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Meta-Analysis of Studies on Accident Contributing Factors in the Greek Construction Industry

Fani Antoniou [1,*] and Nektaria Filitsa Agrafioti [2]

[1] Department of Environmental Engineering, International Hellenic University, 57001 Thessaloniki, Greece
[2] School of Science and Technology, Hellenic Open University, Parodos Aristotelous 18, 26335 Patra, Greece
* Correspondence: fanton@ihu.gr

Abstract: Occupational accidents, especially in the construction sector, are a worldwide phenomenon. There is a large and important collection of repeated studies at an international level, which has identified and categorized construction accident contributing factors in different countries individually. This paper is a quantitative meta-analysis of data from existing research that identifies and ranks a comprehensive list of the main factors contributing to occupational accidents in the construction sector in Greece. The methodology includes: (i) the identification of common factors through a systematic literature review and content analysis (ii) the categorization and development of a comprehensive accident factor breakdown structure and (iii) the evaluation of the importance of the common factors through statistical meta-analysis by calculating the overall ranking index (ORI). The results indicated that six out of the top ten contributing factors to construction site accidents are from the Occupational Risks category, only one from each of the Safety Culture, Worker Training Deficiencies, and Safety Equipment/Measures categories. The amalgamated insights of 25 Greek scientific studies are certain to be used to shape safety management processes by construction companies, clients, and safety policy decision makers.

Keywords: accident factors; construction; risks; overall ranking index; accident causation; health and safety; meta-analysis; hazards

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1. Introduction

Ensuring health and safety (H&S) in construction projects is important during the construction and execution of any project. An industrial accident that occurs during the construction of a project has an impact on all parties involved in the project and generates human, social, and economic costs. Furthermore, these negative effects may also lead to delays in the completion of the construction of the project and deficiency in its quality [1].

The factors leading to occupational accidents are many and vary considerably from one project to another and from one country to another [2]. Particularly, in the construction of civil engineering projects, it is demonstrated that accidents constitute a high percentage of all accidents compared to other economic sectors. In fact, 60,000 fatal workplace accidents are recorded annually worldwide [3].

A significant number of studies have been carried out in previous years on the identification and classification of hazards and factors and/or causes leading to occupational accidents. The countries in which these surveys have been carried out, the type of project (e.g., building, infrastructure, road construction, general construction, etc.), and the methodologies used to analyze them differ in each case.

Through a systematic search in master's and doctoral thesis repositories, 262 Greek research efforts (published or not) were found over the last 20 years, aiming to identify risks, factors, and/or causes contributing to accidents in the construction sector. Despite the abundance of individual studies, none have been identified that aim to summarize and evaluate the findings quantitatively and systematically.

The existing research can be classified into two categories. The first category refers to those that aim to identify and determine the importance of factors causing occupational accidents in Greece [2,4,5]. These were mainly conducted using data from questionnaires or existing accident statistics from construction accidents for data collection. The second category consists of various risk analysis models developed for the analysis of occupational accident causation in the construction workplace in Greece, usually by making use of case studies [6,7]. This research focuses on the first category of studies.

Regardless of the abundance of individual research efforts, it has not been possible to obtain an overall picture and draw safe conclusions because each study is treated individually and presents different findings based on data derived from different sources and with varying sample sizes. In addition, the lack of a common accident factor breakdown structure (AFBS) for classifying accident hazards and factors, which can allow easy comparison of results, has not been identified [2]. One thing that these studies had in common is that they ranked the hazards and factors according to their level of importance. It is, therefore, posited by this research team that the issue has achieved appropriate maturity for meta-analysis of results.

Meta-analysis is a powerful statistical approach that refers to the quantitative synthesis of findings of individual studies by calculating and summarizing their individual results [8,9]. According to Borenstein et al. [10], meta-analysis enables the possibility of using the results of the systematic review of each existing individual survey separately, with different and contradictory results, to evaluate the accuracy of their assessment and draw safe conclusions, especially when the number of participants in each survey is small.

Glass [8] coined the phrase meta-analysis and described its basic features and steps, arguing that new methods of discovering knowledge of findings or results of individual research are needed when there is evidence of the maturity of research efforts. Shadish and Lecy [11] state that meta-analysis has been used in many scientific fields and was the so-called "post-analytic big bang" that occurred in the 1970s. A meta-analysis results in an overall study calculating an aggregate result with greater precision and validity than any individual study separately [10].

Individual studies in the construction industry, looking to rank a set of factors for various risks (delays, cost-overruns, accidents, project success), project managers' characteristics, barriers, or causes of claims, use a plethora of ranking methods. These include the relative importance index (RII) [2,12–15], basic descriptive statistics, i.e., mean, frequency, etc. [2,16,17], correlation analysis [18], factor analysis [19–21], risk priority number (RPN), i.e., the probability multiplied by the severity index [15,22] and fuzzy RPN [23]. Other studies employ various multi-criteria decision-making (MCDM) methods such as the Analytical Hierarchy Process (AHP) [24,25], the Technique for Order Preference by Similarity to Ideal Situation (TOPSIS) [15,26], the Preference Ranking Organization METHod for Enriched Evaluation (PROMETHEE) [27] and recently, the Best Worst Method (BWM) [28]. When numerous similar studies provide such lists of factors and their rankings, the issue is deemed to have achieved appropriate maturity for meta-analysis to synthesize and generalize their individual results.

Meta-analyses in the construction industry are well known and have been applied to unify results from research around the world on numerous topics. An indicative literature review showed the use of meta-analysis techniques for the investigation of global construction delay factors [29,30] factors affecting contractor's decision to bid [31], factors affecting a specific construction site hazard, e.g., fall from height [32,33], general psychosocial factors for safety performance [34], factors affecting accident prevention communications [35], and factors promoting a safety climate in construction companies [36].

The only studies found that employed meta-analysis to determine accident contributing factors were for the country-specific environment of Ethiopia [35,37,38]. Alamneh et al. [37], in their study for Addis Ababa, Ethiopia, included 23 surveys in their statistical meta-analysis. Their results defined the following as critical accident factors in construction: (i) lack of occupational H&S education (ii) lack of personal protective equipment (PPE)

(iii) absence of worker supervision and (iv) workers working more than eight hours per day. Additionally, the statistical meta-analysis by Ashuro et al. [38], again for the Ethiopian capital Addis Ababa and Oromia region, that analyzed 10 studies indicated that the critical factors that occurred were lack of job safety training and non-use of PPE. In their study, Meseret et al. [35], included 12 surveys in their statistical meta-analysis, conducted from 2004 to 2018. They identified factors causing occupational accidents in the construction industry in Ethiopia from the original 1241 surveys they extracted by systematic review. Their results indicated that the use of PPE, occupational safety training, and regular supervision was significantly associated with the prevention of occupational accidents among construction workers.

