Safety Science 190 (2025) 106902

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Analysis of the main components precursors of occupational accidents in the construction industry in Spain (2003–2022)

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ARTICLE INFO

Keywords:
Precursors
Safety Management
Construction industry
Serious and fatal accidents
Principal Component Analysis (PCA)

ABSTRACT

The construction industry is one of the most influential sectors in the economy of many societies; in the European Union, it contributes 5.5 % of GDP. However, it is also one of the most dangerous sectors worldwide due to its high occupational accident rate. The aim of this research is to identify the elements that are considered precursors of occupational accidents in the construction sector. To this end, 40,582 cases of serious and fatal accidents that occurred in Spain between 2003 and 2022 were examined. Although the contributing factors and accident typologies in the construction industry exhibit considerable variability, the Principal Component Analysis conducted allowed for the identification of five groups of variables that capture the key characteristics of occupational accidents, accounting for 64.2 % of the total variance. Among the most significant findings are the worker's experience, the presence of moving objects, electrical risks, falls from different heights, the execution of activities far from the usual place of work, and the size of the company. The results of this research will enable a more focused effort in developing effective strategies to reduce occupational accidents in this sector. The identification of precursor agents of occupational accidents in construction, based on the variables examined, will help determine which specific areas require priority attention.

1. Introduction

Occupational health and safety in the construction industry is a vitally important issue, as occupational accidents not only affect the health and well-being of workers but also have a significant impact on the productivity and reputation of companies (Lee et al., 2021). The economic and social implications of occupational accidents in the construction industry are considerable, highlighting the importance of implementing preventive measures from social, business, and governmental perspectives (Wyke et al., 2023).

Moreover, the construction industry is one of the sectors with the greatest impact on the economy of the European Union, accounting for 5.5 % of its Gross Domestic Product and up to 5.8 % in Spain (Eurostat, 2023). It is worth noting that occupational accidents in the construction industry are very frequent, making it one of the most dangerous sectors worldwide (Mohammadi et al., 2018; Oswald et al., 2018; Pardo-Ferreira et al., 2020; Forteza et al., 2022).

Despite advances in management systems within the construction industry in recent times, it still exhibits reduced stability and efficiency, attributable to the inherent complexity of various activities and the involvement of multiple entities (Lee et al., 2020). Consequently, predicting occupational accidents in the construction industry is challenging due to the unique characteristics and simultaneity of these incidents across different workplaces.

The concept of accident precursors refers to identifiable events, conditions, or unsafe practices that increase the likelihood of an accident occurring (Saleh et al., 2010). However, the severity of an accident is not solely determined by the precursor itself but also by contextual factors such as the working environment, the presence (or absence) of preventive measures, and the level of risk exposure (Zhao et al., 2015). In the construction industry, precursors can manifest differently depending on accident severity:

Serious accidents (e.g., fractures, deep cuts) often result from failures in personal protective equipment (PPE), minor procedural violations, or temporary worker inattention (Samsudin et al., 2022). Very serious accidents (e.g., amputations, severe trauma) are frequently associated with structural deficiencies, absence of adequate fall protection systems, or prolonged exposure to hazardous conditions (Hallowell and

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https://doi.org/10.1016/j.ssci.2025.106902
Received 31 July 2024; Received in revised form 18 March 2025; Accepted 15 May 2025
Available online 20 May 2025

Gambatese, 2009). Major accidents (fatal or catastrophic) typically involve systemic failures, such as lack of proper safety training, ineffective supervision, poor organizational safety culture, or the accumulation of multiple overlooked risk factors (Reason, 2016; Zhou et al., 2015).

Understanding these distinctions is crucial for developing targeted prevention strategies, as different levels of intervention may be required to mitigate risks effectively. For example, while procedural adjustments may reduce serious accidents, major accidents often require a more systemic approach that includes training, regulatory compliance, and cultural shifts in workplace safety (Lingard et al., 2012).

In this regard, extensive research has been conducted over the last few decades to improve the safety performance of construction sites. Among these studies, a significant body of work (López et al., 2008; Lopez-Arquillos et al., 2012; Suárez-Cebador et al., 2014; Carrillo-Castrillo et al., 2017; Trillo-Cabello et al., 2021a; Fuentes-Bargues et al., 2023) has focused on reported workplace accidents, making statistical correlations between variables organized according to the European Statistics on Accidents at Work (ESAW) of the European Commission (2013). Additionally, studies have identified frequent causal factors and their relationships in construction industry accidents (Winge et al., 2019; Berglund et al., 2019). Notably, research by Wu et al. (2010) presents a systematic mechanism to interrupt and prevent precursors and immediate factors in construction site accidents. Other studies have addressed specific non-standardized risk variables related to reported cases of construction accidents (Betsis et al., 2019; Forteza et al., 2022). Finally, research such as that conducted by Trillo-Cabello et al. (2021b) has statistically evaluated the perception of accident risk based on surveys of health and safety professionals in the construction sector.

The reviewed literature in the Spanish context for the construction sector has identified several precursors of serious, very serious, and fatal accidents.

- These include:Material agents: Defective or improperly used tools and equipment are common causes of serious and fatal accidents, particularly in high-risk tasks involving machinery or hazardous materials (Jacinto and Aspinwall, 2004; Salguero-Caparros et al., 2015).
- Deviations in safety procedures: Failures in following safety protocols, such as improper handling of materials or scaffoldings, are often linked to fatal accidents, particularly falls from heights or electrical hazards (Kjellen, 1984; Jacinto et al., 2011).
- Human and organizational factors: Lack of experience, insufficient training, and high staff turnover in the construction sector increase the likelihood of serious and fatal accidents. Poor safety culture and communication can exacerbate these risks, especially in small and medium-sized enterprises (López et al., 2008; Fontaneda et al., 2022).
- Workplace conditions: Accidents occurring outside the usual workplace or in poorly maintained sites tend to be more severe or fatal. Injuries to extremities are common, but fatal accidents are often due to falls, electrical incidents, or being struck by objects (Suárez-Cebador et al., 2014; Fontaneda et al., 2022).
- External factors: Environmental conditions, such as weather and site maintenance, contribute to accident severity. Poor site conditions, particularly during adverse weather, are linked to a higher incidence of fatal accidents (Lopez-Arquillos et al., 2012; Ayodele et al., 2020).

