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Should We Depend on Expert Opinion or Statistics? A Meta-Analysis of Accident-Contributing Factors in Construction

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Abstract: International research overflows with studies looking into the causes of construction accidents. Hundreds of studies by postgraduate students in the past 20 years focus on identifying and assessing risks contributing to accidents on Greek construction workplace sites. Many base their work on results from questionnaire surveys that collect the opinions of construction site professionals or on the analysis of data from actual accident records or statistics. Consequently, this study seeks to determine if the data source leads to differing conclusions by using two techniques to synthesize individual results and rank the accident-contributing factors investigated in the original studies. The first utilizes their relative importance index (RII) values, and the second uses their overall ranking index (ORI) to execute meta-analyses. The professional opinion concludes that factors related to operative behavior are the most significant accident-contributing factors. At the same time, actual accident statistics point to site risk factors of the construction process itself as the most important, indicating that expert opinion of Greek professionals should be considered in conjunction with data from actual accident records to provide the focus points for mitigation and assurance of safe construction sites in Greece.

Keywords: health and safety; safety hazards; meta-analysis; effect summary; overall ranking index; forest plots; causes of construction accidents; risks; accidental factors; risk analysis

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1. Introduction

Accidents, either fatal or nonfatal, are a fact of life in construction. Regardless of safety measures enforced by laws or internal safety procedures of construction companies, accidents still occur. Any civil engineer with construction site experience has witnessed or heard of one or more severe accidents occurring on a project they have been a part of during their career. As a result, researchers and practitioners alike have embarked on numerous studies, on either a site-specific or an industry level, to identify and classify construction site accident-contributing factors.

Statistical information on a European level show that the construction industry from 2012 to 2019 has consistently witnessed at least 500 (per 100,000 people employed) more nonfatal accidents than the transportation industry, and 1000 more than the manufacturing industry. Although there has been a slight decrease in accidents from 3.457 in 2012 to 3.211 in 2019 and 2.987 in 2020 (COVID-19 year), Europe is still far away from achieving a zero-accident rate (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Accidents_at_work_-_statistics_by_economic_activity, accessed on 29 September 2023).

Similarly, the Greek construction industry is prone to on-site construction accidents. As shown by the analysis of statistical data from the Hellenic Statistical Authority (ELSTAT), for the years 2014 to 2021, 345 to 453 nonfatal and 7 to 14 fatal accidents occurred per year (https://www.statistics.gr/el/statistics/-/publication/SHE03/, accessed 29 September 2023). Notably, the smallest number occurred in 2019–2020, when construction activity drastically dropped due to the COVID-19 pandemic. As a result, the need to investigate the reasons behind increased frequency accidents in the construction sector has been attended to significantly by researchers in Greece.

Following an initial search in Scopus, 28 studies were found that provided lists of accident-contributing factors and proceeded to evaluate them (Table 1). Three of these were meta-analyses of multiple similar studies in the Ethiopian construction industry. The statistical methods applied to assess the factor importance include frequencies, correlation analysis, factor analysis, decision trees, and the relative importance index (RII). The studies were based on either questionnaire surveys or actual accident data and were industry- or project-specific. The studies investigated construction site accidents in the USA, Australia, Asia, and Europe.

Table 1. International studies aiming to identify and evaluate accident-contributing factors.

Reference	Country	Data Source	Evaluation Method
[1]	UK	Accident Data	Frequencies
[2]	China	Questionnaires	Factor Analysis
[3]	UK	Accident Data	Frequencies
[4]	Hong Kong	Questionnaires	RII
[5]	China	Interviews/Accident Data	Qualitative analysis
[6]	Greece	Accident Data	Factor Analysis
[7]	China	Questionnaires	Delphi Method
[8]	Taiwan	Accident Data	Frequencies/Correlation Analysis/Factor Analysis
[9]	USA	Accident Data	Frequencies
[10]	Malaysia	Accident Data	Frequencies
[11]	Tanzania	Questionnaires	Frequencies
[12]	USA	Accident Data	Frequencies
[13]	Iran	Accident Data	Decision Trees
[14]	Spain	Accident Data	Frequencies
[15]	Poland	Questionnaires	Correlation Analysis
[16]	Denmark	Questionnaires	Factor Analysis
[17]	Norway	Accident Data	Correlation Analysis
[18]	Malaysia	Questionnaires	Correlation Analysis
[19]	Greece	Accident Data	Correlation Analysis
[20]	China	Accident Data	Grey Relational Analysis
[21]	China	Accident Data	Frequencies/Correlation Analysis
[22]	Saudi Arabia	Questionnaires	Factor Analysis
[23]	Palestine	Questionnaires	RII/Factor Analysis/Correlation Analysis
[24]	USA	Questionnaires	Factor Analysis
[25]	Ethiopia	Published studies	Meta-analysis
[26]	Greece	Questionnaires	RII
[27]	Ethiopia	Published studies	Meta-analysis
[28]	Ethiopia	Published studies	Meta-analysis

Apart from accident factors, similar quantitative methods have been used for ranking sets of factors affecting delay risks [29–34], cost-overruns [35,36], project success [37], project managers' traits [38], barriers to energy upgrading of buildings [39], or causes of claims [40–42] and contracting procedures [43,44]. These methods may be statistical or multicriteria decision-making methods (MCDMs). Statistical methods include mean and frequency [26,43,45] correlation analysis [37], the RII [26,29–32], risk priority number (RPN), and fuzzy RPN [36]. MCDM methods, such as the Preference Ranking Organization Method for Enriched Evaluation (PROMETHEE) [38], the Technique for Order Preference by Similarity to Ideal Situation (TOPSIS) [30,46], Analytical Hierarchy Process (AHP) [47,48], and the Best-Worst Method (BWM) [49], have also significantly been adopted for ranking purposes in the construction management research domain.

In the national universities' postgraduate research repositories, at least 262 Greek research efforts were found that identified factors contributing to accidents in construction during the past 20 years [50]. The aim of most of these studies was to evaluate the importance of the identified factors contributing to accidents based on collected data from questionnaire surveys or actual accident statistics [6,19,26] or to develop risk analysis models for specific case studies [51,52]. As numerous studies exist providing lists of factors leading to accidents in the Greek construction industry and their rankings, the issue is regarded to have attained sufficient readiness to undergo rigorous meta-analysis to highlight their common results. Therefore, this study seeks to amalgamate the results of the former studies to determine if the data source (opinion or actual accident data) leads to differing conclusions using two meta-analysis techniques.

Meta-analysis is a powerful statistical tool named by Glass back in 1976, who described its essential features and steps and supported that it was a new method for discovering new knowledge based on findings of previous similar studies that had reached a significant level of maturity [53]. A meta-analysis results in the calculation of a more precise and homogeneous aggregate result that can be provided by each study separately, allowing the meta-analyst to draw safer conclusions, especially when the additional studies have few participants [54].

Meta-analyses have been used in the construction industry to enhance and synthesize results from research worldwide on numerous topics. Our literature search found that they have been used for identifying construction delay risks [33,55], bid decision criteria [44], specific construction site safety hazards [56,57], psychological factors affecting safety [58], accident prevention communication barriers [28], and safety climate promoting indicators [59]. Publications using meta-analyses to pool the results of a number of similar studies published in international journals were found only for Ethiopia [25,27,28]. As a result, and due to the existence of an abundance of such research theses in Greece, having found only three [6,19,26] that were published in international journals (Table 1), this research team decided to carry out meta-analyses of these research works using different meta-analyses methods according to source type. The first part of this research, which has already been published [50], explained in detail the procedure followed in selecting the 25 studies out of a total of 254 studies to undergo meta-analyses and their content analysis that resulted in the production of the accident factor breakdown structure (AFBS). It then proceeded to employ the overall ranking index (ORI) to meta-analyze the data from all 25 studies to evaluate the importance of the common factors without distinguishing between the type of data source in the original study. The top 10 most important accident factors were presented in tabular form and discussed in detail. This article presents the international literature review that inspired the research work originally and uses the AFBS to meta-analyze the data from the 16 studies based on questionnaires using their RII values to calculate the effect summary and the nine studies based on actual accident statistics using the ORI. The results are presented using forest plots and bar charts, and a comparison is made with the results of the article [50].

Hence, this study aims to synthesize results from 25 extant studies using data based on site experience and actual accidents to determine whether factors perceived as significant by construction-site-experienced engineers and workers are found to have caused actual accidents. Section 2 presents an overview of the applied methodology. It includes statement of the two research questions, a summary of the procedures employed for selecting the 25 studies to be meta-analyzed, and creates the 62 accident factor breakdown structure (AFBS). Section 3 provides the justification, mathematical formulation, and example calculations for the methods applied to evaluate, by ranking, the factors according to importance. Sections 3 and 4 include the presentation and discussion of the results facilitated by the use of forest plots and bar charts. Finally, this paper concludes with Section 5, which describes the results of these meta-analyses and their limitations and provides suggestions for future research.

2. Methodology

The steps followed in this research's methodology are the following:

1. Statement of research questions.
2. Search for relevant studies.
3. Content analysis and study selection.
4. Identifying, classifying, and developing the AFBS.
5. Data meta-analysis.
6. Comparison and discussion of the results.

Once the overabundance of research work into the factors leading to accidents in Greek construction sites was verified, the following questions were posed as the research questions.

Q1. What are the critical construction-accident-contributing factors based on Greek construction site professionals' opinions?

Q2. What are the critical construction-accident-contributing factors based on actual accident data from Greek construction sites?