The aim of this study is the quantitative analysis of data from existing studies, intending to crystalize the main accident hazards and factors in the construction sector in Greece by synthesizing the results of multiple similar studies. In Section 2 an overview description of the methodology to be employed is presented followed by Section 3 which contains the results of the systematic literature review and content analysis necessary for the determination of the 25 studies and 62 accident factors to be incorporated in the meta-analysis. Section 4 describes in detail the development of a national accident factor breakdown structure (AFBS) and the method applied for meta-analysis of the top ten accident factors from each of the studies the results of which are discussed in Section 5. Finally, the conclusions section summarizes the findings of the current meta-analysis, its limitations, and the proposals for future research.

2. Methodology

The methodology employed includes the following stages: (a) formulation of a research question (b) systematic literature review (SLR) to identify relevant published and unpublished studies; (c) systematic content analysis of relevant studies and selection of studies for meta-analysis; (d) recording, categorizing, and creating an AFBS; (e) statistical meta-analysis of the data; (f) presentation and interpretation of the results.

Having discovered the plethora of studies carried out in Greece regarding the determination of accident factors in the construction industry, the research questions were formulated.

Q1. *Can the accident factors found by researchers in Greece be unified in an AFBS?*

Q2. *What are the critical factors that lead to accidents in the Greek construction sector?*

To proceed, an SLR was initially conducted, according to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines by Moher et al. [39] as described in detail in Section 3.1. A total of 262 sources were identified after searching relevant databases. These sources included peer-reviewed articles, conference proceedings, doctoral theses, and postgraduate dissertations by Greek and foreign researchers, as well as a few reports from relevant construction industry bodies such as the Hellenic Institute for Occupational H&S (ELINYAEE) and the Technical Chamber of Greece (TEE), for the period 2001 to 2021. After an initial screening phase, the remaining 165 underwent a full-text evaluation and content analysis, described in Sections 3.2 and 3.3, based on specific inclusion criteria from which 25 studies were selected for meta-analysis. Of the 25 surveys, 16 derived their data from questionnaires while 9 were from the statistics of actual accidents at construction sites.

Next, the process of recording, categorizing, and creating the AFBS of the list of contributing factors to construction accidents was carried out to enable the statistical meta-analysis that followed which is described in Section 4.1. The method applied for the statistical meta-analysis performed to identify and rank the main contributing factors was the overall ranking index (ORI) [30], which considers their ranking position in each study. The justification for employing this method and its mathematical formulation, along with an example calculation, is presented in Section 4.2

This quantitative analysis synthesizes knowledge from multiple scientific researchers that will lead to the improvement of the current situation through the adoption of measures to help prevent construction site accidents by making stakeholders aware of the most common accident-contributing factors that can cause accidents in the Greek construction industry.

3. Systematic Literature Review and Content Analysis

3.1. Search for Relevant Studies

When planning and conducting the implementation of a meta-analysis, there is a need to address the risk of bias in the selection of relevant studies for data extraction and meta-analysis [40]. The widely accepted guidelines of the PRISMA method were followed for the selection of relevant studies executed in the last 20 years [39]. Figure 1 shows the adapted PRISMA flowchart of the SLR process for the screening and selection of the relevant studies, which was conducted in four stages (identification, screening, eligibility, and inclusion).

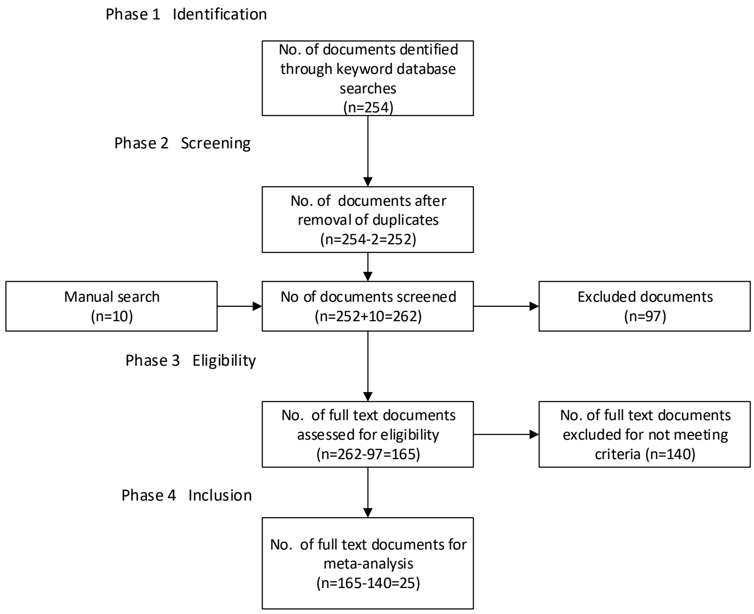

Figure 1. PRISMA flowchart for screening and selecting research documents.

In the first identification stage, a keyword search for peer-reviewed articles, conference proceedings, doctoral theses, and postgraduate dissertations by Greek and foreign researchers, for the period 2001 to 2021, was carried out. The selection of keywords was made by brainstorming while considering the research field (construction sector), scope (accidents, risks) and questions (ranking of accident factors) and their possible synonyms in both English (for the Scopus database) and in Greek (for the Greek academic repositories). Finally, the resulting studies were derived from multiple searches using various combinations of the chosen keywords as follows:

- Occupational accidents/Accidents at work.
- Construction sector /Construction industry/Construction sites.
- Building/Infrastructure/Technical projects.
- Occupational H&S.
- Accident factors/Accident-causing factors.
- Risk/Hazard.
- Risk Analysis/Risk Evaluation.
- Risk Assessment.

Specifically, a search was conducted in the Scopus (Elsevier) bibliographic database for the retrieval of scientific articles from international electronic journals of major publishers since it has been documented that Scopus covers a broader range of journals related to the engineering discipline and provides assistance in keyword searches and citation analysis [36], than Web of Science (WOS). Other studies have compared WOS with Scopus and found that Scopus has a more significant number of indexed publications and is more user-friendly [41].

The next step was to investigate the doctoral theses of Greek researchers, which were conducted at Greek universities, by obtaining data from the National Archive of Doctoral Theses (EADD), which is established, maintained, and made available by the National Documentation Center (https://www.ekt.gr, accessed on 1 June 2022). In addition, the Single Catalogue of the Collaborative Network of Academic Libraries "MITOS" and the academic repositories of the Greek universities through their websites were used to search for other postgraduate theses and dissertations.

First, 254 studies were identified, the details of which (authors, year, title, abstract, and source) were recorded in the initial MS Excel database manually. This led to the removal of two duplicates. Next, a manual search was conducted to minimize potential bias in case relevant studies may have been dropped from the first search [42]. For this reason, reference lists of included articles led to a required search in the publications and conference proceedings of the ELINYAEE and the TEE. This search returned a further 10 publications added to the 252 studies, resulting in 262 in total.

