4	7	-	16
NO. of ranked 3rd	3	6	7	-	16
Percentage of ranked 1st	38 %	25 %	31 %	6 %	100 %
Percentage of ranked 2nd	31 %	25 %	44 %	-	100 %
Percentage of ranked 3rd	19 %	38 %	44 %	-	100 %

Source: the papers collected.

Table 11

The rank sums of the three factors ranked.

Human error	Inappropriate workplaces	Poor safety management
13.5	19.5	2.5
8	10.5	26
4	6	2.5
8	2.5	26
8	6	13
4	15.5	26
8	10.5	13
13.5	6	7
8	2.5	20
13.5	2.5	20
13.5	10.5	13
2	15.5	26
1	10.5	20
4	2.5	13
13.5	15.5	7
13.5	10.5	26
	19.5	7
	19.5	2.5
	15.5	20
	19.5	7
	10.5	13
		20
		13
		20
		7
		2.5
		20
		13

Source: the papers collected.

of occurrences for each rank are displayed. For example, “Human Error” appears six times in the first-rank position, while “Inappropriate Workplaces” appears eight times in the second-rank position.

The sixty-seven factors (Table 9) compiled from the sixteen investigations reflect substantial variation in the research of construction accidents in terms of incident types, analytical methods, factor categorization systems, and geographical coverage. Notably, none of the factors share identical naming across studies, which is strikingly dissimilar to the synthesis of accident types. Due to such diversity and complexity, the rankings of key factors vary considerably, and no consensus seems to be reached for the top ones.

This suggests that it is challenging to locate the key factors that exactly cause incidents and then rank them. However, identifying the most significant category at the first-band level remains feasible. A simple frequency calculation presented in Table 10 indicates that the most important category that causes incidents is “Poor Safety Management”, followed by “Inappropriate Workplaces” and “Human Error”. Compared with the other categories, “Poor Safety Management” contains a larger number of highly ranked factors and records more first, second, and third place rankings.

To improve the statistical rigor of ranking the three groupings (Poor Safety Management, Inappropriate Workplaces, and Human Error), a

Kruskal-Wallis Test was carried out to determine whether statistically significant differences exist among these independent groups. The test is commonly utilized to compare two or more independent samples of unequal size when the data are ordinal. The test statistic equation is given by:

$$H = (N - 1) \frac{\sum_{i=1}^g n_i (\bar{r}_i - \bar{r})^2}{\sum_{i=1}^g \sum_{j=1}^{n_i} (r_{ij} - \bar{r})^2}$$

Where:

- H is the Kruskal–Wallis statistic.
- N is the total number of observations across all groups.
- g is the number of groups.
- n_i is the number of observations in group i .
- $\bar{r}_i = \frac{\sum_{j=1}^{n_i} r_{ij}}{n_i}$ is the average rank of all observations in group i .
- $\bar{r} = \frac{1}{2} (N + 1)$ is the average of all the r_{ij} .

The Kruskal-Wallis Test examines differences in group rank sums. The null hypothesis states that the medians of all groups are equal, whereas the alternative hypothesis states that at least one group’s population median differs from at least one other group. Rank sums were first calculated (Table 11), followed by the H value using the equation above. The calculation of the H value produces a result of 60.7, which exceeds the critical value at 5%, leading to rejection of the null hypothesis and acceptance of the alternative. This outcome indicates that the three factor groups are likely to be independent, not originating from the same distribution.

The results from the Kruskal-Wallis Test aid in authenticating the above ranking of main contributing categories. Reasonably, “Poor Safety Management” emerges as more fundamental than Human Error, since “Human Errors” often reflect underlying system failures, rather than the root cause. It is recognized that a strong safety management system reduces the likelihood of human errors by ensuring adequate training, minimizing production pressure, improving communication, and clarifying procedures. Similarly, inappropriate workplaces can be considered more critical than individual human error in preventing construction accidents because a well-designed workplace reduces both the possibility and impact of human mistakes through engineering controls, safe work procedures, and training.