Understanding these precursors is crucial for enhancing safety measures and preventing accidents in the construction sector. However, most of the research reviewed focuses from the outset on a factor deemed key to analyzing accident rates in this sector. This study delves into Principal Component Analysis (known by its acronym as PCA) affecting occupational accidents in the construction industry in Spain. Through a detailed approach, it investigates the key factors contributing to serious and fatal accidents, drawing on all relevant variables to identify trends, patterns, and potential areas for improvement. This analysis aims not only to understand the root causes of occupational accidents but also to create a predictive and forward-looking model to propose strategies and preventive measures that promote a safer and healthier working environment within the construction industry in Spain.***

1.1. Background on principal component analysis in the construction industry

Principal Component Analysis (PCA) is a statistical technique used to simplify and summarize the variability in a data set by identifying underlying patterns and relationships between variables. Its main objective is to transform an original set of correlated variables into a new set of uncorrelated variables called "principal components." PCA was first proposed by Pearson (1901) and later developed by Hotelling (1933) and Jolliffe (2002) to establish a modernized theory. Today, PCA is widely used in various disciplines, such as statistics, econometrics, biology, psychology, and other scientific areas, to reduce the dimensionality of data and highlight underlying patterns.

Consequently, PCA is one of the most important and powerful methods in chemometrics and many other fields. It is a versatile technique capable of providing an overview of complex multivariate data (Bro and Smilde, 2014). PCA can also be used to reveal relationships between variables and samples (e.g., clustering), detect outliers, find and quantify patterns, and generate new hypotheses (Abdi and Williams, 2010).

Given the above, it is clear that PCA could be applied to identify the main components significantly impacting occupational safety in the construction industry in Spain. For this reason, it was proposed to investigate the scientific studies published that have used PCA to analyze workplace accidents in the construction sector.

The first study identified is that of Katsakiori et al. (2008), which determined the factors attributed to fatal occupational accidents that occurred in the Eastern Attica region during the five years prior to the Athens Olympic Games held in the summer of 2004. This study was based on the analysis of 63 fatal accident investigation reports reviewed by Greek labor inspectors. Five causal variables and two principal components were used for the analysis. The results revealed that poor work practices resulting from a lack of job orientation and training, performance pressure, and worker inexperience associated with knowledge- and skill-based errors are the most common factors attributed to occupational fatalities.

A second study focusing on relevant accident risk factors in construction using PCA is that of Dogbegah et al. (2011). This study was based on a structured survey of 100 construction project managers in Ghana conducted in 2010, using 18 different variables, six of which explained up to 72.44 % of the cumulative variance. The main contribution of this study is that the knowledge areas identified from the PCA now form the basis for project management training requirements in the context of the Ghanaian construction industry.

A third study, conducted by Alexander et al. (2017a), proposed building a mathematical predictive model of fatal accidents in the U.S. construction industry based on PCA drawn from 19 interviews with construction safety experts. Initially, a group of construction safety experts was asked to identify potential precursors of accidents in the construction industry, resulting in the identification of 43 precursors (Alexander et al., 2017b). In the second phase of the study, a logical combination was used, and PCA reduced the number of precursors examined. This step led to the selection of 16 final principal precursors. The results showed that four of the 16 precursors considered as principal components explained 75 % of the variability in the total data set.

The fourth study is by Shao et al. (2019), which analyzed fatal accidents recorded in different regions of China in the construction sector between 2014 and 2015, utilizing an improved PCA from a multidimensional perspective. To address this objective, six indicators that can quantify the situation were selected based on an extensive literature review and interviews with safety experts. With these six principal components, 100 % of the cumulative variance was identified, providing specific direction for improving the accident situation for the government.

A fifth study by Karji et al. (2020) aimed to explore the barriers affecting the construction industry that prevent it from being sustainable in the United States. To achieve this objective, 12 sustainability barriers were identified based on a comprehensive literature review combined with expert opinions to validate the barriers. PCA was used to analyze the data and identify the most significant barriers. In this study, the 12 barriers correspond to the principal components, describing 100 % of the cumulative variance.

A sixth and particularly interesting study is that of Lee et al. (2021). In this work, data processing and event prediction modeling were performed to analyze occupational accidents in the Korean construction industry. The occupational accident data used in this study were collected from the safety management system database of a large construction company in Korea, covering the period from 2015 to 2020. In total, 963 occupational accidents were analyzed, examining 16 different variables using PCA and grouping them around three main components: age, type of accidents, and injured body part.

The seventh study is by Salas et al. (2020), which analyzed the risk tolerance of 11,997 workers in 17 countries based on surveys of contractors and subcontractors in the construction sector. This was achieved through controlled sampling for equal representation, employing principal component analysis and K-means clustering of 35 questions, considering factors such as age, type of employment, and risk in each country.

Following this line of research is the eighth study by Omoraka (2022). This paper examined the skills of supply chain managers as a solution to the challenges posed by occupational accidents in the construction industry in Nigeria. To address the objective of this study, a structured questionnaire was administered to 215 construction professionals, yielding a response rate of 82 %. Subsequently, a principal component analysis was conducted on the data using up to 24 variables.

Finally, the study by Wyke et al. (2023) proposes the use of principal component analysis to identify latent factors affecting cost and time overruns in public construction projects in Denmark. In this study, 26 factors affecting cost and time overruns were identified through qualitative interviews with project managers from Danish government agencies and through a literature review. Ultimately, twelve principal components were determined, accounting for 53.49 % of the cumulative variance.

1.2. Scope and contribution of the present research

In view of the above, the aim of the study presented here is to provide readers—whether they are construction professionals, researchers, or labor policymakers—with a comprehensive overview of the main components affecting occupational safety in this specific sector in Spain. By gaining a thorough understanding of these factors, the study aims to encourage the adoption of safe practices, continuous improvement, and the development of effective strategies to reduce occupational accidents while promoting a safe and healthy working environment in the country's construction industry.

Additionally, the statistics and records of occupational accidents in the construction industry in Spain will be examined to identify recurrent patterns and the most common risk situations. This analysis will be based on a total of 40,582 cases of accidents in the construction industry, obtained from the database of the Spanish Ministry of Labor, Migration, and Social Security for the period between 2003 and 2022. This quantitative analysis will provide a clearer view of the specific areas that require priority attention.