A systematic literature review was conducted using the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines by Moher et al. [60]. The procedure that resulted in the selected studies for meta-analysis is described in Antoniou and Agrafioti [50]. Initially, 262 references were found, including postgraduate dissertations, peer-reviewed articles, and conference proceedings by Greek researchers from 2001 to 2021. Initially, 97 studies were disqualified during the screening of their title and abstract as being irrelevant to the research scope. As described by the researchers in their previous publication [50], the full texts of the remaining studies were analyzed to determine their eligibility. Of the final 25 eligible studies, sixteen used survey data and nine used real accident statistics (Table 2). The studies selected for inclusion in the meta-analyses were those that

- Investigated safety rather than health hazards;
- Identified and assessed factors leading to accidents;
- Referred to civil engineering projects;
- Analyzed data obtained through surveys, statistics, and/or accident records;
- Provided factor importance or information regarding occurrence frequency.

Table 2. Profile of selected studies (adapted from [50]).

Reference	Study Code	No. of Factors	Data Source	Sample Size (*n*)	Ranking Method
[26]	S1	104	Questionnaires	102	RII
[61]	S2	28	Questionnaires	149	Mean/Freq./St. Dev
[62]	S3	22	Questionnaires	65	Freq.
[63]	S4	21	Questionnaires	46	Freq.
[64]	S5	37	Questionnaires	131	Freq.
[65]	S6	19	Questionnaires	89	Freq.
[66]	S7	29	Questionnaires	141	Freq.
[67]	S8	20	Questionnaires	130	Freq.
[68]	S9	20	Questionnaires	82	Freq.
[69]	S10	42	Questionnaires	57	Freq.
[70]	S11	19	Questionnaires	70	Freq.
[71]	S12	25	Questionnaires	25	RII
[72]	S13	135	Questionnaires	55	Mean/Freq./St. Dev.
[73]	S14	26	Questionnaires	60	Freq.
[74]	S15	33	Questionnaires	56	Freq.
[75]	S16	40	Questionnaires	50	Freq.
[76]	S17	10	Accidents	169,381	AHP
[77]	S18	8	Accidents	149	DMRA/FAHP/FTOPSIS
[78]	S19	8	Accidents	11,171	PRAT/TSP
[79]	S20	8	Accidents	41,081	PRAT/FTA
[80]	S21	8	Accidents	13,776	PRAT/TSP

Table 2. *Cont.*

Reference	Study Code	No. of Factors	Data Source	Sample Size (*n*)	Ranking Method
[19]	S22	13	Accidents	413	Freq.
[81]	S23	8	Accidents	2615	Freq.
[82]	S24	11	Accidents	137	Freq.
[6]	S25	6	Accidents	3332	Freq.

AHP = analytical hierarchy process; FAHP = fuzzy extended AHP; FTA = fault tree analysis; FTOPSIS = fuzzy TOPSIS; RII = relative importance index; TSP = time-series stochastic process; DMRA = decision matrix risk-assessment technique; PRAT = proportional quantitative risk assessment technique.

Following the data extraction process described in detail in Antoniou and Agrafioti [50], 62 factors were coded and categorized into five main and eleven subcategories, as shown in Figure 1. This comprehensive accident factor breakdown structure (AFBS) was used to code the accident factors to enable the meta-analysis of the data.

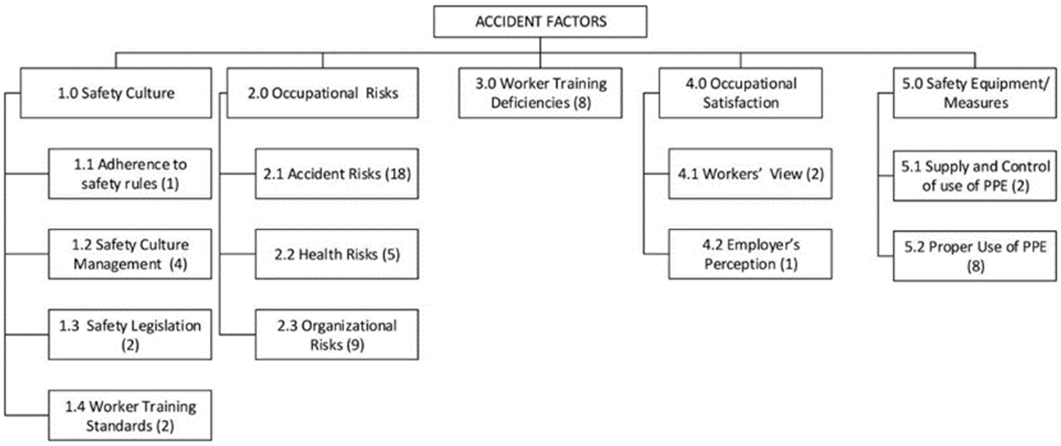

Figure 1. AFBS (no. of factors) [50].

Two methods were utilized to meta-analyze the data statistically. For research question 1, the fixed or random effects models were used, which consider the RII for each factor as provided by, or calculated for, each accident factor in each study. The ORI was used for research question 2. The justification for employing these methods, their mathematical formulation, and example calculations, as well as forest plots and bar charts for the ten most important accident-contributing factors, follow in the next section.

3. Data Meta-Analysis

3.1. Meta-Analysis of Opinion-Based Data

Sophisticated statistical methods employed by most meta-analyses are the fixed or random effect models. In most cases, forest plots are adopted for result presentation purposes [25,27,28,44,54,58]. However, these can only be applied to studies based on questionnaire surveys in which participants rank each factor on a Likert scale. In such a meta-analysis, the outcome of each study is translated into an effect size (es) estimate. It then utilizes each study's es estimate to statistically determine an aggregate weighted effect size estimate (effect summary denoted as ($\overline{es}$) and tests the statistical significance of this effect summary value [83]. As some studies are more accurate than others, rather than simply averaging the effect sizes, a weighted average is calculated where more weight is allocated to some studies and less to others [54]. Therefore, an effect summary is obtained by synthesizing the selected studies' effect sizes. Each study affects the effect summary according to its sample size, so studies with a small sample of participants have less accuracy, and their results are subject to random errors.

Two statistical models are commonly employed for calculating the contribution of each study to the effect summary: (i) the fixed effect model and (ii) the random effects model. Their difference lies in the variations in the primary studies' results, i.e., they assume different elements regarding the nature of the examined studies, which generate different combined effect summaries [54]. In the fixed effect model, all included studies are assumed to have a standard effect size, and it seeks to find the "true" value of the pooled effect [54]. Any differences between the effect sizes are due to random sampling. For the random effects model, the actual outcome may vary from study to study, so it is assumed that the studies to be meta-analyzed are a random sample of the population of all possible studies and, correspondingly, their effect sizes are a random sample of all possible effect sizes. The values of the effect summary under the two models only show substantial numerical differences if the heterogeneity between studies is significant [54].

The fixed effect model was used to determine the effect summary for each factor examined by the sixteen studies using respondents' opinions obtained through appropriate questionnaire surveys as the data source. If a high degree of heterogeneity was detected, the random effects model was used since it could fit the sampling distribution, allowing generalization of the findings [54]. The aggregate summary effect for each factor was achieved by giving weights to each study according to the inverse of the total—error variance. The meta-analysis procedure is presented in Table 3 and was conducted using the MS Excel wizard and step-by step guide created by [54,84].

Table 3. Meta-analysis steps using the fixed effect or random effect models.

	Step	Variable Notation	Equation
1	Calculation of effect size using *RII* calculates in each study (Table 4)	es	$es = RII = \frac{\Sigma W}{a \times n}$ [85]
2	Calculation of standard error	SE	$SE = \frac{es}{\sqrt{es \times n}}$ n = sample size
3	Calculation of variance	Var	$Var = SE^2$
4	Calculation of individual study weights (fixed effect)	w	$w = \frac{1}{SE^2}$
5	Calculation of effect summary (fixed effects)	$\overline{es}$	$\overline{es} = \frac{\sum(w \times es)}{\sum w}$
6	Calculation of Q (chi-squared statistic), null hypothesis:	Q	$Q = \sum\left(w \times es^2\right) - \frac{[\sum(w \times es)]^2}{\sum w}$ $v = 0, \ \text{if } Q \leq df$ Null hypothesis: all studies equal Df: (k − 1), k: no. of studies
7	Calculation of I Negative values are replaced by zero. I^2 = 0, no heterogeneity	I^2	$I^2 = \frac{Q - df}{Q} * 100$
8	Calculation of constant v to account for the variability between studies (random effects)	v	$v = \frac{Q - df}{\sum w - \left(\frac{\sum w^2}{w}\right)}$ if $Q \leq df$ $v = 0, \ \text{if } Q \leq df$
9	Calculation of new weights for each individual study (random effects)	w_v	$w_v = \frac{1}{SE^2 + v}$
10	Calculation of effect summary (random effects)	$\overline{es_v}$	$\overline{es_v} = \frac{\sum(w_v \times es)}{\sum w_v}$
11	Calculation of standard error (random effects)	SE_{es_v}	$SE_{es_v} = \sqrt{\frac{1}{\sum w_v}}$ $Lower\ limit = es_v - 1.96 \times SE_{es_v}$ $Upper\ limit = es_v + 1.96 \times SE_{es_v}$
12	Calculation of Z to verify the null hypothesis	Z_{es_v}	$Z_{es_v} = \frac{es_v}{SE_{es_v}}$
13	Repeat steps 6 and 7 using new weights for null hypothesis testing	$Q_v\ \kappa\alpha\iota\ {I_v}^2$	

Table 4. RII values for factors included in the opinion-based studies.