A detailed exploration of advanced statistical methods to further validate the ranking is beyond the scope of this paper. Nevertheless, further studies employing more sophisticated quantitative techniques could help to prove whether “Poor Safety Management” is the most important cause that directly and immediately leads to construction accidents on site.

3.5. The models

The third and final theme in this review concerns the models developed and/or tested for analysing construction accident causation. Compared with the other two themes, the development and application of models are often theoretically more challenging but also practically

Table 12

Summary of the purposes and aims of models in construction accident causation analysis.

Purpose	Model	Aim
To find factors	Latent Class Clustering Analysis (LCCA) Text Mining (TM) technology Multiple linear regression model	To find key attributes that affect the severity level of incidents To identify risk factors from construction accident reports To explore the relations between the number of accidents deaths and various factors in construction safety To identify root causes of construction accidents To develop a contributing factor classification framework to support systemic accident investigation in construction To investigate the causes of construction accidents To identify potential hazards in construction projects To analyse the interaction between fatal accident root causes and their relationship to commonly quoted direct causes To identify critical accident causes To identify root causes of accidents To assist in classifying the root causes of fatal falls from height (FFH) accidents
	Accident Root Causes Tracing Model (ARCTM) Contributing Factors Classification System Framework (CFCFSF) Ordinary least squares regression and spatial regression modelling Association-rule method of data mining Social Network Analysis (SNA) model Construction Accident Causation System (CACS) model Behavioural Causes Model Modified Human Factor Analysis and Classification System (HFACS) model Casual Structure model	To explain how and why any participant involved in a construction project might contribute to an accident To identify the causation paths leading to the accident To describe the wide range of factors involved in construction accidents To understand the underlying causes of construction fatal accidents To describes the constraints and responses experienced by the parties involved in project conception, design, and construction, which may affect accident causation To further the understanding of accident severity To increase understanding of the production system factors that affect the frequency of accident To identify the causes of accidents To evaluate the potential of CPFs to cause harm and consequently their health and safety (H&S) risk implications To investigate the existence and nature of relationships between variables To estimate posterior probabilities about the severity of accidents To characterize the causal structure of the system
To examine causation	Bow-tie model Construction Accident Causation (ConAC) ARAMIS (Accidental Risk Assessment Methodology for Industries) and Human Factor Analysis and Classification System (HFACS) Constraint-response accident model Conceptual model of construction injury severity Accident causation model Causal map A graphical model Regression analysis (ordinary least square) Bayesian theorem System dynamics model for the causation of unsafe behaviours (SD-CUB) Fault tree analysis Institutional analysis & Deviation analysis Data mining analysis Incorporates the systems theory into Heinrich's domino theory Systematic safety risk generation and control model	To present the causal relationships among events and causes that contributed to a construction accident To investigate the causation of construction accident To evaluate the contribution of the top ranked risks to accidents To explore the interrelationships of risks and break the chain of accident causation To improve the understanding of safety risk and provide a theoretical background for safety risk analysis in the construction industry To retrieve and analyse construction accident cases To systematically classify and analyse reports of past accidents To carried out to extract useful information and to further explore the relationship For predicting the six types of accident
To retrieve and/or analyse data	Natural Language Processing (NLP) Story-builder Frequency analysis technique & Correlation coefficient analysis	
To predict accident type	Fine-tuned generative pre-trained transformer	
To compare models	From twenty-one models, five popular accident causation models are selected and compared with other models. Choosing and analysing a typical construction accident based on four popular contemporary accident causation models and evaluate them	

Source: the papers collected.

more valuable due to their versatility in revealing relationships, understanding failures, identifying causal factors, predicting future incidents, and improving mitigation strategies.