After setting the issues and objectives in context in the introduction, the rest of the document is structured as follows. Section 2 is devoted to explaining the sample of accident investigation reports employed, as well as describing the methodology-based approach. In terms of methodology, the classification of the variables analyzed and the statistical treatment of these variables are detailed. Section 3 presents the results obtained, and Section 4 includes a discussion of the main results, concluding with guidelines for future research in Section 5.

2. Materials and methods

Before detailing the materials and methods used, it is important to make a note on the definition of the term "accident" and its classification according to severity. The term "accident" has a very holistic definition, as it refers to any unforeseen, undesired, and generally unplanned event that causes damage, harm, or disruption to the normal state of things (Sklet, 2004). However, in this study, the term "occupational or work-related accident" is used. Therefore, the manuscript defines a work accident as an event that occurs in the course of work or in relation to work, causing professional injuries or even death (International Labour Organization, 1988). Additionally, the European Statistics on Accidents at Work (European Commission, 2013) defines the concept of 'Accident at work' as a discrete occurrence in the course of work which leads to physical or mental harm. The phrase 'in the course of work' means 'while engaged in an occupational activity or during the time spent at work'.

Regarding the definitions of serious and fatal accidents, it should be noted that the European Statistics on Accidents at Work (European Commission, 2013) defines a 'fatal accident' as one which leads to the death of a victim within one year of the accident. On the other hand, a minor accident is defined as one that results in the absence of three or fewer calendar days from work. Consequently, a serious accident is one without fatal consequences, but with the absence of more than four calendar days from the workplace.

The data used for this research come from the Occupational Accident Statistics of the Ministry of Labour, Migration, and Social Security of the Spanish Government. The study covers the period from 2003 to 2022. All accidents registered in Spain within the construction sector (coded according to CNAE-1993 and CNAE-2009) were collected. The analysis focused on accident reports that included serious or fatal injuries, discarding those involving minor injuries. A total of 40,582 accident reports were included in this research, comprising serious or fatal accidents in the construction sector that occurred between 2003 and 2022 in Spain (see Fig. 1).

The focus of this study has been exclusively on accidents classified as serious and fatal because, as Bayona et al. (2024) argue, serious injuries and fatal accidents occur for different reasons than less severe injuries, highlighting the need for a specific approach to the prevention of serious and fatal accidents.

The official accident report forms submitted in Spain provide detailed information on each recorded accident resulting in time off work. This information is organized into various sections, which include data on the injured worker, the workplace where the injured worker is affiliated, the location of the accident, the causes and circumstances of the accident, the care received, the type of injury, the temporary disability incurred, and other demographic data.

To extract the main patterns or factors that characterize accidents in the construction sector in Spain over the last two decades, a Principal Component Analysis (PCA) was conducted as an analytical tool. For this purpose, a series of variables contained in the accident reports that meet the requirements for PCA have been selected. The PCA will facilitate the extraction of latent characteristics and the relationships between the chosen variables. This technique is based on three primary procedures (Shrestha, 2021). The first step is to check whether the available data and the chosen variables are suitable for the intended PCA factor analysis. Secondly, the main factors are extracted to reduce the number of variables in the study, making it easier to identify the primary

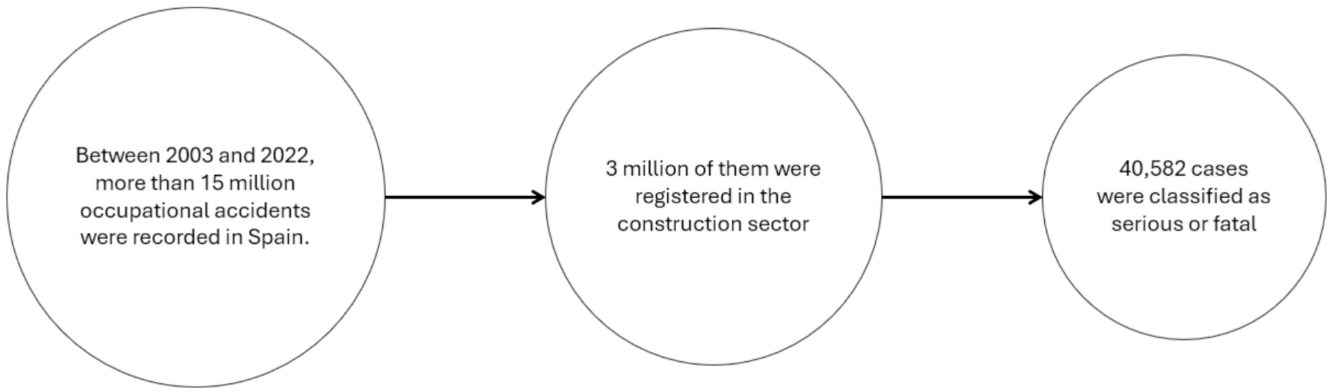

Fig. 1. Selection of accidents reports in the construction industry in Spain 2003–2022.

characteristics of the sample. The third step, following a rotation of the extracted factors, involves the interpretation of the factors. The software used for the statistical analysis was IBM SPSS Statistics version 25.

2.1. Variables selected

The Occupational Accident Statistics databases of the Spanish Ministry of Labour, Migration and Social Security are compiled through the Electronic Declaration of Injured Workers (Delt@, 2024). This declaration of accidents consists of a total of 61 main variables, providing comprehensive information on each occupational accident, including: data on the injured worker; information about the workplace here the worker is affiliated; details of the location and circumstances of the accident; care data; and information regarding the worker's discharge and sick leave. It is important to note that companies are required to notify the labor authority in writing of any damage to the health of workers that may have occurred during the course of their work (Art. 23.3 of Law 31/95 on the Prevention of Occupational Risks).

Of the 61 initial variables contained in Delt@, 14 were discarded as they do not represent data of interest for this research, although they may be useful in other contexts. These discarded variables include: the amount of benefit; duration of sick leave; date of the accident; type of preventive organization; type of company; and redundant variables such as the worker's length of service expressed in days and months.