AFBS Code		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
1.0	**Safety Culture**																
1.1	*Safety Rules Compliance*																
1.1.1	Noncompliance	0.706		0.719		0.722	0.770		0.695	0.683	0.723	0.500	0.770	0.884	0.796		0.740
1.2	*Safety Culture*																
1.2.1	Deficient use of safety measures	0.704			0.917				0.785		0.716			0.920			
1.2.2	Organizational competitive advantage					0.594			0.708		0.656			0.785			
1.2.3	Lack of safety commitment					0.684					0.726		0.410	0.815			
1.2.4	Lack of risk management					0.701					0.670		0.760	0.822			
1.3	*Safety legislation*																
1.3.1	Violation of legislation	0.982	0.866									0.554		0.676			
1.3.2	Insufficient legislation implementation	0.661		0.692	0.904	0.638					0.709				0.813		
1.4	*Training Standards*																
1.4.1	Inadequate training	0.554				0.728	0.427	0.429		0.616	0.509	0.814	0.670	0.375	0.517	0.366	0.528
2.0	**Occupational Risks**																
2.1	*Hazard Risks*																
2.1.1	Dangerous working conditions					0.685	0.607	0.661		0.668	0.509	0.625	0.770	0.531		0.688	0.776
2.1.2	Building structures deficiencies						0.604			0.649	0.502			0.436			
2.1.3	Hazardous site environmental conditions	0.189													0.554	0.679	0.760
2.1.4	Objects falling or being ejected	0.710	0.636		0.839			0.746					0.690			0.670	0.768
2.1.6	Falling or slipping	0.675	0.690	0.827	0.857		0.685	0.784							0.725	0.679	0.776
2.1.7	Poor safety signage	0.196						0.463								0.629	0.648
2.1.8	Poor machinery or vehicle operation	0.703	0.520	0.831	0.791		0.492	0.798				0.479	0.750			0.710	0.784
2.1.9	Equipment safety deficiencies	0.627					0.652	0.693		0.616	0.428			0.415			
2.1.11	Poor safety installations	0.604					0.458			0.637	0.477			0.367			
2.1.12	Use and mobility of hazardous material	0.739		0.592			0.320			0.546	0.372			0.360	0.717		
2.1.13	Risk of electrocution	0.688	0.495	0.758	0.830		0.379	0.564		0.625	0.460			0.480	0.633	0.388	0.564
2.1.14	Explosions and fires		0.386	0.615	0.504		0.553	0.495		0.522			0.530	0.444		0.594	
2.2	*Health Risks*																
2.2.1	Exposure to occupational diseases					0.727	0.632			0.735	0.519			0.509	0.708		
2.2.2	Exposure to chemicals	0.573	0.498	0.669				0.684			0.418			0.498		0.688	0.684
2.2.3	Physical factors		0.643	0.492				0.644			0.544			0.516		0.661	0.712
2.2.4	Noise	0.313	0.757	0.750				0.667								0.656	0.676
2.2.5	Biological factors		0.757					0.622			0.474			0.356			0.520
2.3	*Organizational Risks*																
2.3.1	Work scheduling problems	0.677			0.791	0.623					0.446			0.440	0.513		0.784
2.3.2	Psychological factors			0.865		0.661					0.614			0.487		0.746	0.644
2.3.3	Exhaustion		0.775	0.800	0.687				0.795			0.607	0.780		0.521	0.710	0.692
2.3.4	Stress (physical/mental)		0.804			0.432										0.741	0.708
2.3.5	Ergonomic issues	0.639				0.623					0.582			0.433			
2.3.6	Deficient communication	0.814	0.820			0.608							0.550			0.366	0.604
2.3.8	Stressful working conditions	0.524			0.691	0.608					0.502			0.436	0.717		0.732

Table 4. *Cont.*

AFBS Code		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
2.3.9	Extreme weather	0.699	0.784	0.735				0.745									0.704
3.0	**Worker Training Deficiencies**																
3.1	Training level	0.599	0.721		0.870		0.764	0.738	0.746	0.762	0.604		0.550	0.727	0.800		0.720
3.2	At work position training		0.820			0.536			0.738	0.625	0.505	0.793		0.691	0.783		0.684
3.3	On site training					0.554			0.677		0.502	0.561		0.705	0.750	0.888	0.676
3.4	Lack of official H&S agency training and information					0.406				0.543	0.439			0.571	0.533		0.316
3.5	Accident prevention training			0.627		0.776	0.744	0.784		0.665				0.691			
3.6	Training for emergency situations						0.736			0.607	0.530			0.691			
3.7	Training in new safety measures		0.772			0.773	0.610		0.689	0.759	0.495			0.600	0.713		
3.8	Safety legislation training					0.979	0.919			0.808	0.804			0.782		0.879	0.796
4.0	**Occupational Satisfaction**																
4.1	*Workers' point of view*																
4.1.1	Workers' lack of qualifications							0.768	0.722							0.884	0.700
4.1.2	Workers' safety satisfaction					0.638	0.837	0.784	0.680	0.689	0.646			0.702			
4.2	*Employer's Perception*																
4.2.1	Workers' job performance satisfaction					0.638			0.763		0.751			0.651			
5.0	**Safety Measures**																
5.1	*Personal Protection Equipment (PPE)*																
5.1.1	Frequency of provision			0.742	0.839	0.823		0.773							0.858	0.848	0.636
5.1.2	Supervision of correct use	0.698	0.779	0.696		0.795				0.793		0.811					
5.2	*Proper use of each piece of PPE*																
5.2.2	Helmet		0.614	0.869	0.900	0.719	0.879	0.683		0.817		0.886					0.600
5.2.3	Mask		0.586	0.842		0.773	0.640	0.683		0.543							
5.2.4	Earplugs		0.465	0.727	0.635			0.732				0.500					0.476
5.2.5	Special footwear		0.826	0.877	0.887	0.640	0.978	0.803		0.899							0.776
5.2.6	Work uniforms					0.476		0.605				0.707					0.708
5.2.7	Glasses		0.663	0.781	0.787		0.747			0.601							0.584
5.2.8	Gloves		0.723	0.877	0.835	0.533	0.896	0.768		0.643		0.868					0.380

The sixteen relevant studies (S1 to S16 in Table 2) used in the meta-analysis in response to research question 1 were conducted between 2010 and 2020. They were based on opinions collected from questionnaire surveys that were sent by post, e-mail, or delivered in person. No studies between 2001–2009 and 2011–2014 were included in the systematic review process because they did not meet the inclusion criteria for statistical meta-analysis. Three (3) categories of respondents were found in the various studies: (i) Engineers, (ii) Engineers–Workers, and (iii) Workers. However, since only two (2) studies were addressed to Engineers only, one (1) to Workers only, and the remaining fourteen (14) to both (Engineers and Workers) without giving separate results; they were not examined in terms of correlation of results according to respondent category. In terms of publication type, all studies were master's theses, but only one was published in a scientific journal (S1). The Likert rating scale used by the researchers was from 1 to 4 for ten of the studies and from 1 to 5 for the remaining six. The total sample size was 1308 respondents, while the sample size per study ranged from 25 to 149 (Table 2). The accident-contributing factors that appeared in more than four studies were considered in our meta-analysis. As a result, 54 factors of the 62 codified by Antoniou and Agrafioti [50] in the AFBS were included and classified into all five categories according to Figure 1.

For each factor in each study, the effect size (*es*) was taken as the RII, giving 360 RII values in total. Fourteen studies reported mean values for individual factors for which the RII was calculated by applying Equation (1) [85]. Only the studies S1 [26] and S12 [71] directly provided RII values. The RII ranges from 0 to 1, where the maximum values indicate the most critical accident-contributing factors.

$$RII = \frac{\Sigma W}{a \times n} \tag{1}$$

where ΣW is the total weight given to each factor by all respondents, a is the highest weight that can be given to a response on the Likert scale, and n is the number of respondents per study.

Table 4 below presents the RII values calculated for each factor examined in at least one opinion-based study. The sample size of each study (n) is given in Table 2. The necessary analytical calculations and/or RII calculation transformations for the 54 factors found in these studies were performed in an MS Excel spreadsheet. An example calculation for the RII for factor 2.3.9 Extreme weather in study S2 [61] follows. In their research, the Likert scale ranged from 1 to 4 (never, rarely, often, always), the maximum weight that could be given to a response was a = 4, and the number of participants was n = 149. To calculate the total weight for the factor, the sum of the products of the number of responses given by respondents at each scale degree was calculated. Therefore, in this case, ν1 = 8, since eight respondents answered "never", ν2 = 16, since 16 respondents answered "rarely", ν3 = 73, since 73 respondents answered "often", and ν4 = 52, since 52 respondents answered "always". Thus, by applying Equation (1),

$$RII_{2.3.9} = ((1 \times 8 + 2 \times 16 + 3 \times 73 + 4 \times 52)/(4 \times 149)) \Longrightarrow RII_{2.3.9} = 0.784$$

Next, by using the step-by-step guide by Neyeloff et al. [84], the necessary calculations of the statistical formulae (standard error and variance), mentioned in steps 2 to 9 of Table 3, were performed in MS Excel to calculate the effect summary of the meta-analysis carried out for each factor. Considering that the data of the primary studies are continuous, the weighted mean difference is used as an outcome estimator [44]. For example, for factor "Organization competitive advantage (1.2.2)", by applying steps 1 to 5 from Table 3, ($\overline{es}$) = 0.665. The relevant example calculations are presented in Table 5.

As a result, Table 6 presents the ranking of the factors according to frequency in the 16 studies using a cut-off point equal to or greater than 4 (column Rank 1) and their ranking (column Rank 2) based on each fixed effect summary value ($\overline{es}$).

Table 5. Sample calculation for effect summary (fixed effect) for accident factor 1.2.2.