The main source of these documents was the Hellenic Open University master theses repository, which produced 156 of these studies. This was expected because it offers the only postgraduate master's program in Greece with a focus exclusively on Construction Project Management and includes a major module regarding safety in construction. Other university repositories that provided multiple relevant studies were the Aristotle University of Thessaloniki (8), the University of Patras (5), the National Technical University of Athens (3), Piraeus University of Applied Sciences (3) and the University of West Macedonia (2), while five relevant studies were published by ELINYAEE. With respect to international scientific journals, the International Journal of Occupational Safety and Ergonomics provided 18 studies, followed by Safety Science with 13, and the Journal of Safety Research and MDPI/Sustainability with 4 and 3 contributions, respectively. Additionally, the following journals returned 2 relevant studies each: Accidents Analysis & Prevention, Construction Management and Economics, International Journal of Injury Control and Safety Promotion, and Journal of Loss Prevention in the Process. Finally, the remaining 34 studies were found in 34 different sources, i.e., four additional university repositories, the TEE, and 29 journals or conference proceedings.

The above 262 studies underwent the initial screening phase based only on their title and abstract. During this phase, 97 were rejected because they were not relevant to the topic under study. The remaining 165 studies were subjected to a full-text evaluation and content analysis as described in Section 3.2 to determine eligibility.

3.2. Content Analysis

A systematic manual content analysis was performed by which for each study in the initial MS Excel database the research aim, data source, methodology, method of statistical analysis, method of risk analysis, type of projects, and category of respondents were recorded. The remaining 165 studies that passed the eligibility phase were analyzed statistically to conclude the selection of studies for inclusion in the meta-analysis.

Out of the total of 165 studies selected in the screening phase, eighty-one (81) papers aimed at the identification of factors/causes and/or hazards that cause occupational accidents in the construction sector, and eighty-four (84) the assessment of risks in the construction workplace. It is noted that the trend in the scientific community's involvement is at approximately the same level for both of these research objectives. The analysis showed that the most popular source of data used by researchers is existing statistical data (45%) followed by questionnaires (26%), case studies (23%), and 6.0% using empirical qualitative research or a combination of two data sources. One of the two main analytical methodologies used by researchers to draw conclusions is the statistical analysis of the collected data at 40.61% (67 studies), of which 47.88% use descriptive statistical analysis.

Tools/techniques for risk assessment analysis in a construction site is the other main methodology at 52.12% (86 studies), of which 26.67% prefer to use a combination of risk assessment techniques, 10 of which chose to use MCDM methods.

3.3. Selection of Studies for Meta-Analysis

The comprehensive MS Excel database that was developed included all sources in rows and the following columns: Authors/Year, Research Aim, Data Source, Methodology, Method of Statistical Analysis, Method of Risk Analysis, Type of Projects, Category of Respondents in case of questionnaires, Safety and/or Health, Journal or University, and Abstract. This allowed a comprehensive review of the studies to identify the dominant research aims, methods of statistical analysis, and project type. Twenty-five (25) studies were selected for investigation based on the following inclusion criteria:

- Studies focusing on occupational accidents rather than health hazards in construction sites in Greece.
- Studies focusing on determining and evaluating factors that cause construction accidents but not studies focusing on risk analysis methods.
- Studies referring to building and/or infrastructure projects.
- Studies using a questionnaire or existing statistics from construction accidents as a data source and not case studies.
- Studies creating a ranked list of factors in terms of importance or frequency of occurrence.
- No restriction on the year of publication or type of publication.

The first two inclusion criteria were chosen based on the research questions that focus on finding, classifying, and evaluating Greek construction site accident factors. Studies dealing with building and or infrastructure projects were included to keep the focus on pure civil engineering projects. The last two inclusion criteria were chosen in order to determine which studies provide results that rank a list of factors in order to be able to apply the ORI method.

After the application of the above inclusion criteria, 25 studies emerged for meta-analysis. Sixteen of these studies derived their data from questionnaire surveys, while nine were from real accident statistical data. Table 1 presents the 25 studies including the data source, the ranking method employed, and the number of participants for questionnaire surveys or the number of accidents for statistical data.

Table 1. Content analysis of studies selected for meta-analysis.

First Author	Study Code	Year	Data Source	No. of Participants/ Accidents	No. of Factors	Ranking Method
Antoniou [2]	S1	2021	Questionnaires	102	104	RII
Kokkini [43]	S2	2020	Questionnaires	149	28	mean/Frequency/ St. Dev
Papadatou [44]	S3	2021	Questionnaires	65	22	Frequency
Ritsa [45]	S4	2019	Questionnaires	46	21	Frequency
Tsianas [46]	S5	2020	Questionnaires	131	37	Frequency
Kapellakis [47]	S6	2020	Questionnaires	89	19	Frequency
Kotsalos [48]	S7	2020	Questionnaires	141	29	Frequency
Touloupi [49]	S8	2020	Questionnaires	130	20	Frequency
Pantos [50]	S9	2019	Questionnaires	82	20	Frequency
Marazioti [51]	S10	2019	Questionnaires	57	42	Frequency
Pigounaki [52]	S11	2018	Questionnaires	70	19	Frequency
Theodorakopoulos [53]	S12	2016	Questionnaires	25	25	RII
Alamanos [54]	S13	2017	Questionnaires	55	135	mean/Frequency/ St. Dev.
Papastathakis [55]	S14	2016	Questionnaires	60	26	Frequency
Charitonidou [56]	S15	2015	Questionnaires	56	33	Frequency
Tzegkas [57]	S16	2010	Questionnaires	50	40	Frequency
Koulinas [58]	S17	2017	Accident data	169,381	10	AHP
Bougelis [59]	S18	2021	Accident data	149	8	DMRA/FAHP/FTOPSIS
Vroudas [60]	S19	2016	Accident data	11,171	8	PRAT/TSP
Fekos [61]	S20	2018	Accident data	41,081	8	PRAT/FTA
Panagiotopoulos [62]	S21	2020	Accident data	13,776	8	PRAT/TSP
Betsis [4]	S22	2019	Accident data	413	13	Frequency
Katsolas [63]	S23	2018	Accident data	2615	8	Frequency

Table 1. *Cont.*

First Author	Study Code	Year	Data Source	No. of Participants/ Accidents	No. of Factors	Ranking Method
Mylona [64]	S24	2019	Accident data	137	11	Frequency
Katsakiori [5]	S25	2008	Accident data	3332	6	Frequency

RII = Relative Importance Index, AHP-Analytical Hierarchy Process, DMRA= Decision Matrix Risk-Assessment technique, FAHP= Fuzzy Extended AHP, FTOPSIS = Fuzzy TOPSIS, PRAT = Proportional Quantitative Risk Assessment Technique, TSP = Time-series Stochastic Process, FTA = Fault Tree Analysis.