The remaining 47 variables from each Delt@ report were sent to a panel of experts to assess the importance of each variable concerning the variability of the occupational accident rate. An expert panel on occupational health and safety within the Spanish construction industry was conducted. The experts were rigorously selected for this study based on the criteria outlined by Hallowell and Gambatese (2009). Each candidate was assessed according to three main factors: The first factor was prior experience working in companies dedicated to occupational health and safety management within the construction sector. The second factor was experience, with a minimum requirement of 10 years. The final factor was education. Candidates needed to be technical experts in occupational health and safety with a degree in Engineering or Architecture, with or without postdoctoral training. As a result of this selection process, a panel consisting of ten participants was considered acceptable.

A Likert scale was used, ranging from 1 to 5, where 1 represented very little importance for the accident rate at work and 5 indicated significant importance. After analyzing the experts' opinions on the 47 proposed variables, the 20 variables with the highest scores were selected, as these were deemed by the experts to have the greatest impact on workplace accidents. The expert survey was conducted with the assistance of the Laboratory-Observatory of Preventive Management in SMEs in Andalusia (LAGEPYME) during the first quarter of 2023.

As a final step in selecting the variables for this research, it was verified how many of the 20 variables selected by the experts met the requirements for PCA analysis. Malhotra et al. (2020) advise discarding variables with low communalities (<0.4) and/or low factor loadings (<0.3). Fig. 2 illustrates the variable selection process employed in this research.

The variables selected are listed in Table 1.

The adequacy of the drawn sample data is supported by the obtained Cronbach's Alpha value of 0.604, which is greater than the minimum threshold of 0.500. This indicates that the data used for the research are reliable for analysis (Field, 2005; Rajput and Singh, 2019). The Kaiser-Meyer-Olkin (KMO) measure, which assesses the suitability of the data for performing PCA, yielded a value of 0.674, higher than the required 0.500 for this sample size (Field, 2005; Child, 2006). As a final check, Bartlett's test of sphericity was performed to examine the homogeneity of variance, resulting in a value of 0.000, which is less than the 0.001 threshold (Rajput and Singh, 2019). Therefore, the data sample used is reliable and suitable for conducting a PCA.

3. Main results

3.1. Descriptive analysis

The present study is based on a sample of 40,582 occupational accident cases recorded in Spain between 2003 and 2022, inclusive. The analyzed data originate from the Delt@ system and correspond to accidents classified as severe, very severe, or fatal. To ensure comparability with European regulations and recommendations, accidents have been grouped into two categories: severe (including both severe and very severe cases) and fatal. Table 2 provides a descriptive analysis of the sample used in this study.

Table 2 illustrates the evolution of the number of accidents recorded in the construction sector based on data from the Delt@ system. A general downward trend in the number of accidents is observed throughout the analyzed period, with more marked declines during the years corresponding to the financial crisis (2012–2013), which had a significant impact on economic activity. Given the construction sector's high sensitivity to economic fluctuations, this relationship is evident both in the volume of activity and in the number of recorded accidents.

Severe accidents (both serious and very serious) account for 89.4 % of all recorded accidents, compared to 10.6 % for fatal accidents. This is significant because, in the analysis of principal components as precursors to accidents in construction, and considering that the precursors vary based on accident severity, these findings would more accurately explain the case of serious or very serious accidents. However, this is not the focus of this research. The disaggregation of precursors by accident severity could serve as the starting point for future studies.

3.2. Factorial analysis

The first step of the study is to perform a factor analysis of the data

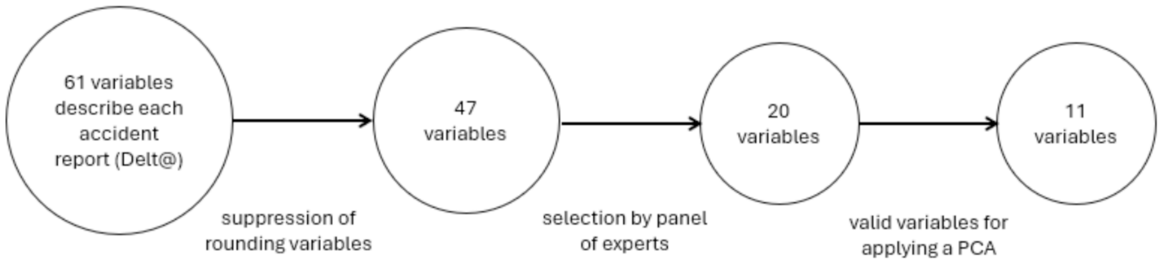

Fig. 2. Selection of variables for PCA analysis.

extracted from the accident reports using the Principal Component Analysis technique with Varimax rotation (Park et al., 2002). This analysis checks the communalities of the 11 chosen variables, which indicate how much of each variable is shared with the rest of the variables in this analyzed set. The communalities analysis also served to discard variables for the PCA. Table 3 shows the communalities of the 11 variables ultimately selected. No variable exhibits a communality below 0.500, so they are considered suitable for the PCA (Field, 2005).

The PCA performed provides a principal component matrix based on the variance explained. To facilitate the interpretation of the principal components, a Varimax rotation is applied (Park et al., 2002). In total, five principal components are extracted, explaining 64.2 % of the total variance. The total variance of each extracted component is as follows: the first principal component (PC1) explains 21.003 % of the total variance; the second component (PC2) explains 11.522 %; the third component (PC3) explains 11.509 %; the fourth component (PC4) explains 10.670 %; and the fifth component (PC5) explains 9.499 %. The criterion for the cumulative proportion of variance indicates that the extracted components must collectively explain a minimum of 50 % of the total variance (Field, 2005). In this analysis, a cumulative proportion of 64.204 % is achieved (Table 4).

Table 4 presents the explained variance after rotation. Although all 11 possible components are listed, accounting for 100 % of the model's variance, only those with eigenvalues greater than 1 (PC1 to PC5) have been highlighted, as they explain a significant proportion of the variance and contribute most of the relevant information. Components PC6 to PC11 account for less variance than recommended. This dimensionality reduction simplifies the model, reducing it from 11 original variables to just 5, which together explain 64.2 % of the total variance.

The final stage consists of analyzing the factor loadings that each variable contributes to each of the five principal components extracted (PC1, PC2, PC3, PC4, and PC5). This analysis provides the necessary information to identify the latent factors and primary causes of accidents in the construction industry in Spain, which are the objectives of this research. Table 5 highlights the cells of the factor loadings, indicating the variables that contribute to each component with a value greater than 0.500, which is considered the minimum required threshold.