Data from Table 4				**Step 2**	**Step 3**	**Step 4**
Study	n	$es = RII$	$SE = \frac{es}{\sqrt{es \times n}}$	$Var = SE^2$	$w = \frac{1}{SE^2}$	$w \times es$
S5	131	0.594	0.0673376	0.0045344	220.5387205	131
S8	130	0.708	0.0737981	0.0054462	183.6158192	130
S10	57	0.656	0.1072789	0.0115088	86.8902439	57
S13	55	0.785	0.1194685	0.0142727	70.0636943	55
				Sums	561.1084779	373
				Step 5	$\overline{es} = \frac{\sum(w \times es)}{\sum w} = 0.665$	

The two ranking methods show that each factor's frequency in each study may not correspond to its level of importance. For example, factors "Deficient use of safety measures (1.2.1)" and "Violation of legislation (1.3.1)" are in the top five based on the summary effect value ($\overline{es}$). Nevertheless, these factors achieved a frequency of occurrence that rank lower than the top five. Similarly, there are significant differences between rankings for other factors such as 1.1.1 "Noncompliance to safety rules (1.1.1)", "Falling or slipping (2.1.6)", "Risk of electrocution (2.1.13)", "Explosions and fires (2.1.14)", "Inadequate training (1.4.1)", and "Frequency of provision of PPE (5.1.1)".

Indeed, these marked differences between the two rankings indicate the necessity for additional analysis to ascertain the significance of individual factors with increased certainty by estimating the effect size with confidence intervals. The degree of accuracy and validity of the aggregate result (effect summary) is directly proportional to the degree of homogeneity of each individual study. Therefore, the next step was to detect whether there was heterogeneity between the studies to determine whether the result obtained by the meta-analysis could be reliable. Controlling the degree of heterogeneity is essential to prevent erroneous conclusions. The assessment and detection of heterogeneity between the opinion-based studies was carried out initially by calculating the statistical function Q, known as the chi-squared statistic (X^2). Then, to quantify the degree of heterogeneity, the I^2 statistic by Higgins [86], which refers to the percentage of total variability due to true heterogeneity between studies, was calculated. The I^2 ranges from 0 to 100%. A value of 25% or less indicates little heterogeneity, whereas a value greater than 50% indicates significant heterogeneity [33,44]. For those factors with I^2 greater than 25% and Q greater than $k - 1$ (the number of studies that investigated the specific factor less one), the random effects model was applied by calculating a new effect summary value $\overline{es_v}$, according to step 9 in Table 3, resulting in acceptable Q and I^2 values for these factors. The fixed effect model is reliable for those accident factors with no heterogeneity; therefore, the ($\overline{es}$) value was used for ranking purposes. Instead, the ($\overline{es_v}$) value calculated by the random effects model was used for those showing significant heterogeneity. Hence, Table 6 presents the overall rank for each accident-contributing factor in the last column.

Based on the effect summary ($\overline{es}$) calculated and presented in Table 6, of the 54 factors found in the sixteen (16) opinion-based studies, the ten most important factors leading to construction site accidents are presented in Figure 2.

Table 6. Frequency of appearance, fixed effect, random effect, and overall rank comparative results table.

AFBS Code	Frequency of Appearance		Fixed Effect Model						Random Effects Model for Factors with Heterogeneity						Overall Rank
	Freq	Rank (1)	$\overline{es}$	Rank (2)	95% CI	Q	I^2 (%)	Z-Score p-Value	$\overline{es_v}$	Rank (3)	Q_v	$I^2{}_v$ (%)	Z-Score p-Value	95% CI	
1.1.1	12	1	0.707	15	0.653–0.762	9.377	0	25.450							16
1.2.1	5	7	0.780	4	0.692–0.868	3.280	0	17.441							4
1.2.2	4	8	0.665	25	0.582–0.747	2.467	0	15.747							25
1.2.3	4	8	0.673	24	0.574–0.771	5.822	0	13.425							24
1.2.4	4	8	0.721	12	0.619–0.823	1.029	0	13.900							12
1.3.1	4	8	0.777	5	0.688–0.867	12.841	0	17.097							5
1.3.2	6	6	0.700	18	0.624–0.776	4.097	0	17.963							19
1.4.1	12	1	0.516	48	0.469–0.562	28.722	48	21.759	0.530	7	12.858	0	14.417	0.458–0.602	48
2.1.1	10	2	0.641	30	0.584–0.698	5.842	0	22.010							32
2.1.2	4	8	0.551	46	0.465–0.638	3.568	0	12.490							46
2.1.3	4	8	0.337	54	0.267–0.406	38.339	61	9.498	0.529	8	2.986	0	4.076	0.275–0.783	49
2.1.4	7	5	0.705	17	0.636–0.774	2.790	0	20.034							18
2.1.6	9	3	0.730	10	0.669–0.791	3.548	0	23.519							10
2.1.7	4	8	0.352	53	0.290–0.414	30.009	50	11.086	0.459	10	4.367	0	5.196	0.286–0.632	53
2.1.8	10	2	0.636	33	0.580–0.691	23.130	35	22.450	0.659	2	10.927	0	16.012	0.578–0.739	26
2.1.9	6	6	0.583	38	0.518–0.649	10.512	0	17.519							39
2.1.10	6	6	0.653	28	0.586–0.719	3.195	0	19.188							29
2.1.11	5	7	0.506	49	0.435–0.577	7.275	0	13.954							51
2.1.12	7	5	0.479	51	0.418–0.539	27.095	45	15.622	0.507	9	8.733	0	9.338	0.401–0.614	50
2.1.13	12	1	0.537	47	0.490–0.584	25.167	40	22.611	0.551	7	13.800	0	16.193	0.485–0.618	46
2.1.14	9	3	0.488	50	0.436–0.539	8.002	0	18.586							52
2.2.1	6	6	0.645	29	0.572–0.717	6.218	0	17.481							31
2.2.2	8	4	0.571	43	0.514–0628	10.989	0	19.635							43
2.2.3	7	5	0.606	36	0.542–0670	4.953	0	18.632							37
2.2.4	6	6	0.574	42	0.512–0.637	34.647	57	17.983	0.627	5	4.526	0	8.395	0.480–0.773	36
2.2.5	5	7	0.569	44	0.499–0.639	15.919	6	16.037	0.564	6	12.679	0	14.212	0.487–0.642	45
2.3.1	7	5	0.588	37	0.520–0.655	17.158	0	17.158							38
2.3.2	9	3	0.709	14	0.645–0.774	8.205	0	21.490							14
2.3.3	6	6	0.655	27	0.577–0.733	7.296	0	16.471							28
2.3.4	4	8	0.608	35	0.530–0.686	18.556	19	15.321	0.647	3	6.269	0	10.176	0.523–0.772	30
2.3.5	4	8	0.580	39	0.500–0.660	3.690	0	14.145							40
2.3.6	6	6	0.638	32	0.569–0.707	21.862	31	18.095	0.634	4	8.366	0	11.234	0.523–0745	34
2.3.8	7	5	0.577	41	0.510–0.643	8.047	0	17.001							42
2.3.9	5	7	0.740	8	0.666–0.815	0.712	0	19.376							8
3.1	12	1	0.715	13	0.662–0.768	7.310	0	26.550							13
3.2	9	3	0.674	23	0.616–0.731	14.978	0	22.980							23
3.3	8	4	0.633	34	0.570–0.696	10.180	0	19.636							35
3.4	6	6	0.448	52	0.385–0.511	6.970	0	13.962							54
3.5	7	5	0.865	1	0.781–0.950	3.398	0	20.038							1

Table 6. *Cont.*

AFBS Code	Frequency of Appearance		Fixed Effect Model						Random Effects Model for Factors with Heterogeneity						Overall Rank
	Freq	Rank (1)	$\overline{es}$	Rank (2)	95% CI	Q	I^2 (%)	Z-Score p-Value	$\overline{es_v}$	Rank (3)	Q_v	$I^2{}_v$ (%)	Z-Score p-Value	95% CI	
3.6	6	6	0.727	11	0.656–0.797	2.638	0	20.225							11
3.7	4	8	0.639	31	0.545–0.732	2.769	0	13.443							33
3.8	8	4	0.687	20	0.628–0.746	9.069	0	22.745							21
4.1.1	4	8	0.756	7	0.669–0.844	1.496	0	16.887							7
4.1.2	7	5	0.707	15	0.644–0.770	4.349	0	22.014							16
4.2.1	4	8	0.696	19	0.611–0.780	1.856	0	16.110							20
5.1.1	7	5	0.786	3	0.712–0.860	2.958	0	20.771							3
5.1.2	6	6	0.763	6	0.639–0.833	1.546	0	21.375							6
5.2.2	9	3	0.734	9	0.676–0.793	12.986	0	24.579							9
5.2.3	6	6	0.659	26	0.597–0.721	8.344	0	20.803							26
5.2.4	6	6	0.566	45	0.502–0.631	12.700	0	17.177							44
5.2.5	8	4	0.807	2	0.743–0.871	9.966	0	24.648							2
5.2.6	4	8	0.578	40	0.503–0.654	5.874	0	15.056							41
5.2.7	6	6	0.680	22	0.606–0.753	3.758	0	18.082							22
5.2.8	9	3	0.684	21	0.627–0.740	30.799	51	23.721	0.709	1	10.497	0	13.792	0.608–0.809	14

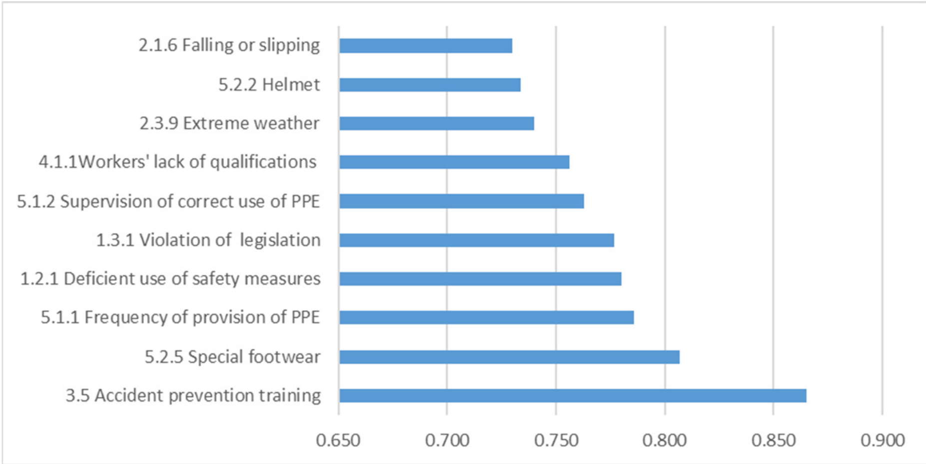

Figure 2. Top ten accident-contributing factors based on construction site experience ($\overline{es}$ values).