4. Data Meta-Analysis

4.1. Accident Factor Break down Structure

The majority of researchers internationally identify accident hazards or factors from literature reviews and then proceed to categorize and rank them in various ways. The number of factors each researcher utilizes and analyses also varies. The development of a unified classification of factors contributing to workplace accidents and the creation of a common codification can provide a basis for comparing the results of international research and facilitating the application of meta-analysis techniques [2]. The total number of factors examined in these studies ranged from 6 to 135 as shown in Table 1.

The data selection process followed for the determination of the accident factors to be coded and analyzed is shown in Figure 2. After the initial collection and production of an accident factor table with 702 factors (rows) and 25 studies (columns), the removal of factors with the same name, and the grouping of others with similar meanings, were consolidated to obtain a master list of 284 factors. The frequencies of appearance of each factor in the 25 studies range between 1 to 15. Finally, those factors appearing at least once in the top ten ranks were selected for statistical meta-analysis.

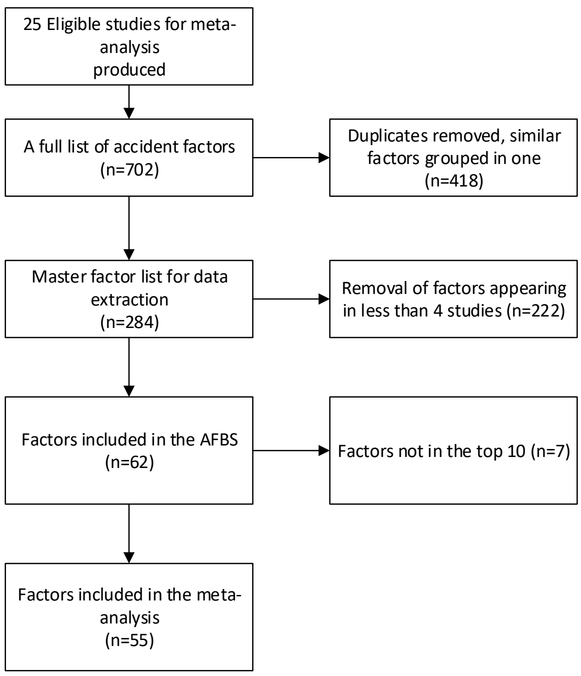

Figure 2. The data extraction process for selecting factors to be included in the meta-analysis.

As for all risks, accident factors should be coded and structured to provide a standard presentation that can improve understanding, communication, and management on a project and industry level. Defining risk sources in such a hierarchical structure is referred to as a risk breakdown structure [65]. As a result, 62 factors were coded and arranged in the AFBS shown in Figure 3. It provides a comprehensive yet detailed view of the hierarchy of the predominant accident factors that emerged based on their frequency of occurrence in the 25 studies.

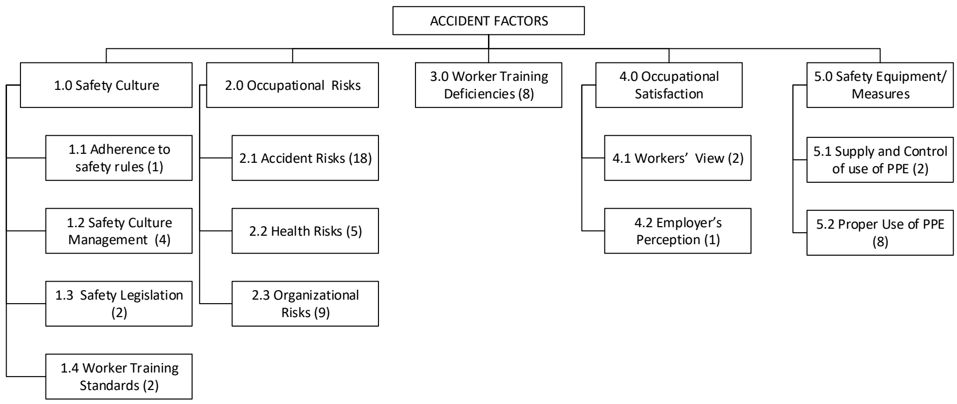

Figure 3. Accident Factor Breakdown Structure (no. of factors in each category).

The four first main categories were defined by adapting the sections from Alamanos' [54] questionnaire survey that provided the most factors (Table 1). In fact, Alamanos based the choice of factors in the category 2.0 Occupational Hazards on the classification provided by the ELINYAEE guidelines for methodological assessment and prevention of occupational risks [66]. The next stage was to correspond all factors from the other studies to the initial list of factors and to add any additional factors found. This led to the renaming of category 1.0 from "Occupational Health and Safety" to "Safety Culture" to better describe factors included in this category, such as 1.2.2 Competitive advantage of the organization, 1.2.3 Deficient organization's commitment to safety, 1.2.4 Lack of occupational risk management, 1.3.2 Inadequate supervision of the implementation of legislation, 1.4.1 Inadequate training of workers, etc. Finally, since eleven out of the 25 studies included factors related to the lack of proper use of PPE, both in general and per specific type of PPE, it was decided to add a fifth category, 5.0 Supply, and Control of Use of PPE. According to the AFBS, the 62 factors were classified into 5 categories and 11 sub-categories, as shown in Figure 3. The full list of factors is included in Table 2.

The first category, 1.0 Safety Culture, consists of 9 factors relating to the degree of compliance with H&S rules and compliance with applicable legislation, as well as the corporate culture. Ensuring H&S in the construction site workplace is the obligation of all those involved in the workplace (organization, engineers, employees), because the probability of the occurrence of risks is undoubtedly high, making compliance with the necessary H&S measures a key priority.

The second category, 2.0 Occupational Risks, contains 32 hazards and is comprised of 3 major sub-categories, i.e., Accident Risks, Health Risks, and Organizational Risks. Eighteen 18 factors are included in the first sub-category, Accident Risks, and relate to the potential for injury to workers as a consequence of exposure to the source of the hazard [67]. Sub-category 2.2 Health Risks includes the possibility of workers' exposure to agents in the working environment resulting in occupational disease in workers. They are due to the possible exceedance of exposure limits to chemical agents (ingestion, skin contact or inhalation of chemicals, dust, gas leakage, etc.), physical agents (noise, microclimate, vibration, shocks, etc.) and the presence of biological/harmful pollutants and germs [66,67]. The last sub-category 2.3 Organizational Risks includes the risks that are characterized by the interaction of the relationship between workers and the work organization. The causes of these risks can be traced back to the organization of the construction phases. These risks are usually due to the planning and organization of work on the construction site (e.g., the inappropriate layout of premises, etc.), psychological factors (work stress, time pressure, time pressure, moral harassment, shift work, night work, intensification, physical and/or mental strain, etc.), ergonomic factors (e.g., confused communication or role conflict, etc.) and inappropriate/adverse working conditions.