Table 5 presents the relationship between each component and the 11 key variables selected in this study. The values assigned to each variable within each component represent the degree of association between the variable and the component. For instance, the variable "Material agent associated with the deviation" is strongly associated with PC1 (0.908), indicating that this factor significantly contributes to the variance explained by that component. Within PC1, the other two variables related to material agents also exhibit the highest loadings. Conversely, when a variable has values close to zero or below 0.500, it suggests a weak association with the component. Variables displaying a negative coefficient for a given component (e.g., "Deviation that caused the accident": −0.642) indicate an inverse relationship, meaning that this factor contributes in the opposite direction to the construction of the component. The discussion section provides a detailed analysis of the nature of each extracted component.

4. Discussion

Based on the critical examination of the inherent relationships between the variables of each component, the following interpretations were deduced to represent the underlying dimensions of the components. In this context, component 1 was named Present Material Agents; component 2, Triggering Deviations and Degree of Injury; component 3, Management of Experience and Age of Workers; component 4, Location, contact mechanism, and injury; and component 5, Company Staff and degree of injury. The titles of these five components were derived from their interrelated characteristics and the combination of variables with high factor loadings. Fig. 3 schematically represents the main results obtained, detailing each component.

Fig. 3 shows the composition of the 5 extracted components. The first four components are primarily defined by at least two variables each: PC1 (3 variables), PC2 (2 variables), PC3 (2 variables), and PC4 (3 variables); Component 5 is supported by only one variable (company staff). This is a significant finding, indicating that the company size is a cross-cutting aspect across the other factors, which is why it has been placed encompassing the rest. Another notable fact is that the main component PC2 (Triggering deviations and degree of injury) and PC3 (Managing the experience and age of employees) explain the same variance. In other words, according to this research, factors such as the deviation that caused the accident and the severity of the injury have the same relevance as the experience and age of the injured worker. Previous studies have highlighted the relevance of these factors and analyzed their importance in accident studies; however, it has never been detected that this group of variables could present the same relevance for studying construction accident fatalities.

5. Component PC1: Present Material agents

The first principal component (PC1) in Table 5 recorded high factor loadings for the following variables: material agent associated with specific physical activity (83.9 %); material agent associated with deviation (90.8 %); and material agent associated with the form of contact (87.2 %). The numbers in parentheses indicate the respective factor loadings, which represent the relative importance of each variable within the component's dataset. This component accounted for 21.003 % of the explained variance, as shown in Table 4, and was labeled Present Material Agents, which are associated with the causes and circumstances of accidents.

When using the harmonised variable "material agent" within the ESAW coding system in accident analysis, it is important to differentiate between the material agent associated with specific physical activity, the material agent associated with deviation, and the material agent associated with the form of contact (European Commission, 2013). The first is defined as the tool, object, or instrument used by the victim immediately before the accident occurred. The second is defined as the tool, object, or instrument involved in the anomalous event. The third is defined as the object, instrument, or tool with which the victim came into contact.

This component is straightforward to interpret in that identifying the

Table 1
Coding of selected variables.

Variable	Description	Coding of the variable
V1	Length of service	1. Up to 1 year 2. 1–5 years 3. 5–10 years 4. More than 10 years
V2	Accident location	1. At centre or usual workplace 2. In mission 3. In itinere 4. In another centre or workplace
V3	Deviation that triggered the accident	Coding according to ESAW 2013 1. No information or Other Deviations not listed (0 y 99) 2. Deviation due to electrical problems, explosion, fire (10 a 19) 3. Deviation by overflow, overturn, leak, flow, vaporisation, emission (20 a 29) 4. Breakage, bursting, splitting, slipping, fall, collapse of Material Agent (30 a 39) 5. Loss of control (total or partial) of machine, means of transport or handling equipment, hand-held tool, object, animal (40 a 49) 6. Slipping – Stumbling and falling – Fall of persons (50 a 59) 7. Body movement without any physical stress, causes external and internal injury (60 a 79) 8. Shock, fright, violence, aggression, threat, presence (80 a 89)
V4	Contact-Mode of injury	Coding according to ESAW 2013 1- No information or Other Contacts – Modes of Injury not listed (0 y 99) 2- Contact with electrical voltage, temperature, hazardous substances (10 a 19) 3- Drowned, buried, enveloped (20 a 29) 4- Horizontal or vertical impact with or against a stationary object (30 a 39) 5- Struck by object in motion, collision with (40 a 49) 6- Contact with sharp, pointed, rough, coarse Material Agent (50 a 59) 7- Trapped, crushed, etc. (60 a 69) 8- Physical or mental stress (70 a 79) 9- Bite, kick, etc. (animal or human) (80 a 89) 10- Infarcts, strokes, other non-traumatic pathologies (90)
V5	Part of body injured	Coding according to ESAW 2013 1- Not specified or Other Parts of body injured, not mentioned (0 y 99) 2- Head (10 a 29) 3- Trunk (30 a 49) 4- Upper Extremities (50 a 59) 5- Lower Extremities (60 a 69) 6- Whole body and multiple sites (70 a 78)
V6	Age of the injured worker	1- Up to 24 years old 2- 25–34 years old 3- 45 years or older
V7	Material Agent of the Specific Physical Activity	Coding according to ESAW 2013
V8	Material Agent associated with the Deviation	Coding according to ESAW 2013
V9	Material Agent associated with the Contact — Mode of injury	Coding according to ESAW 2013
V10	Severity of injury	3- Serious and Very Serious 4- Fatal
V11	Company staff	1- 0–9 employees (microenterprise) 2- 10–49 employees (small enterprise) 3- 50–249 employees (medium-sized enterprise) 4- 250 or more employees (large enterprise)

Table 2
Number of Recorded Accidents by Year and Severity.

Year	Serious	Fatal	Total
2003	4492	455	4,947
2004	4259	398	4,657
2005	3855	437	4,292
2006	3818	429	4,247
2007	3799	398	4,197
2008	2634	357	2,991
2009	1475	204	1,679
2010	2576	328	2,904
2011	1013	138	1,151
2012	691	82	773
2013	470	75	545
2014	573	81	654
2015	612	86	698
2016	548	83	631
2017	713	102	815
2018	860	111	971
2019	1095	152	1,247
2020	944	122	1,066
2021	928	129	1,057
2022	935	125	1,060
Total	**36,290**	**4,292**	**40,582**
Percentage	**89.4 %**	**10.6 %**	**100 %**

Table 3
Communalities. Extraction Method: Principal Component Analysis.