Significant scholarly efforts have been devoted worldwide to developing and improving models in construction accident causation analysis, from the early frameworks such as the Domino Model and the Swiss Cheese Model to more recent developments like the ConCA Model. However, “Whilst various models exist, none is yet universally accepted, but elements of different models are.” [31]. This underscores the challenge, and perhaps the impracticality, of developing a single model that universally applies across all construction contexts.

Nevertheless, in the last one to two decades, researchers have shown increasing interest in adopting systematic principles in model development as “a sociotechnical systems approach presents new opportunities

to understand accident causation” [49]. In this section, 36 papers involving the development of new models or the application and testing of existing ones [6] are reviewed, addressing a range of analytical issues. A summary of these studies is exhibited in Table 12.

From Table 12, five overall purposes are identified: (1) examining accident causation, (2) identifying contributing factors, (3) retrieving and/or analysing accident data, (4) predicting accident types, and (5) comparing models. Among the 36 papers, most serve two closely related aims: examining causation and identifying factors. Once again, it verifies the finding that the core of the construction causation analysis is to explore the causation mechanisms and the factors of construction accidents.

Assorted models have been built/tested for construction accident analysis, especially for the two dominant purposes mentioned above. Given the intricacy of the field, a comprehensive evaluation of each

model falls outside the scope of this paper. Broadly, models used for factor identification and causation analysis can be categorized as Qualitative and/or Quantitative, each offering distinct strengths, limitations, and context-specific suitability. However, most of them are qualitative, such as Factor identification models: Text Mining technology, Accident Root Causes Tracing Model, Social Network Analysis, Modified Human Factor Analysis and Classification System; Causation analysis models: Causal Structure model, Bow-tie model, Construction Accident Causation (ConAC), Constraint-Response Accident model, Systematic Safety Risk Generation and Control model. Qualitative models excel in providing deep, context-rich insights into accident factors and causation, making them particularly valuable for complex or unique projects, but they can be time-consuming and may introduce subjectivity into the analysis. Their context-specific suitability lies in their ability to capture nuanced information from diverse sources like surveys, accident reports, and registration systems.

Compared with the qualitative models, quantitative approaches are used less frequently. However, they offer advantages such as data-driven objectivity, improved accuracy in analysing large datasets, and, in some cases, the ability to support predictive modelling of accident types. At the same time, quantitative models face challenges, including issues related to data quality and availability, methodological assumptions, and the potential to overlook complex interactions among human, environmental, and managerial factors.

It could be expected that the statistical methods of linear regression are effective and advantageous in helping pinpoint and determine the factors/causes (the independent variables) that influence the results (the dependent variables). However, only limited efforts have been made to apply statistical techniques in this domain. Examples include the investigation of construction accident causes using ordinary least squares regression and spatial regression modelling [36] and the application of the multicollinearity method to establish a multiple regression model for identifying the suitable three-dimensional variables [59]. Given the analytical power of statistical tools, there is considerable scope for further research employing such methods.

A focused interest in understanding causation mechanisms is clearly evident. Table 12 lists 17 models dedicated to this purpose. Among them, systematic approaches have gained increasing prominence in recent publications [28,32,35,49].

These models analyse accidents as the result of complex interrelationships across multiple system levels, from individual actions to organizational influences, rather than attributing causation to isolated failures. So far, one of the most prominent and successful implementations of this systems-based approach is the ConAC Model, initially developed by scholars mostly from Loughborough University and formally published in the mid-2000s [8]. The model has subsequently been applied and validated in various contexts, including studies by Behm & Schneller [43] in the USA, Gibb et al. [69] in Australia and the USA, and Winge, Albrechtsen [28] in Norway.

Drawing on earlier models such as HFACS, the model investigates how accidents in construction happen through a hierarchy of three layers of causal circumstances, factors, and influences: Originating Influences, Shaping Factors, and Immediate Accident Circumstances. This structure provides a comprehensive systems-level framework for understanding accident mechanisms and has demonstrated practical value for both research and on-site application. Yet, the model largely focuses on analysing past events rather than supporting proactive prevention, and it does not fully account for the unique, dynamic, and project-specific nature of construction environments. Additionally, it offers limited guidance on actionable mitigation strategies.