Table 2. Top 10 factor rankings, frequency of occurrence in top 10, and ORI value per factor.

AFBS Code	Factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19a	S19b	S20	S21a	S21b	S22	S23	S24	S25	F	ORI
1.0	Safety Culture																													
1.1	Adherence to Safety Rules																													
1.1.1	Non-compliance with safety rules	5				8	6		8	9	4		2	2	4		6												10	0.887
1.2	Safety Culture Management																													
1.2.1	Lack of implementation of safety measures	6			1				2		5			1											7				6	0.669
1.2.2	The competitive advantage of the organization								7		8			5															3	0.052
1.2.3	Deficient organization’s commitment to safety										3		9	4															3	0.077
1.2.4	Lack of occupational risk management					10					7		3	3															4	0.135
1.3	Safety Legislation																													
1.3.1	Violation of existing legislation	1	1									10																	3	0.233
1.3.2	Inadequate supervision of the implementation of legislation				2						6				2														3	0.130
1.4	Worker Training Standards																													
1.4.1	Inadequate training of workers					6						3	6												1		2		5	0.401
1.4.2	Deficient work experience of workers																													
2.0	Occupational Risks																													
2.1	Accident Risks																													
2.1.1	Unsafe working conditions									10		7	2			8	3												5	0.222
2.1.2	Shortcomings in building structures																9	5											2	0.023
2.1.3	Environmental conditions of the workplace																								5		5		2	0.03
2.1.4	Falling or ejection of objects	4			7			6					5		7	10	4	2	2						8			4	11	1.070
2.1.5	Crushing or catching between or within objects																	4							9			3	3	0.077
2.1.6	Falling or slipping			6	6			3							7	9	3	2	4	1	1	1	1	2	2	1		1	15	4.308
2.1.7	Inadequate safety signage																													
2.1.8	Collision—Poor handling—Tipping of machinery or vehicles	7		5	10			2					4			7	2								4	5			9	0.762
2.1.9	Safety deficiencies of machinery/equipment							10												3	4	3	4	5	6	2			8	0.632
2.1.10	Poor quality of mechanical equipment/tools																													
2.1.11	Shortcomings in the safety of installations																													
2.1.12	Use and movement of hazardous substances	3													8														2	0.034
2.1.13	Electrical installation/electrocution hazards	10		9	9													5	8	7	6	5	7	7		4		2	12	0.974
2.1.14	Fires and explosions												8							6	7	6	6	6		6			7	0.285
2.1.15	Breakage, slipping, falling, material agent																			4	5	4	3	4					5	0.238
2.1.16	Overflow, overturning, spillage, leakage, flow, evaporation, emission																			5	3	8	8	8		8			6	0.23
2.1.17	Unforeseen events																										6		1	0.006
2.1.18	Other factors																			2	2	2	2	3		3	4	5	8	0.923
2.2	Health Risks																													
2.2.1	Level of exposure to occupational disease hazards					7				7					10													6	4	0.082
2.2.2	Chemical factors															8													1	0.005
2.2.3	Physical factors																9												1	0.004
2.2.4	Noise		9	10																									2	0.016
2.2.5	Biological factors		9															3											2	0.033
2.3	Organizational Risks																													
2.3.1	Work scheduling deficiencies				10												2												2	0.044
2.3.2	Unfavorable psychological factors			3							10				5														3	0.07
2.3.3	Exhausting work		7	7					1			8	1			7													6	0.567
2.3.4	Physical or mental stress		4													6	10	8		8	8	7	5	1	10	7	3		12	1.249
2.3.5	Ergonomic factors																													
2.3.6	Confusion in communication	2	3										7																3	0.108
2.3.7	Mental capacity, Bad Habits																										1		1	0.037
2.3.8	Stressful working conditions														8		7												2	0.020
2.3.9	Exposure to extreme weather conditions	8	5															10							3				4	0.112
3.0	Worker Training Deficiencies																													
3.1	Level of training				6		7	9	4	4			7	7	3		8												9	0.555
3.2	Training at the working position		3						5			5		10	5														5	0.062
3.3	Training at the workplace											9		8	6	1													4	0.208
3.4	Training or information from agencies																													
3.5	Training in prevention measures					4	9	3						10															4	0.118
3.6	Training for emergency needs						10							10															2	0.015
3.7	Need for training in new measures		8			5			9	6					9														5	0.132
3.8	Training in safety regulations					1	2			3	1			6		3	1												7	1.123
4.0	Occupational Satisfaction																													
4.1	Workers’ View																													
4.1.1	Incompetence—lack of qualifications of employees							5	6							2													3	0.096
4.1.2	Degree of worker satisfaction with safety conditions						5	3	10	8	9			9															6	0.218
4.2	Employer’s Perception																													
4.2.1	Satisfaction with workers’ job performance								3		2																		2	0.062

Table 2. *Cont.*

AFBS Code	Factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19a	S19b	S20	S21a	S21b	S22	S23	S24	S25	F	ORI
5.0	Safety Equipment/Measures																													
5.1	Supply and Control of the use of PPE																													
5.1.1	Frequency of provision of appropriate PPE				7	2		4							1	4													5	0.397
5.1.2	Check for the correct use of PPE	9	6			3				4		4																	5	0.206
5.2	Proper Use of PPE																													
5.2.1	PPE in general																													
5.2.2	Helmet			2	3	9	4			2		1																	6	0.599
5.2.3	Mask			4		5																							2	0.033
5.2.4	Earplugs							9																					1	0.004
5.2.5	Special footwear		2	1	4		1	1		1							3												7	1.318
5.2.6	Work uniforms											6					10												2	0.020
5.2.7	Glasses			8			8																						2	0.019
5.2.8	Gloves		10	1	8		3	5				2																	6	0.502

The third category, 3.0 Worker Training Deficiencies, includes 8 factors that examine the degree of employee training. According to Choudhry et al. [68], safety in construction is ensured by the appropriate information, education, and training of all site workers (engineers, workers, etc.). Training is a main and critical factor for the H&S of construction site workers, which contributes to the formation of an H&S culture in the performance of workers' duties. The implementation of training and qualification programs should meet the immediate and future needs of workers and organizations. The processes of successful training instruction of employees on H&S issues are not always easy; it requires proper implementation planning and the selection of the appropriate training method (on-the-job training and participation in seminars and workshops outside the workplace in cooperation with various official bodies) as well as the active participation of employees [68].

In the fourth category, 4.0 Occupational Satisfaction, there are 3 factors aimed at examining the perception of construction workers on the degree of correlation between the implementation of H&S measures and their satisfaction and performance. Proper H&S measures combined with continuous information and training contribute to the prevention, control, and/or elimination of risks and improve the job satisfaction and performance of workers. Job satisfaction and performance are directly linked to adherence to H&S measures and the reduction of occupational accident rates [69,70].