Variable	Initial	Extraction
Length of service	1.000	0.615
Accident location	1.000	0.766
Deviation that triggered the accident	1.000	0.510
Contact-Mode of injury	1.000	0.500
Part of body injured	1.000	0.502
Age of the injured worker	1.000	0.624
Material Agent of the Specific Physical Activity	1.000	0.674
Material Agent associated with the Deviation	1.000	0,615
Material Agent associated with the Contact — Mode of injury	1.000	0.704
Severity of injury	1.000	0.826
Company staff	1.000	0.763

material agent variable in any of its associations is vital for precisely establishing the causes and prior circumstances of the accident (Jacinto and Aspinwall, 2004; Rajala and Väyrynen, 2010; Jacinto et al., 2011; Palamara et al., 2011; Salguero-Caparros et al., 2015; Molinero-Ruiz et al., 2015; Jacinto et al., 2016; Salguero-Caparros et al., 2018). However, there are few published studies that have employed the material agent variable in the analysis of accidents in the construction industry, with notable exceptions being the works of López et al. (2008), Betsis et al. (2019), and Fontaneda et al. (2022).

6. Component PC2: Triggering Deviations and degree of injury

The second principal component (PC2) explained 11.522 % of the variance (see Table 4). The reported factor loadings for the variables are as follows: deviation that triggered the accident (64.2 %) and degree of injury (75.4 %) (Table 5). This component was labeled Triggering Deviations of the Accident and Degree of Injury.

The findings of the present study reveal that workers who experience accidents due to electrical failures or falls from heights, resulting from slips or trips, have a significantly higher incidence of serious and/or fatal injuries compared to other cases. In situations involving fatal accidents related to electrical issues, this incidence can be up to five times higher than would normally be expected.

Given the complex, dynamic, and challenging nature of activities performed in the construction industry, the relationship between the last anomalous event leading to the accident and its injurious consequences seems inevitable. In this regard, authors such as Kjellen (1984), Kjellén and Hovden (1993), and Jacinto et al. (2011) have argued that the

Table 4
Total variance explained and extraction of principal components.

Total variance explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of variance	% cumulative	Total	% of variance	% cumulative	Total	% of variance	% cumulative
PC1	**2.325**	**21.132**	**21.132**	**2.325**	**21.132**	**21.132**	**2.310**	**21.003**	**21.003**
PC2	**1.421**	**12.918**	**34.051**	**1.421**	**12.918**	**34.051**	**1.267**	**11.522**	**32.526**
PC3	**1.167**	**10.612**	**44.663**	**1.167**	**10.612**	**44.663**	**1.266**	**11.509**	**44.035**
PC4	**1.144**	**10.399**	**55.061**	**1.144**	**10.399**	**55.061**	**1.174**	**10.670**	**54.704**
PC5	**1.006**	**9.142**	**64.204**	**1.006**	**9.142**	**64.204**	**1.045**	**9.499**	**64.204**
PC6	0.907	8.247	72.451						
PC7	0.894	8.127	80.577						
PC8	0.742	6.746	87.324						
PC9	0.694	6.306	93.629						
PC10	0.441	4.005	97.635						
PC11	0.260	2.365	100.000						

Table 5
Rotated component matrix.

	Component PC1	PC2	PC3	PC4	PC5
Length of service	0.040	0.036	0.779	0.031	−0.062
Accident location	0.027	0.393	0.065	0.510	−0.327
Deviation that triggered the accident	−0.117	−0.642	0.087	0.237	0.103
Contact-Mode of injury	0.004	0.351	0.196	−0.502	0.310
Part of body injured	−0.001	−0.059	−0.016	0.797	0.188
Age of the injured worker	−0.045	−0.022	0.777	−0.076	0.057
Material Agent of the Specific Physical Activity	0.839	0.004	0.003	0.014	−0.005
Material Agent associated with the Deviation	0.908	0.035	0.010	−0.007	0.025
Material Agent associated with the Contact — Mode of injury	0.872	0.036	−0.020	−0.007	0.009
Severity of injury	−0.052	0.754	0.065	0.142	0.169
Company staff	0.031	0.049	−0.018	0.048	0.872
Extraction method: principal component analysisRotation method: Varimax with Kaiser normalisation					
Rotation has converged in 6 iterations					

deviation variable is crucial as it precisely establishes the prior circumstances in which the accident occurred. Similarly, studies by Molinero-Ruiz et al. (2015) and Jacinto et al. (2016) analyzed the reliability and validation of the variables used in reporting occupational accidents in both Spain and Portugal, confirming that the deviation variable ranks among the highest in terms of agreement.

Regarding the use of the harmonised deviation variable within the ESAW coding system in accident analysis, it is worth highlighting the studies published by Salguero-Caparrós et al. (2023), which identified and analyzed the deviation variable from 241 investigation reports of occupational accidents that occurred in Spain between 2009 and 2014. Additionally, research such as that by Lopez-Arquillos et al. (2012), which examined the probable causes of occupational accidents in the Spanish construction sector between 2003 and 2008, indicated that the severity of accidents was related to the triggering deviation of the accident. This aspect was corroborated more recently in the study published by Katsakiori et al. (2022), which found that falls from different levels, slips, and same-level falls accounted for the highest number of occupational deaths in the Greek construction industry from 2009 to 2017. Therefore, the analysis of this component is crucial for identifying activities in the construction industry that can lead to very serious injurious consequences.

7. Component PC3: Management of experience and age of workers

The third principal component (PC3) in Table 5 presented factor loadings for the variables: length of service in the job (77.9 %) and age of the injured worker on the day of the accident (77.7 %). This component accounts for 11.509 % of the explained variance, as shown in Table 4. After critically examining the latent characteristics of the variables, this component was labelled Experience Management and Age of Workers.