4. Conclusion

This paper set out to synthesize progress in construction accident causation analysis over the past two decades by synthesizing seventy-eight studies published in well-established academic journals. A thematic

synthesis approach was employed to provide a structured and concentrated appraisal that deepens understanding of the specific topic, highlights research gaps, and generates new insights. Five themes were selected based on several considerations, such as the relevance to the aim, the pattern and meaningfulness, their coherence and distinctness, and their impact on future research. These themes are inherently interconnected, have evolved over time, and are broadly applicable across the domain.

The themes concerning research focus and methodology constitute essential elements of all academic inquiry, including construction accident causation analysis. The other three themes of accident type, key factors, and modelling are more specific to this field, and their systematic assessment facilitates the identification of precise hazards, allowing for targeted interventions and more advanced trend analysis.

The review summarizes four research focuses on the field, with “Cause/Factor” being the most prominent, followed by “Causation Model”. It also outlines a geographical imbalance, with studies heavily concentrated in high-income countries. Regarding methodology, a clear relationship emerges between research focus and method selection, with the former seemingly dictating the latter. Besides, this paper further clarifies and consolidates what is known about the most frequent accident types by providing a statistical ranking for both developed and developing economies. A major contribution of this synthesis lies in ranking the critical categories of accident causation. After collecting sixty-seven key causation factors and conducting a Vote Count analysis, we grouped them into four categories. “Poor Safety Management” emerged as the most influential, followed by “Inappropriate Workplaces” and “Human Error”. The statistical rigor of these results is further strengthened by the application of a Kruskal-Wallis Test.

Several limitations of this review should be acknowledged. The first is the selection of journal papers and the database, which leans towards high-income English-speaking countries due to issues of data accessibility and linguistic constraints. Expanding future searches to include non-English and emerging-economy databases would help address representational gaps, particularly in the Global South. The second is the ranking of accident types. After collecting the studies that mathematically rank the most frequent types of accident, this paper conducts additional ranking to determine the most common types for general construction projects and fatal injuries by employing mean frequency and stratified analysis. Additional datasets and more sophisticated analytical techniques would further strengthen these rankings. The third is the determination of key factors. Intense efforts have been made to define the key factors and thus to catalogue them into four groups, which led to the finding of the top category (poor safety management) in causing construction accidents. Although the resulting categorization and ranking are supported by certain statistical techniques, more rigorous statistical tests are needed to validate these findings.

With the rapid development of emerging technologies, particularly artificial intelligence and Big Data, scholars around the world are increasingly leveraging these tools to advance construction accident causation research. Such technologies enable real-time data collection and monitoring, automate pattern extraction from massive datasets, support risk prediction, and enhance the identification of causal factors, ultimately contributing to a safer and healthier construction industry.

Notes

[1] In many cases, the group of “general construction building project” encompasses injuries ranging from minor to severe and fatal. The group of “fatal injuries” is singled out because of the ultimate consequences of this accident.

[2] Tool and equipment, modular construction, and cranes in the specific construction building division are not included in Table 5.1 and Table 5.2 because their sample sizes are small, and the data are not meaningfully comparable.

[3] The accident categories for fatal injuries are derived from general construction projects.

[4] The sum of rates for each group in Table 5.1 and Table 5.2 does not equal 100 % because each rate represents the mean of the corresponding category percentages from the selected papers.

[5] The category “safety management factor” includes the sub-factors of “work organization”, “workplace design”, and “work method”.

[6] In Table 12, seventeen papers are recognized as the ones that focus on building a causation model. In this section, thirty-six are collected that cover more areas. Additionally, all models in the thirty-six studies were either newly established or newly applied after 1998.

CRedit authorship contribution statement

Gu GUOWEI: Writing – original draft. **Olayinka Omoboye:** Writing – review & editing. **Rose Wong:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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