The last category, 5.0 Safety Equipment/Measures, concerns 10 factors related to the provision and control of the frequency and proper use of PPE. In the workplace of the construction sector, it is imperative to provide and inform about the use of PPE (e.g., helmets, gloves, earplugs, special footwear, etc.). H&S on construction sites involves a range of actions, including training workers in the use of PPE. Systematic training and proper use of PPE protect workers from a variety of hazards and should be provided to workers according to the type of work they do [71].

4.2. Meta-Analysis of Data Using the Overall Ranking Index (ORI)

Many methods are available for ranking construction site accident factors that depend on the researcher's fields of knowledge and interest as well as the source of the data analyzed. When carrying out a meta-analysis, the results of similar studies can be synthesized qualitatively and quantitatively. Both methods have been implemented for meta-analyses in the construction industry. The qualitative methods entail linguistic descriptions of the similarities and differences between studies, sometimes based on simple bar graphs, pie charts, or tabular verbal presentations. For example, Nadhim et al. [32] and Hu et al. [33] conducted meta-analyses to determine the prevalent factors causing falls from height accidents. The first research team compared the results of 75 studies based on the frequency of the appearance of each factor. At the same time, the latter proceeded to codify the heterogeneous methods used in the studies they meta-analyzed. Similarly, Musarat et al. [72] applied descriptive qualitative comparisons of results to draw conclusions from 19 studies regarding the impact of various communication methods on on-site accident prevention. Another descriptive meta-analysis was employed to compare and synthesize results from 16 studies to determine a safety climate factor model [36].

Three different quantitative methods for meta-analysis were found in the literature. For example, Chan et al. [73] proceeded to rank categories of mental ill-health risk factors based on each category's constituent factor's average frequency of appearance. More sophisticated statistical methods employed in the vast majority of these meta-analyses were fixed or random effect models using forest plots to present the results [10,29,31,34,35,37,38]. These methods could only include studies based on questionnaire surveys that provided sufficient statistical data such as mean scores or RII for each factor. On the other hand, only the ORI method was found that synthesizes the rankings of each factor per each study into one index regardless of the source of data or ranking method used in each study [30]. In this method, it is sufficient for each study to provide a ranked list of at least the top 10 factors for inclusion in the meta-analysis.

The choice of the appropriate statistical model in a meta-analysis depends on the type of survey data included in it. As a result, the ORI was chosen since it can combine the results of studies that have data sources from both questionnaires and statistics of real accidents. Thus, all 25 studies in the current meta-analysis, i.e., the 16 studies based on questionnaires and the nine based on statistics from actual construction sites, were included. Table 1 shows the variety of ranking methods used in the individual studies, including means, frequencies, RII, and the MCDM methods AHP, DMRA, FEAHP, FTOPSIS, PRAT, TSP, and FTA.

Each of the 25 studies used one or more of these methods to classify the factors under investigation, producing a top-ten list of factors that were included in this meta-analysis. Two studies, i.e., S19 [60] and S21 [62] presented two rankings using two different methods, both of which were included in this meta-analysis. As a result, a table in MS Excel consisting of 62 rows (one for each factor of the AFBS) and 27 columns (one for each ranking per study). In each cell, a number ranging from 1 to 10 and corresponding to the rank position per study was inputted. If a factor in a particular study was ranked at a lower position than 10 the cell was left blank (Table 3). At this stage, it was evident that 7 factors that were included in the AFBS did not appear in the top ten in any of the studies.

Table 3. Example ORI Calculation for factor 2.1.13 Electrical installation /electrocution hazards.

ι	N_ι	$\frac{N_\iota}{\iota}$
1	0	0
2	1	0.5
3	0	0
4	1	0.25
5	2	0.4
6	1	0.166
7	3	0.428
8	1	0.125
9	2	0.222
10	1	0.100
Total (Σ)	12	2.192

The next step was to calculate the frequency of appearance in the top ten for each factor (F in Table 3) and finally to calculate the ORI for each factor as follows, according to Equation (1).

$$\mathrm{ORI} = \frac{1}{\mathrm{F}} \times \sum_{i=1}^{10} N_i * \sum_{i=1}^{10} \frac{N_i}{\mathrm{i}}, \tag{1}$$

where F is 27 (the total number of studies providing rankings), i is the number representing the ranking position of each factor in each study, and N_i is the frequency of occurrence of each ranking position for each factor. The necessary analytical calculations of the ORI index for each factor were performed usiMS MS Excel.

An example is the calculation of the ORI for the accident factor 2.1.13 Electrical installation /electrocution hazards, which was ranked in the top 10 twelve times as shown in Tables 2 and 3. For example, it ranked in second place 1 time and in 5th place twice, etc.

Therefore, the total occurrences of factor 2.1.13 are $\sum_1^{10}(Ni) = 12$.

The ratio 1/F = 1/27 = 0.0370 and

The sum of the ratios $\sum_1^{10}\left(\frac{Ni}{i}\right) = 2.192$.

As a result,

$$\mathrm{ORI} = \frac{1}{\mathrm{F}} \times \sum_{i=1}^{10} N_i * \sum_{i=1}^{10} \frac{N_i}{\mathrm{i}} = \frac{1}{27} \times 12 * 2.192 = 0.974 \tag{2}$$

5. Results and Discussion

Following the meta-analysis of the 55 accident contributing factors ranked in the top ten by 25 researchers, the cumulative results are a much more reliable result and can be safely generalized. The top ten national construction site accident factors are shown in Table 4. In the following subsections, each of the top ten factors is discussed in more detail in relation to similar findings in international studies and national practices and regulations. Mitigation measures are also proposed.

Table 4. Top ten factors based on the ORI.

AFBS Code	Factors	F	ORI	RANK
2.1.6	Falling or slipping	15	4.308	1
5.2.5	Special footwear	7	1.318	2
2.3.4	Physical or mental stress	12	1.249	3
3.8	Training in safety regulations	7	1.123	4
2.1.4	Falling or ejection of objects	11	1.070	5
2.1.13	Electrical installation/electrocution hazards	12	0.974	6
2.1.18	Other factors	8	0.923	7
1.1.1	Non-compliance with safety rules	10	0.887	8
2.1.8	Collision—Poor handling—Tipping of machinery or vehicles	9	0.762	9
1.2.1	Lack of implementation of safety measures	6	0.669	10

5.1. Rank 1: Falling or Slipping (2.1.6)

It was revealed that the top contributing factor to construction accidents is 2.1.6 Falling or slipping (ORI = 4.308). It appeared 15 times in the top 10 and was ranked six times in first place. This is in agreement with research by Chong and Low [74] and Phoya et al. [75], where workers' falling from heights or ladders also emerged as the most critical factor causing accidents in the Malaysian and Tanzanian construction industries.