Forest plots are the typical way of visualizing the results of meta-analyses. They provide a clear and direct picture of the meta-analysis, and their interpretation requires no special knowledge. They are the graphical method of detecting heterogeneity, where confidence intervals are visually interpreted. Forest plots show the results of both the individual studies (*es*) and the meta-analysis aggregate result ($\overline{es}$). It is also possible to draw several conclusions:

- Whether the summary effect is derived from the synthesis of a large or small number of studies;
- Whether the effect sizes of the individual studies have close numerical values, and whether their confidence intervals (95%) overlap;
- Whether the effect summary is based on many or few studies;
- Whether studies with extreme effect size values are included in the meta-analysis [44].

Figures 3–5 present the forest plots for the 10 highest-ranking factors identified in the meta-analysis, where they were multiplied by one hundred to obtain percentages. They show impact estimates and confidence intervals at the 95% confidence level of individual studies (i.e., individual error indices on the y-axis) and summary results from the meta-analysis. The lowest indicator at the base of each diagram that is crossed by a vertical line indicates the effect summary ($\overline{es}$). Further, variations between studies that contributed differently to the estimate of the pooled result can be detected. At the same time, the horizontal lines show the extent of the 95% confidence interval.

Figures 3–5 show that those studies with effect sizes to the right of the aggregate effect summary line contribute positively to its value, while those to the left contribute negatively. Furthermore, studies with longer horizontal lines have a large confidence interval and are less precise in determining the summary effect size ($\overline{es}$) [54,84]. For example, in Figure 4, in the forest plot for the factor "Deficient use of safety measures (1.2.1)", we observe that the number of studies that add to the summary result either positively or negatively is two on both sides (right and left) of the vertical line, respectively. Furthermore, the error bars for each study suggest less precision in those studies with relatively broad widths of the of the confidence interval line. However, in a meta-analysis, the accuracy of the summary of the result is more critical than the accuracy of each study [54].

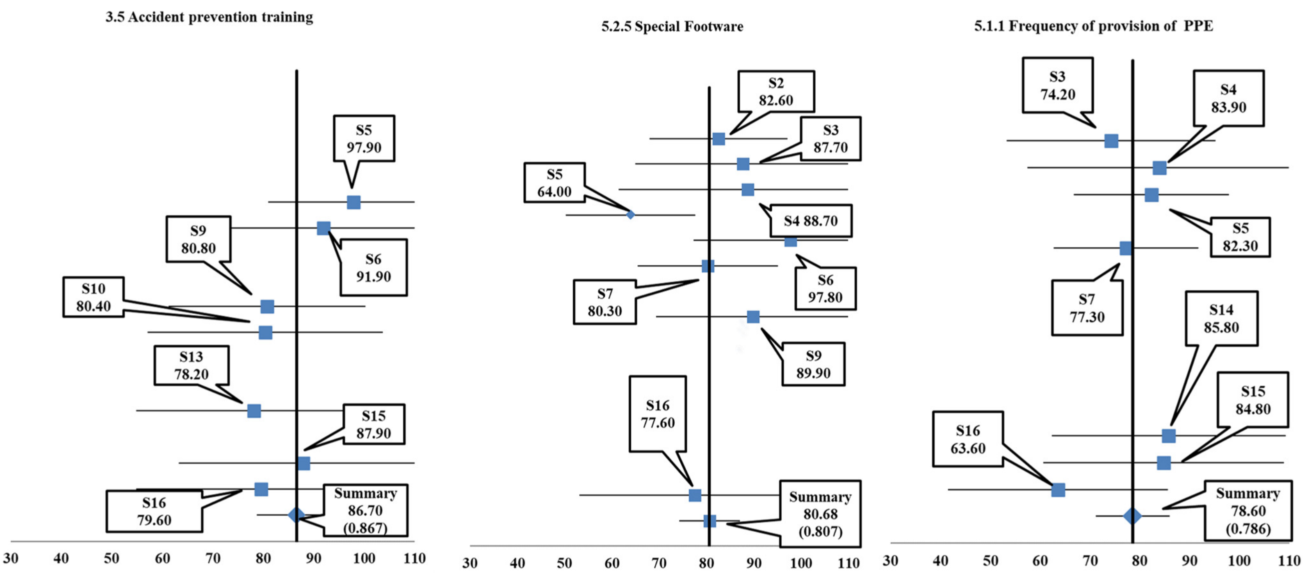

Figure 3. Forest plots for factors 3.5, 5.2.5, and 5.1.1.

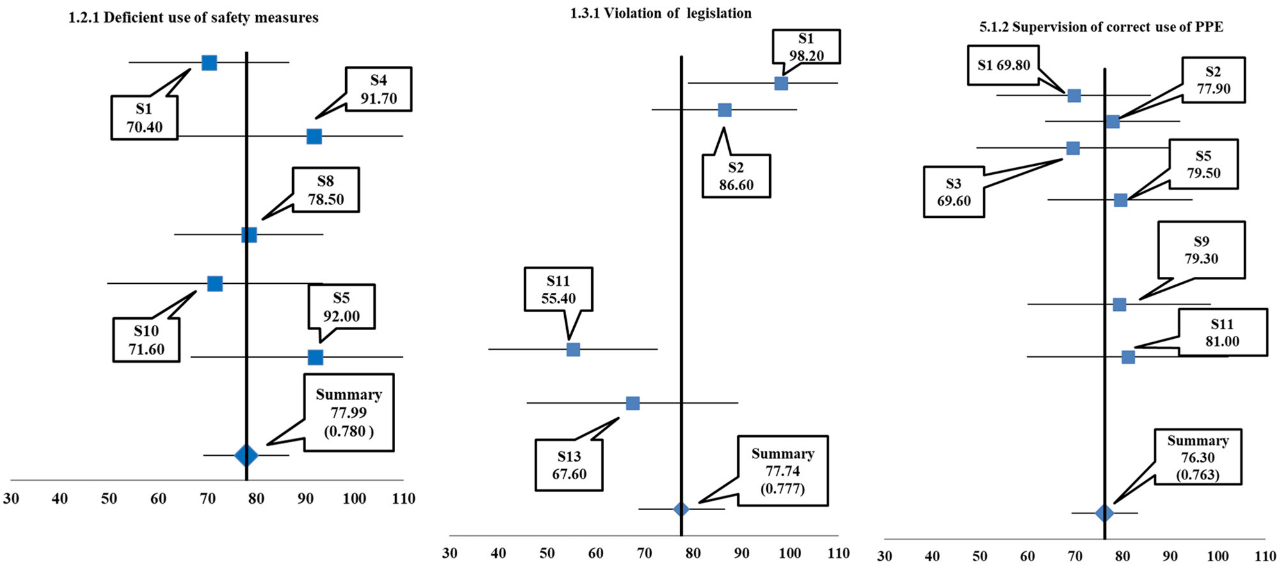

Figure 4. Forest plots for factors 1.2.1, 1.3.1, and 5.1.2.

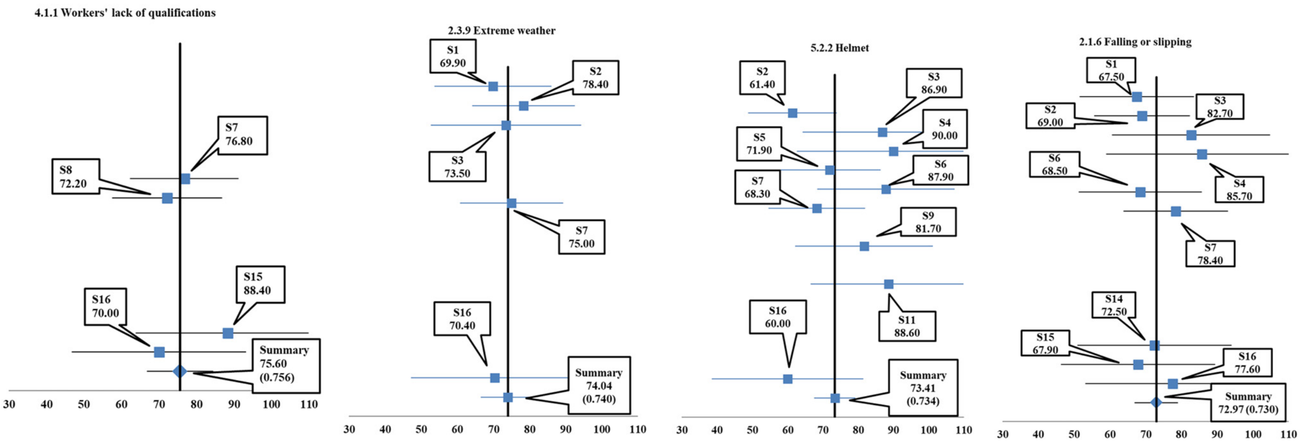

Figure 5. Forest plots for factors 4.1.1, 2.3.9, 5.2.2, and 2.1.6.