This component is straightforward to interpret, as it is linked to high levels of temporary employment and turnover across various workplaces, as well as the frequent transitions between jobs that are commonly observed in this sector, making it one of the most recognised risk factors for accidents (López et al., 2008). Additionally, a longer duration of employment within a company should imply greater training and experience, resulting in a lower probability of serious accidents. However, the misjudgement of hazards can be detrimental to this group of workers, leading them to underestimate the risks involved (Chi et al., 2013). Furthermore, studies such as those conducted by Salas et al. (2020) demonstrate that workers with more years of service exhibit a negative attitude towards safety and health, whereas those with fewer years show a markedly positive attitude.

Regarding the worker's age, as demonstrated in other studies (Suárez-Cebador et al., 2014), older workers tend to experience more severe injuries. This study provides further evidence on this issue, showing that as the worker's age increases, the severity of the injuries they sustain also tends to increase.

The results derived from the present study, which analyses accidents in the construction industry from 2003 to 2022, indicate that workers with over 10 years of experience have a higher incidence of serious or fatal accidents than expected.

Length of service and age are important factors to consider when interpreting accidents in the construction industry (Betsis et al., 2019). Nonetheless, further study and research are necessary to understand the differential roles of these two variables within the work conducted in this sector. Therefore, this component is crucial for identifying the personal characteristics that a worker involved in an accident may possess in the construction industry.

8. Component PC4: Location, Contact mechanism and injury

As shown in Table 5, the principal component (PC4) consists of:

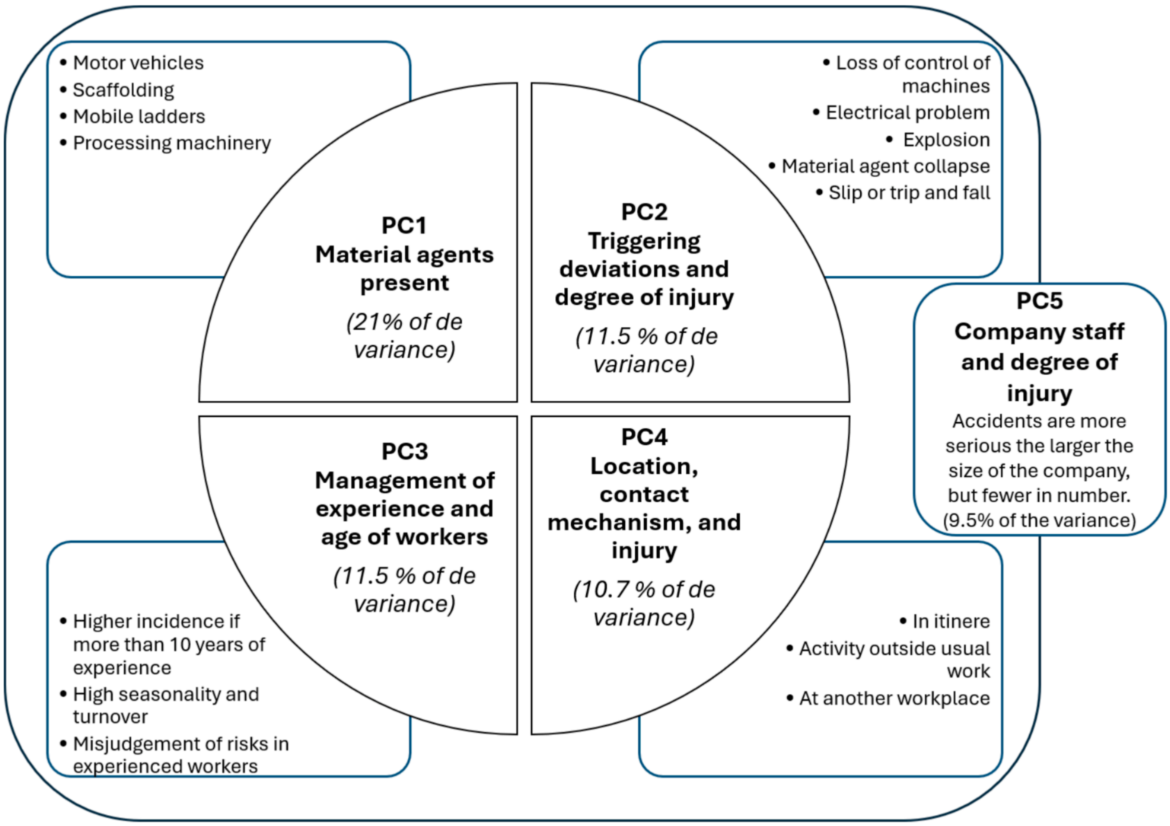

Fig. 3. Principal components extracted, % variance explained and determining factors.

accident location (51.0 %); injured body part (79.7 %); and form of contact that produced the injury (50.2 %). It was labelled Accident Location, Contact, and Injured Body Part, representing 10.670 % of the total variance (see Table 4).

Regarding the accident location variable, the work of Lopez-Arquillos et al. (2012) found that accidents occurring away from the usual workplace had more severe consequences than those occurring at the usual workplace. This result is logical, as workforce mobility is common in the construction industry. Workers often move between different construction sites or areas within a particular site. This can be due to various reasons, such as the need to perform specific tasks at different locations, the progression of the construction project, or the assignment of workers to different teams (Ayodele et al., 2020). Consequently, accidents frequently occur outside the usual workplace.

As for the variable 'Contact-Mode of Injury,' which describes the way in which the victim was injured by the material agent that caused the injury, this study shows that the predominant contact types are 'crushing against or onto an immovable object as a result of a fall,' accounting for 36.22 % of severe accidents and 23.69 % of fatal accidents. This data is consistent, given that falls from height are the most prevalent deviation in accidents in the construction sector (Salguero-Caparrós et al., 2023).

However, special attention must also be paid to 'heart attacks, strokes, and other traumatic pathologies,' since although these accounted for only 0.13 % of all accidents, they represented 20.75 % of fatal accidents and 5.14 % of severe accidents. This situation aligns with the findings of Lopez-Arquillos et al. (2012), where severe accidents represented 2.46 % and fatal accidents 17 % over a decade ago.