This significant result indicates that it is necessary for workers in workplaces with a considerable difference in height from the surrounding area, who cannot be protected against the risk of falling by technical or other collective protection measures, to be provided with PPE belts and safety ropes. Under the relevant safety standards, safety belts, wire ropes, and all attachments and anchorages shall, either individually or assembled, have a breaking strength of not less than 1300 kg and be capable of safely supporting a suspended load. In addition, safety belts and wire ropes shall be checked before each use; and examined with due care to ensure that they have not been permanently cut or deformed. In addition, safety belts should be attached directly or with ropes to a stable and secure anchorage point [50]. To ensure that these safety standards are met, training in their use on-site should be mandatory for every worker, and the safety officer should conduct daily checks on their use.

5.2. Rank 2: Special Footwear (5.2.5)

The second-ranked factor 5.2.5 Special footwear (ORI = 1.318), or more specifically, lack of use of special footwear, was found seven times in the top ten; four times in first place. This result is in unison with research by Ashuro et al. [38] and Alamneh et al. [37] who identified the non-use of PPE as the second most crucial factor in causing workplace accidents in the construction sector in the Ethiopian capital Addis Ababa. Additionally, Meseret et al. [35] indicated that the chances of having an accident in the Ethiopian construction industry are higher in workers who do not use PPE. The use of PPE is one of the most basic measures to improve the safety level in construction sites. Still, one of the most common causes leading to construction accidents is the workers' dislike of using them and their low awareness of the benefits of their use [76].

PPE is "an instrument designed and manufactured to be worn or held by a person for protection against one or more risks to the health or safety of that person" (EU Regulation 2016/425, Article 3). Employers are obliged to provide workers with the correct PPE for the type of work they are doing, under EU regulations and guidelines, and to check through formal written procedures that workers are using them correctly [66]. Therefore, systematic training on the proper use of PPE can significantly ensure their safety [54,71].

5.3. Rank 3: Physical or Mental Stress (2.3.4)

According to the data in Tables 3 and 4, in third place is factor 2.3.4 Physical or mental stress (ORI = 1.249). It appeared 12 times in the top ten. In his research, Panagiotakopoulos [62] applied the PRAT and TSP methods to data from the annual reports of the Hellenic Labor Inspectorate (SEPE) for the period from the second half of 1999 to 2017 and Eurostat, respectively, from 2008 to 2017. He found that factor 2.3.4 is the only one that shows an increasing trend over time, which shows that the human factor plays a vital role in causing construction accidents. In their meta-analysis of 68 international studies that summarize the psychosocial factors related to the safety performance of construction workers, Tong et al. [34] indicated that psychosocial factors indirectly affect workers' safety performance.

Daily fatigue, especially when performing manual tasks, affects the performance and concentration of workers. It is, therefore, necessary for workers to be rested, attentive, calm, and have psychological well-being. Planning and taking the measures needed to prevent and protect workers from the risks mentioned above aims to achieve a dynamic balance between workers and the working environment, with the primary objective of adapting work to the worker [66,67].

5.4. Rank 4: Training in Safety Regulations (3.8)

The fourth ranking factor, 3.8 Training in safety regulations, is found seven times in the top ten and is ranked three times in first place, one time in second place, and twice in third place. At the same time, Phoya et al. [75], in their research, identified that in the Tanzanian construction industry, 60% of workers had not been trained in H&S issues and 50% on the proper use of PPE. Hence, achieving H&S protection against risks in the workplace in the construction sector through training is a critical priority.

A safety culture can be advocated by educating employees on the observance of H&S regulations in the workplace. This is bound to lead to widespread compliance with safety measures and enforcement of relevant H&S legislation and, consequently, to diminish the possibility of occupational hazards occurring in construction sites [54,77]. The implementation of training programs should correspond to the specific training needs of workers for particular jobs to meet their and their organizations' immediate and future needs.

5.5. Rank 5: Falling or Ejection of Objects (2.1.4)

In fifth place is factor 2.1.4 Falling or ejection of objects (ORI = 1.070), which appears eleven times in the top ten and is ranked twice in second place. This finding coincides with Toccalino et al. [78], who performed a meta-analysis on the causes of work-related traumatic brain injuries. They identified the leading causes are falls of persons, being struck by an object or person, and collisions with motor vehicles. This accident factor systematically is in the top three causes of fatal accidents worldwide [79–81]. Grant and Hinze [81] recommend that further research focus on stabilizing incomplete roof structures and implementing best practices for fall protection while performing roof-related work. It is, therefore, essential for construction site safety officers to possess specialized knowledge of safety issues and hazard identification [71,82].

5.6. Rank 6: Electrical installation/Electrocution Hazards (2.1.13)

Next in sixth place is factor 2.1.13 Electrical installation/electrocution hazards (ORI = 0.974), which occurred 12 times in the top ten positions. It has been documented that electric shock accident is one of the main causes of fatal construction accidents [83,84]. By analyzing workers' compensation data related to construction apprentices between 2008 and 2019 in Australia, Kamardeen and Hasan [83] concluded that the predominant mechanisms that occurred in thirteen fatalities were vehicle incidents, electrocution, and falls from a height and that apprentices who trained as carpenters, electricians, plumbers, bricklayers, and structural steel workers were more vulnerable to fatalities and permanent incapacities. From the 101 investigation reports of fatal electrocution accidents in China, Li and Wen [84] identified process management loopholes, inadequate safety education training, and poor crew resource management as the top 3 accident contributing factors.

On the other hand, in Greece, by applying the time series method to the static data from SEPE on the causes of occupational accidents in construction for the years from 1996 to 2016, Vroudas [60] observed that accidents due to electrical problems showed a downward trend through time. Nevertheless, electricity remains a significant source of workplace risks with severe consequences for workers. Regular inspection and maintenance of electrical equipment and installations per ELOT HD 384 are required, as well as more efficient training programs for workers and apprentices.

5.7. Rank 7: Other Factors (2.1.18)

In seventh place was the factor 2.1.18 Other factors (ORI = 0.923) from the Accident Risks sub-category. This vague factor appeared eight times in the top 10 and was ranked four times in position two and twice in position three. This shows that there are frequent accidents caused in the construction sector, the causes of which are not recorded and reported to the relevant Greek authorities. It is, therefore, impossible to identify the possible causes, which may be extremely dangerous and require particular attention.