3.2. Meta-Analysis of Real-Accident-Based Studies

The previously described and applied statistical meta-analysis method using fixed or random effect models can only include studies that rate factors on a Likert scale and provide average values or RII for each accident-contributing factor examined, whereas the ORI method can be applied in all cases, as long as the results of the primary studies present a ranked list of the top ten factors as determined, regardless of their data source [55].

Hence, to rank the accident-contributing factors examined by the nine studies based on data from actual accident records or statistics, their ranking position in each study was considered. Their ORI was calculated based on the mathematical formula shown in Equation (2), as defined by Zidane and Andersen [55], to distinguish from the calculation of the RII described previously. Each factor's ORI was calculated by Equation (2), where F equals the total number of studies being analyzed with this method, i is the factor rank in each study, and N_i corresponds to the number of times the particular factor has held position in all studies.

$$ORI = \frac{1}{F} \times \sum_{i=1}^{10} N_i * \sum_{i=1}^{10} \frac{N_i}{i} \tag{2}$$

Initially, 80 accident-contributing factors were found in the 9 studies based on actual accident data. Following a consolidation/summarization process, 20 accident-contributing factors emerged that were ranked at least once in the top 10. All twenty factors are included in the 62 total AFBS factors presented in Antoniou and Agrafioti [50]. Two studies (S19 and S21) rated factors using two different methods. Therefore, both ranking lists resulting from these studies were used as two separate studies, giving a total of 11 studies to be analyzed. Therefore, a 62-row by 11-column table was set up in MS Excel. A value between 1 to 10 representing the rank achieved by a particular factor (row) in a particular study (column) was included in the corresponding cell. The cell was left blank if a factor was not included or ranked lower than 10 in the original study. By applying Equation (2), the ORI values for each factor were derived, and those for the top 10 are presented in Table 7 and Figure 6.

Table 7. Rankings per study, occurrence frequency (N_i), and *ORI* values.

AFBS Code	Factors	S17	S18	S19a	S19b	S20	S21a	S21b	S22	S23	S24	S25	N_i	*ORI*
1.2.1	Deficient use of safety measures								7				1	0.013
1.4.1	Inadequate training								1		2		2	0.273
2.1.3	Hazardous site environmental conditions								5		5		2	0.073
2.1.4	Objects falling or being ejected	2	2						8			4	4	0.500
2.1.5	Being crushed by or caught between objects	4							9			3	3	0.189
2.1.6	Falling or slipping (values refer to falling)	2	5						2			1	4	0.8
2.1.6	Falling or slipping (values refer to slipping)	2	3	1	1	1	1	2		1			8	4.606
2.1.8	Poor machinery or vehicle operation								4	5			2	0.082
2.1.9	Equipment safety deficiencies			3	4	3	4	5	6	2			7	1.294
2.1.13	Risk of electrocution	5	8	7	6	5	7	7		4		2	9	1.530
2.1.14	Explosions and fires			6	7	6	6	6		6			6	0.532
2.1.15	Material breakage, slippage or falling			4	5	4	3	4					5	0.583
2.1.16	Liquids: spillage, leakage, evaporation, emission			5	3	8	8	8		8			6	0.564
2.1.17	Unanticipated events										6		1	0.015
2.1.18	Other factors			2	2	2	2	3		3	4	5	8	2.267
2.2.1	Exposure to occupational diseases											6	1	0.015
2.2.5	Biological factors	3											1	0.030
2.3.4	Stress (physical/mental)	8		8	8	7	5	1	10	7	3		9	2.389
2.3.7	Mental capacity, bad habits										1		1	0.091
2.3.9	Extreme weather	10							3				2	0.079

For example, for the factor "Risk of electrocution (2.1.13)", it can be seen in Table 7 that it was ranked once in second place, once in fourth place, twice in fifth place, once in sixth place, three times in seventh place and once in eighth place. Hence, by using Equation (2), as results shown in Equation (3)

$$ORI_{2.1.13} = \frac{1}{F} \times \sum_{i=1}^{10} N_i \times \sum_{i=1}^{10} \frac{N_i}{i} = \frac{1}{11} \times (1+1+2+1+3+1) \times (\frac{1}{2} + \frac{1}{4} + \frac{2}{5} + \frac{1}{6} + \frac{3}{7} + \frac{1}{8}) = 1.53 \tag{3}$$

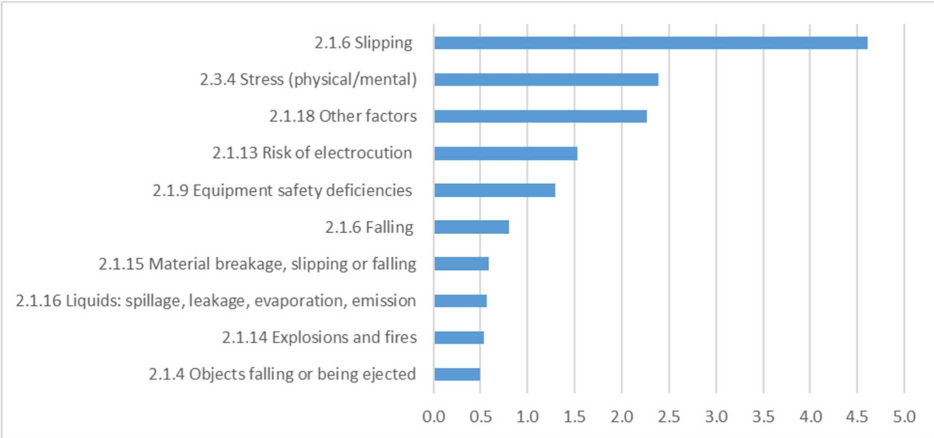

Figure 6. Top 10 accident-contributing factors based on real accident data (ORI values).

4. Discussion

To facilitate the discussion of the results of the previously described meta-analyses, a comparative table was prepared (Table 8). It includes the top ten ranking factors as found by the fixed effect and random effects models used to analyze the results of the sixteen studies based on the opinions of construction site professionals compared to those found by the ORI method applied to the nine studies that derived their data from actual accident records or statistics. In addition, the top 10 factors produced by the calculation of the ORI for all accident-contributing factors examined by all studies previously published by the authors [50] are also juxtaposed to derive more compelling results.

Table 8. Comparative table of top 10 factors according to the data source.

Rank	Opinion-Based Data $\overline{es}$ or $\overline{es_v}$ (16 Studies)	Accident Based Data *ORI* (9 Studies)	All Studies *ORI* (25 Studies) [50]
1	3.5 Accident prevention training	2.1.6 Slipping	2.1.6 Falling or slipping
2	5.2.5 Special footwear	2.3.4 Stress (physical/mental)	5.2.5 Special footwear
3	5.1.1 Frequency of provision of PPE	2.1.18 Other factors	2.3.4 Stress (physical/mental)
4	1.2.1 Deficient use of safety measures	2.1.13 Risk of electrocution	3.8 Safety legislation training
5	1.3.1 Violation of legislation	2.1.9 Equipment safety deficiencies	2.1.4 Objects falling or being ejected
6	5.1.2 Supervision of correct use of PPE	2.1.6 Falling	2.1.13 Risk of electrocution hazards
7	4.1.1 Workers' lack of qualifications	2.1.15 Material breakage, slippage or falling	2.1.18 Other factors
8	2.3.9 Extreme weather	2.1.16 Liquids: spillage, leakage, evaporation, emission	1.1.1. Noncompliance to safety rules
9	5.2.2 Helmet	2.1.14 Explosions and fires	2.1.8 Poor machinery or vehicle operation
10	2.1.6 Falling or slipping	2.1.4 Objects falling or being ejected	1.2.1 Deficient use of safety measures

The comparative Table 8 presents very different results between the meta-analysis of opinion-based studies and actual accident data ones. More specifically, the meta-analysis based on actual accidents highlighted as important only factors from the "Occupational Risk (2.0)" category while the meta-analyses of those factors examined by studies based on opinion promoted only two factors from category 2.0 and four from the "Safety Equipment category (5.0)", two from the "Safety Culture (1.0)" category, and one from each of the remaining two categories ("Worker Training Deficiencies (3.0)" and "Occupational Satisfaction (4.0)"). This indicates the significance of the data source of the individual studies used in a meta-analysis. The opinion-based results enhance the opinion that deficiencies in the training of accident prevention measures (3.5), the lack of proper use of safety measures (1.2.1), violation of safety legislation (1.3.1), and the lack of appropriate worker qualifications (4.1.1) lead to construction site accidents. All these factors are related to operative behavior on site, which, in most cases, are not documented as factors when actual accident causes are investigated. Similarly, the combined opinions of site-experienced participants also recognize the need to ensure frequent provision of PPE (5.1.1), especially special footwear (5.2.5) and helmets (5.2.2), as well as the need for better supervision of the proper use of PPE (5.1.2). Finally, the combined experienced opinion showed that the most frequently encountered occupational risks are “Exposure to extreme weather (2.3.9)” and “Falling or slipping (2.1.6)”.

Of these occupational risks, only “Falling or slipping (2.1.6)” was verified by the meta-analysis based on the nine studies using actual accident records or statistics as their data source. This single common factor appeared in the nine opinion-based studies, ranked nine times in the top ten, six of which were in first place. This coincides with findings by [10] and Phoya et al. [11], where falls from heights in Malaysia and Tanzania were found to be the most significant cause of accidents in their construction industries.