On the other hand, the study by Suárez-Cebador et al. (2014) analysed the severity of work accidents related to electricity in the Spanish construction sector, comprising 2,776 accidents between 2003 and 2008. This research examined the significant statistical association between accident location and severity, as well as the relationship between injured body part and accident severity. Accidents at the usual workplace were predominant, with hands and eyes being the most frequently injured body parts. Continuing with the injured body part variable, studies such as that by Fontaneda et al. (2022) showed that injuries to the upper limbs accounted for 33.8 % and injuries to the lower limbs for 28.4 % of the total injuries sustained in the construction industry.

Although no studies have been identified that relate accident location to injured body parts, this remains an intriguing area for further research. Exploring the relationship between accident location and the resulting injuries could provide valuable insights for accident prevention and safety improvements in various environments.

9. Component PC5: Company staff and degree of injury

The last component, PC5, accounted for 9.499 % of the total explained variance (see Table 4) and is comprised of the variable: Workforce size at the centre where the injured worker is affiliated (87.2 %) (Table 5). It was labelled Company Staff.

The analysis of workplace size where accidents occur in the construction industry in Spain (2003–2022) reveals that most accidents happen in smaller workplaces. In this regard, based on the definition provided by the European Commission (2003), small and medium-sized enterprises (SMEs) are defined as companies with fewer than 250 employees, encompassing microenterprises (0–9 employees), small enterprises (10–49 employees), and medium-sized enterprises (50–249 employees).

The results of the present study have shown that workers in microenterprises account for 40.71 % of all serious and fatal accidents, while those in small enterprises account for 39.94 %, and those in medium-sized enterprises account for 16.49 %. In contrast, large companies with more than 250 employees report only 2.94 % of all serious and fatal accidents. These data are highly consistent with findings from López et al. (2008) and Fontaneda et al. (2022), both of which focused on the construction industry in Spain. Such results may be expected, given that the total number of companies in each category gradually decreases as company size increases, along with the number of recorded accidents.

However, statistical analysis reveals that as a company increases in size, there is a proportional increase in serious and fatal accidents, contradicting the expectation of a safer environment. This finding supports the assertion made by Lopez-Arquillos et al. (2012) that a large company is not necessarily safer than a small one regarding fatal accidents. This phenomenon is notable despite large companies having considerable resources, both material and human, which should facilitate more efficient management of health and safety and legal compliance (Segarra et al., 2017). It is also important to acknowledge that small and medium-sized enterprises (SMEs) are the predominant type of company in the construction sector, both in terms of the number of companies and the occurrence of problems related to occupational health and safety (Fan et al., 2020).

10. Conclusions

The number and severity of injuries position the construction industry as one of the most dangerous sectors globally. Numerous investigations into occupational accidents have focused on this industry with a common goal: reducing accident rates in the sector. Determining the origins and consequences of accidents, and attempting to predict their causes, is inherently challenging. Despite advancements in management systems, the construction industry remains highly complex compared to other sectors. This complexity arises mainly from the numerous variables involved in each situation, further complicating the task.

This scenario makes reducing occupational accidents and their severe consequences one of the greatest challenges in the work environment, placing significant responsibility on all parties involved. Although progress continues to be made, the high accident rates of recent years necessitate sustained efforts and new research to provide useful information aimed at reducing accidents and limiting their consequences, especially in severe and fatal cases.

In this regard, this research has identified a set of factors that can be considered precursors to occupational accidents in the construction industry in Spain. The Principal Component Analysis (PCA) conducted was able to explain 64.2 % of the total variance based on 40,582 serious and fatal accidents that occurred in this sector over the last two decades, from 2003 to 2022. The robustness tests applied to both the data used and the results obtained were satisfactory.

The results obtained group a set of variables that could influence the occurrence of occupational accidents into five principal components, highlighting the following: the importance of controlling certain present material agents, such as motor vehicles, scaffolding, or mobile ladders; the impact that the triggering deviation of the accident has on the degree of injury produced (loss of control of machines, electrical problems, slips or trips and falls, or explosions); the effect that workers' experience and age have on accident rates; the relationship between the accident location, the contact produced, and the injured body part (in itinere, activity outside usual work, or another workplace); and company size, where it is notable that accidents are more severe in large companies, although they occur relatively less frequently than in smaller companies.

These results do not exclude other circumstances that should be considered in occupational safety strategies and policies. Nevertheless, they represent progress in identifying precursor factors for serious and fatal occupational accidents in the construction sector. This research focuses on those factors that, independently or in combination with others within each subgroup, have a greater incidence of serious and fatal accidents compared to other elements that may also contribute to such incidents. Thus, the results obtained allow for the targeting and directing of efforts and the development of more effective strategies to reduce serious and fatal accidents in this sector by addressing areas that require priority intervention.

Moreover, this research can serve as a starting point for future studies that address each principal component detailed in the PCA more specifically. Similarly, the proposed methodology can be applied to the study of occupational accidents in other sectors or even in disaggregated sections within the construction industry.

11. limitations

When interpreting the conclusions of this study, it is important to consider some inherent limitations. First, as with any study based on administrative records, the Delt@ reports used as the data source may contain inaccuracies in their completion. However, given the large number of cases analyzed, it is reasonable to assume that this potential issue has been minimized. Additionally, although reports on severe and fatal accidents are typically more accurately documented, we cannot be entirely certain that each incident occurred exactly as described in the report.

Second, there is a limitation related to the data source itself. While the analysis includes all recorded accidents in the construction sector in Spain between 2003 and 2022, it is possible that some incidents were not officially reported.

Third, the study focuses exclusively on the Spanish context, meaning that the 40,582 cases analyzed may not be fully generalizable to other European countries or different regions worldwide.

Finally, an alternative approach could have been to disaggregate the results for severe and fatal accidents, as the underlying contributing factors may differ between these two categories. This would have allowed for the development of two distinct models with separate principal component analyses (PCA), potentially yielding more precise and detailed findings.

CRediT authorship contribution statement

C. de las Heras-Rosas: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Data curation, Conceptualization. **M. Suárez-Cebador:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Data curation, Conceptualization. **F. Salguero-Caparrós:** Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Data curation, Conceptualization. **J.C. Rubio-Romero:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Investigation, Formal analysis.

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.

Acknowledgments

We acknowledge the support of the Ministry of Economic Affairs and Digital Transformation of the Government of Spain through the project "Complexity and resilience: a systemic approach for the monitoring and improvement of safety management in construction" with the code number PID2020-114502 GB-I00

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