5.8. Rank 8: Non-Compliance with Safety Rules (1.1.1)

Factor 1.1.1 noncompliance with safety rules (ORI = 0.887) follows in eighth place, appearing ten times in the top ten and twice in second place. Similarly, in the studies by Suraji [85] and Antoniou and Merkouri [2], factor 1.1.1 ranked first and seventh, respectively. This supports the view that regular monitoring of construction sites by the relevant public authorities, supervisors, and safety officers is necessary to evaluate their continuous compliance with legislation and the application of necessary safety measures to prevent accidents [2]. The observance of safety rules and the correct use of PPE through information should be a daily routine and, in this way, a better quality of work and a more efficient and safe everyday life.

5.9. Rank 9: Collision—Poor Handling—Tipping of Machinery or Vehicles (2.1.8)

The ninth-ranked factor was 2.1.8 Collision—Poor handling—Tipping of machinery or vehicles (ORI = 0.762), which appeared nine times in the top ten and twice in second place. According to Hong and Gui [86], the misuse of machinery/vehicles is mainly due to poor training of workers. Individuals not qualified to use machinery/vehicles while performing work on the construction site are a source of occupational accidents. Therefore, qualified and trained personnel only should be allowed to use machinery, vehicles, and mechanical equipment. Preventive measures must be taken to avoid the falling of vehicles and machinery on site. In fact, under Presidential Decree 305/96, 'Minimum safety and health requirements to be applied at temporary or mobile construction sites in compliance with Directive 92/57/E.E.C.', earth-moving and material-handling machinery must be fitted with appropriate systems, per the manufacturer's specifications so that the driver is protected against falling objects and crushing in the event of the machine overturning.

5.10. Rank 10: Lack of Implementation of Safety Measures (1.2.1)

Factor 1.2.1 Lack of implementation of safety measures (ORI = 0.669), which appears six times in the top ten and twice in the first place, was ranked last among the ten leading contributing factors to occupational accidents in the construction sector. Katsakiori et al. [5], who analyzed the factors causing workplace accidents in the construction industry in East Attica from 1999 to 2003, deduced that there was a lack of understanding and ability for workers to adhere to established work practice procedures. This factor, along with the non-compliance of workers to safety rules (1.1.1), is directly related to the safety culture in the

Greek construction industry, which is in dire need of improvement as certified by numerous research efforts [2,87]. While few publications focus on safety culture in the construction industry [88], this observation has also been documented in developing countries such as South Africa [89] and Ghana [90]. Therefore, it is necessary to examine methods for enhancing safety culture at the site, organization, and industry levels. An assessment of the existing safety culture using a specially developed maturity model, along the lines of that developed by Trinh and Feng [91], can help organizations to evaluate their capabilities of managing safety risks and to attain higher safety performance.

6. Conclusions and Further Research

While significant research work regarding the determination and mitigation of contributing factors to accidents in construction sites worldwide is extensive, few studies exist that attempt to apply meta-analysis techniques and synthesize results. In addition, at a national level, 262 academic studies were found relating to H&S in the construction industry, 25 of which focused on assessing the factors leading to accidents in the construction industry. Few of these have been published. Only one published study exists that evaluates contributing factors based on expert opinion via a structured questionnaire survey [2], even though it is a common method of research in this field. While more studies have been published based on statistical information available from the relevant H&S bodies in Greece, these provide information mostly regarding the type of accident and the victim and possibly the main direct factor leading up to the accident. Few considered more detailed accident reports that provide slightly more information about contributing factors as well [4,5].

Therefore, the main innovations of this study are twofold. First, it utilizes the factors examined by each study ranging in number from 6 to 104 to produce a national AFBS contributing to the development of a uniform contributing factor taxonomy and breakdown structure that can become the basis for defining, comparing, and reporting construction safety performance. Second, it attempts to overcome the shortcomings of each study such as small sample size, particular focus groups, and lack of detail in studies based only on published statistical data. This approach will affect construction safety practices by synthesizing knowledge from multiple scientific researchers to young civil engineers to help prevent construction site accidents by making them aware of the most common hazards and factors that can cause accidents in the Greek construction industry. This knowledge can also be availed by government officials for the development of a more vigorous system of construction safety standards.

The results showed that six out of the top ten contributing factors to construction site accidents are from the 2.0 Occupational Risks category, only one from the 1.0 Safety Culture, 3.0 Worker Training Deficiencies, and 5.0 Safety Equipment/Measures categories, and none from the 4.0 Occupational Satisfaction category. It was revealed that the top contributing factor to workplace accidents is 2.1.6 Falling or slipping, followed by 5.2.5 Lack of special footwear. These two factors are indeed related and provide the first red flag that must be noted. It is necessary to provide construction workers with adequate footwear as part of the mandatory PPE, support systems (railings, ropes, etc.) for construction work at a height, and all other necessary measures to mitigate this most significant accident risk. 2.3.4 Physical or mental stress and 3.8 Training in safety regulations follow in third and fourth place, indicating the necessity to ensure the well-being of all workers and that they have received proper training before the commencement of work. A series of factors from the Accident Risks category, including 2.1.4 Falling or ejection of objects, 2.1.13 Electrical installation/electrocution hazards, 2.1.18 Other factors, and 2.1.8 Collision—Poor handling and Tipping of machinery or vehicles follow in 5th, 6th, 7th, and 9th place, respectively. These findings enunciate the importance of strict safety measures for the prevention of such accident hazards. The final two factors in the top ten are related to the non-compliance of workers to safety rules (1.1.1) and the lack of implementation of safety measures by employers (1.2.1) both indicating the need to promote safety culture among workers and employers in the Greek construction industry.

In summary, the amalgamated insights of 25 Greek scientific studies, provided by the results of this meta-analysis, are certain to be used to shape safety management processes by construction companies, clients, and safety policy decision-makers in the following manners:

- The inception of streamlined autonomous construction site inspections by H&S auditors to shrink the margin for differentiation from the safety rules designated in national H&S legislation. This will enforce the implementation of mandatory safety measures with special emphasis on the development of control mechanisms and intervention planning to reduce the risk of falls, electrocution, and machinery collisions.
- Upgrading of worker safety training programs and other actions that push for a change in the Greek construction industry's safety culture by promoting the use of PPE and specific safety measures against the most common safety hazards. Government institutions responsible for occupational H&S should organize relevant construction site accident prevention campaigns.

A limitation of this study is that it is focused on a very specific construction industry with its own unique cultural factors. Further research work should include the execution of a similar meta-analysis encompassing results of similar international research work to compare the status of the Greek construction industry with other European and/or developing countries. Another limitation of this study is that it does not differentiate results according to the profile of the participants in the 16 questionnaire surveys, which may provide different viewpoints and ideas for solutions focused on specific categories of workers (technicians, machine operators, unskilled labor, engineers, and specialists). In addition, it fails to consider the trend through time to examine if the same types of accident factors predominate through time or if technological advancements have led to the mitigation of some as opposed to others. Nonetheless, the results of this research can be considered another step toward the development of a hybrid human information processing and systemic accident factor model for the Greek construction industry.

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