It is interesting to note that nine out of the top 10 accident-data-based meta-analysis factors are from the “Accident Risks (2.1)” subcategory, i.e., “Falling or slipping (2.1.6)”, “Other factors (2.1.18)”, “Risk of electrocution (2.1.13)”, “Equipment safety deficiencies (2.19)”, “Material breakage, slippage or falling (2.1.15)”, “Liquids: spillage, leakage, evaporation, emission (2.1.16)”, and “Explosions and fires (2.1.14)”. Only one is from the “Organizational Risks” subcategory (“Stress (physical/mental) (2.3.4)”). This is an obvious result since the source of data in all these studies was statistical data available from the Greek Work Inspection Organization, which included event-specific data such as type of accident, type of injury, the related dangerous situation under which the accident occurred, the time of the accident, the injured body part, and the material factor. Out of these, only the type of accident, the dangerous situation, and the material factor categories contained information relating to the causes of the accident [19]. Factors included and described as “type of accident” include falls, being struck by falling objects, walking or hitting objects, compression in/between, overworking, exposure to high temperature, contact with electricity, and exposure to harmful substances or radiation. Similarly, factors such as unsuitable workplace, dangerous situation, floors, corridors, fixed ladders, emergency exits, work positions, arranging, machinery, facilities, tools and equipment, organization and safety management and work environment are considered when examining the “dangerous situation” that caused the accident. Finally, in the “material factor” category, factors relating to means of transport and lifting equipment, general equipment issues, materials, substances, or radiation found in the work environment may be noted. As a result, these studies could not provide information related to other accident-contributing factors from categories “Safety Culture (1.0)”, “Worker Training Deficiencies (3.0)”, or “Occupational Satisfaction (4.0)”.

The last significant conclusion drawn from comparative Table 8 is evident when comparing the previous results published by the authors [50] with the results of this research paper. In Antoniou and Agrafioti [50], all 25 studies were included in the meta-analysis, and the ORI methodology was applied. A natural conclusion would be to assume that it would consist of only factors from the top 10 of each separate meta-analysis per data source. Instead, three factors emerged in the top 10 when all 25 studies were compared, but not in either of the other two distinct cases examined in this study. These factors are “Safety legislation training (3.8)”, “Noncompliance to safety rules (1.1.1)”, and “Poor machinery or vehicle operation (2.1.8)”. This can only be attributed to the use of the ORI method, which evaluated the importance of each factor based on the ranking it achieved in each study, regardless of the method used in the original study, and ignored factors ranking lower than tenth place in any of the studies.

5. Conclusions

The existence of hundreds of research studies by construction management postgraduate students during the past twenty years in Greece emphasizes the industry’s concern regarding identifying and mitigating contributing factors to accidents in national construction sites. Of these, only one that evaluates accident-contributing factors based on the expertise of participants was published in an international scientific journal [26], even though it is a standard research method. Two published studies used statistical data available from the national H&S bodies [6,19] that gave specific data related to the accident type, the victim, and the direct cause of the accident.

Therefore, the novelty of this study is that it seeks to define the main factors leading to accidents by unifying the results of multiple analogous studies at the postgraduate level to determine if the data source (opinion or actual accident data) leads to differing conclusions. Meta-analysis techniques are used to surmount imperfections of each individual study, like small sample sizes, different focus groups, and deficient detail in studies based only on published statistical data.

The results showed significant differences that indicate the need to investigate accident-contributing factors further by using a combination of data sources. Results based on opinion, intuition, and safety culture promoted factors related to operative behavior on site as the most significant accident-contributing factors. At the same time, the results of the analysis of actual accident data focuses on on-site risk factors of the construction process itself as most important. Since opinion-based studies take a broader view of the problem than those based on actual accident data, it is postulated that the opinions expressed when rating the importance of accident-contributing factors should not be considered independently of data from actual accident records. A combination of the two can be achieved if a questionnaire is circulated to all working in the construction site when an accident occurs to obtain a more contextual opinion on the factors that led to the specific accident while at the same time considering the event-specific data gathered for the Greek Work Inspection Organization.

Therefore, such further research should be carried out by targeting the opinions of construction site professionals on the causes and context of specific actual accidents that they have had direct personal experience with and examining the relevant accident records for each accident. Following up on the work by Antoniou and Merkouri [26], who found that building, urban renovations, and urban road projects are the most prone to construction site accidents in Greece, these project types should be prioritized and investigated using a hybrid data collection method including expert opinion and actual accident data via in-depth interviews and analytical quantitative and qualitative analysis of the data provided by accident records. Another interesting aspect to consider for further research is to carry out a meta-analysis of international studies, such as those presented in Table 1, to define a global or even a European rank of accident-contributing factors in terms of importance. This will enable country-specific researchers to use this global ranking as a benchmark to evaluate the level of safety awareness in their construction industry as compared to other countries.

In addition, even though the general opinion that lack of training on preventive measures is a significant accident-contributing factor is not backed up by actual accident data, this factor has been red-flagged repeatedly by Antoniou and Merkouri [26], Antoniou and Agafioti [50], Betsis et al. [19], and Katsakiori [6]. To contribute to this end, researchers and practitioners alike should seek to take advantage of new technologies in the digital era, such as virtual reality simulation (VRS), as proposed by Zhao and Lucas [87]. Using VRS, virtual site-specific training programs can be developed for workers to rehearse safe work practices during risky construction stages and practice intervention actions when facing a pseudo-accident scenario.

A limitation of this study is that it focuses on the Greek construction industry, and its results have significance to stakeholders in Greece. Nevertheless, there are bound to be abundant similar studies by postgraduate students all over Europe. If similar meta-analyses for a series of country-specific industries were conducted and compared, the results could become a starting point for lessening the gap between the status of construction site accidents (actual accident statistics) and expectations (professional opinion) in Europe.

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References

1. Suraji, A. Construction Accidents and the Lesson Learnt from 1000 Cases. *Int. J. Constr. Manag.* **2003**, *3*, 41–49. [CrossRef]
2. Fang, D.P.; Xie, F.; Huang, X.Y.; Li, H. Factor Analysis-Based Studies on Construction Workplace Safety Management in China. *Int. J. Proj. Manag.* **2004**, *22*, 43–49. [CrossRef]
3. Haslam, R.A.; Hide, S.A.; Gibb, A.G.F.; Gyi, D.E.; Pavitt, T.; Atkinson, S.; Duff, A.R. Contributing Factors in Construction Accidents. *Appl. Ergon.* **2005**, *36*, 401–415. [CrossRef]
4. Ng, S.T.; Cheng, K.P.; Skitmore, R.M. A Framework for Evaluating the Safety Performance of Construction Contractors. *Build. Environ.* **2005**, *40*, 1347–1355. [CrossRef]
5. Choudhry, R.M.; Fang, D.; Mohamed, S. The Nature of Safety Culture: A Survey of the State-of-the-Art. *Saf. Sci.* **2007**, *45*, 993–1012. [CrossRef]
6. Katsakiori, P.; Manatakis, E.; Goutsos, S.; Athanassiou, G. Factors Attributed to Fatal Occupational Accidents in a Period of 5 Years Preceding the Athens 2004 Olympic Games. *Int. J. Occup. Saf. Ergon.* **2008**, *14*, 285–292. [CrossRef] [PubMed]
7. Hon, C.K.H.; Chan, A.P.C.; Wong, F.K.W. An Analysis for the Causes of Accidents of Repair, Maintenance, Alteration and Addition Works in Hong Kong. *Saf. Sci.* **2010**, *48*, 894–901. [CrossRef]
8. Cheng, C.W.; Leu, S.S.; Lin, C.C.; Fan, C. Characteristic Analysis of Occupational Accidents at Small Construction Enterprises. *Saf. Sci.* **2010**, *48*, 698–707. [CrossRef]
9. Behm, M.; Schneller, A. Application of the Loughborough Construction Accident Causation Model: A Framework for Organizational Learning. *Constr. Manag. Econ.* **2013**, *31*, 580–595. [CrossRef]
10. Chong, H.Y.; Low, T.S. Accidents in Malaysian Construction Industry: Statistical Data and Court Cases. *Int. J. Occup. Saf. Ergon.* **2014**, *20*, 503–513. [CrossRef]
11. Phoya, S.; Eliufoo, H.; Pietrzyk, K.; Nyström, M. Assessment of Health and Safety Risk Perception of Site Managers, Supervisors and Workers in Tanzania Urban Construction Sites. In Proceedings of the CIB W099 Conference, Washington, DC, USA, 24–26 August 2011. Available online: https://www.irbnet.de/daten/iconda/CIB_DC24275.pdf (accessed on 29 September 2023).
12. Fard, M.M.; Terouhid, S.A.; Kibert, C.J.; Hakim, H. Safety Concerns Related to Modular/Prefabricated Building Construction. *Int. J. Inj. Contr. Saf. Promot.* **2017**, *24*, 10–23. [CrossRef] [PubMed]
13. Amiri, M.; Ardeshir, A.; Fazel Zarandi, M.H.; Soltanaghaei, E. Pattern Extraction for High-Risk Accidents in the Construction Industry: A Data-Mining Approach. *Int. J. Inj. Contr. Saf. Promot.* **2016**, *23*, 264–276. [CrossRef]
14. Carrillo-Castrillo, J.A.; Trillo-Cabello, A.F.; Rubio-Romero, J.C. Construction Accidents: Identification of the Main Associations between Causes, Mechanisms and Stages of the Construction Process. *Int. J. Occup. Saf. Ergon.* **2017**, *23*, 240–250. [CrossRef]
15. Hoła, B.; Nowobilski, T.; Szer, I.; Szer, J. Identification of Factors Affecting the Accident Rate in the Construction Industry. *Procedia Eng.* **2017**, *208*, 35–42. [CrossRef]
16. Andersen, L.P.; Nørdam, L.; Joensson, T.; Kines, P.; Nielsen, K.J. Social Identity, Safety Climate and Self-Reported Accidents among Construction Workers. *Constr. Manag. Econ.* **2018**, *36*, 22–31. [CrossRef]
17. Winge, S.; Albrechtsen, E.; Mostue, B.A. Causal Factors and Connections in Construction Accidents. *Saf. Sci.* **2019**, *112*, 130–141. [CrossRef]
18. Yap, J.B.H.; Lee, W.K. Analysing the Underlying Factors Affecting Safety Performance in Building Construction. *Prod. Plan. Control* **2020**, *31*, 1061–1076. [CrossRef]
19. Betsis, S.; Kalogirou, M.; Aretoulis, G.; Pertzinidou, M. Work Accidents Correlation Analysis for Construction Projects in Northern Greece 2003–2007: A Retrospective Study. *Safety* **2019**, *5*, 33. [CrossRef]
20. Zhang, W.; Zhu, S.; Zhang, X.; Zhao, T. Identification of Critical Causes of Construction Accidents in China Using a Model Based on System Thinking and Case Analysis. *Saf. Sci.* **2020**, *121*, 606–618. [CrossRef]
21. Chen, Y. The Development and Validation of a Human Factors Analysis and Classification System for the Construction Industry. *Int. J. Occup. Saf. Ergon.* **2020**, *28*, 479–493. [CrossRef]
22. Mosly, I. Factors Influencing Safety Performance in the Construction Industry of Saudi Arabia: An Exploratory Factor Analysis. *Int. J. Occup. Saf. Ergon.* **2022**, *28*, 901–908. [CrossRef] [PubMed]
23. Tayeh, B.A.; Salem, T.J.; Abu Aisheh, Y.I.; Alaloul, W.S. Risk Factors Affecting the Performance of Construction Projects in Gaza Strip. *Open Civ. Eng. J.* **2020**, *14*, 94–104. [CrossRef]
24. Asilian-Mahabadi, H.; Khosravi, Y.; Hassanzadeh-Rangi, N.; Hajizadeh, E.; Behzadan, A.H. Factors Affecting Unsafe Behavior in Construction Projects: Development and Validation of a New Questionnaire. *Int. J. Occup. Saf. Ergon.* **2020**, *26*, 219–226. [CrossRef]

25. Alamneh, Y.M.; Wondifraw, A.Z.; Negesse, A.; Ketema, D.B.; Akalu, T.Y. The Prevalence of Occupational Injury and Its Associated Factors in Ethiopia: A Systematic Review and Meta-Analysis. *J. Occup. Med. Toxicol.* **2020**, *15*, 14. [CrossRef]
26. Antoniou, F.; Merkouri, M. Accident Factors per Construction Type and Stage: A Synthesis of Scientific Research and Professional Experience. *Int. J. Inj. Contr. Saf. Promot.* **2021**, *28*, 439–453. [CrossRef] [PubMed]
27. Ashuro, Z.; Zele, Y.T.; Kabthymer, R.H.; Diriba, K.; Tesfaw, A.; Alamneh, A.A. Prevalence of Work-Related Injury and Its Determinants among Construction Workers in Ethiopia: A Systematic Review and Meta-Analysis. *J. Environ. Public Health* **2021**, *2021*, 9954084. [CrossRef] [PubMed]
28. Meseret, M.; Ehetie, T.; Hailye, G.; Regasa, Z.; Biruk, K. Occupational Injury and Associated Factors among Construction Workers in Ethiopia: A Systematic and Meta-Analysis. *Arch. Environ. Occup. Health* **2022**, *77*, 328–337. [CrossRef]
29. Amoatey, C.T.; Ankrah, A.N.O. Exploring Critical Road Project Delay Factors in Ghana. *J. Facil. Manag.* **2017**, *15*, 110–127. [CrossRef]
30. Antoniou, F. Delay Risk Assessment Models for Road Projects. *Systems* **2021**, *9*, 70. [CrossRef]
31. Kaliba, C.; Muya, M.; Mumba, K. Cost Escalation and Schedule Delays in Road Construction Projects in Zambia. *Int. J. Proj. Manag.* **2009**, *27*, 522–531. [CrossRef]
32. Mahamid, I.; Bruland, A.; Dmaidi, N. Causes of Delay in Road Construction Projects. *J. Manag. Eng.* **2012**, *28*, 300–310. [CrossRef]
33. Sanni-Anibire, M.O.; Mohamad Zin, R.; Olatunji, S.O. Causes of Delay in the Global Construction Industry: A Meta Analytical Review. *Int. J. Constr. Manag.* **2022**, *22*, 1395–1407. [CrossRef]
34. Vu, H.A.; Cu, V.H.; Min, L.X.; Wang, J.Q. Risk Analysis of Schedule Delays in International Highway Projects in Vietnam Using a Structural Equation Model. *Eng. Constr. Archit. Manag.* **2017**, *24*, 1018–1039. [CrossRef]
35. Edwards, D.J.; Owusu-Manu, D.-G.; Baiden, B.; Badu, E.; Love, P.E. Financial Distress and Highway Infrastructure Delays. *J. Eng. Des. Technol.* **2017**, *15*, 118–132. [CrossRef]
36. Sharma, S.; Goyal, P.K. Fuzzy Assessment of the Risk Factors Causing Cost Overrun in Construction Industry. *Evol. Intell.* **2022**, *15*, 2269–2281. [CrossRef]
37. Wu, Z.; Nisar, T.; Kapletia, D.; Prabhakar, G. Risk Factors for Project Success in the Chinese Construction Industry. *J. Manuf. Technol. Manag.* **2017**, *28*, 850–866. [CrossRef]
38. Aretoulis, G.N.; Papathanasiou, J.; Antoniou, F. PROMETHEE-Based Ranking of Project Managers Based on the Five Personality Traits. *Kybernetes* **2020**, *49*, 1083–1102. [CrossRef]
39. Gupta, P.; Anand, S.; Gupta, H. Developing a Roadmap to Overcome Barriers to Energy Efficiency in Buildings Using Best Worst Method. *Sustain. Cities Soc.* **2017**, *31*, 244–259. [CrossRef]
40. Abdul Nabi, M.; El-adaway, I.H. Understanding Disputes in Modular Construction Projects: Key Common Causes and Their Associations. *J. Constr. Eng. Manag.* **2022**, *148*, 04021184. [CrossRef]
41. Mishmish, M.; El-Sayegh, S.M. Causes of Claims in Road Construction Projects in the UAE. *Int. J. Constr. Manag.* **2018**, *18*, 26–33. [CrossRef]
42. Shen, W.; Tang, W.; Yu, W.; Duffield, C.F.; Hui, F.K.P.; Wei, Y.; Fang, J. Causes of Contractors' Claims in International Engineering-Procurement-Construction Projects. *J. Civ. Eng. Manag.* **2017**, *23*, 727–739. [CrossRef]
43. Antoniou, F.; Aretoulis, G.N.; Konstantinidis, D.K.; Kalfakakou, G.P. An Empirical Study of Researchers' and Practitioners' Views on Compensating Major Highway Project Contractors. *Int. J. Manag. Decis. Mak.* **2013**, *12*, 351–375. [CrossRef]
44. Oo, B.L.; Lim, T.H.B.; Runeson, G. Critical Factors Affecting Contractors' Decision to Bid: A Global Perspective. *Buildings* **2022**, *12*, 379. [CrossRef]
45. Abbasi, G.; Abbasi, G.Y.; Abdel-Jaber, M.S.; Abu-Khadejeh, A. Risk Analysis for the Major Factors Affecting the Construction Industry in Jordan. *Emir. J. Eng. Res.* **2005**, *10*, 41–47.
46. Jozi, S.A.; Shafiee, M.; MoradiMajd, N.; Saffarian, S. An Integrated Shannon's Entropy–TOPSIS Methodology for Environmental Risk Assessment of Helleh Protected Area in Iran. *Environ. Monit. Assess.* **2012**, *184*, 6913–6922. [CrossRef] [PubMed]
47. Aminbakhsh, S.; Gunduz, M.; Sonmez, R. Safety Risk Assessment Using Analytic Hierarchy Process (AHP) during Planning and Budgeting of Construction Projects. *J. Saf. Res.* **2013**, *46*, 99–105. [CrossRef]
48. Zayed, T.; Amer, M.; Pan, J. Assessing Risk and Uncertainty Inherent in Chinese Highway Projects Using AHP. *Int. J. Proj. Manag.* **2008**, *26*, 408–419. [CrossRef]
49. Marinelli, M.; Janardhanan, M. Green Cement Production in India: Prioritization and Alleviation of Barriers Using the Best–Worst Method. *Environ. Sci. Pollut. Res.* **2022**, *29*, 63988–64003. [CrossRef] [PubMed]
50. Antoniou, F.; Agrafioti, N.F. Meta-Analysis of Studies on Accident Contributing Factors in the Greek Construction Industry. *Sustainability* **2023**, *15*, 2357. [CrossRef]
51. Kalogeraki, M.; Antoniou, F. Improving Risk Assessment for Transporting Dangerous Goods through European Road Tunnels: A Delphi Study. *Systems* **2021**, *9*, 80. [CrossRef]
52. Koulinas, G.K.; Marhavilas, P.K.; Demesouka, O.E.; Vavatsikos, A.P.; Koulouriotis, D.E. Risk Analysis and Assessment in the Worksites Using the Fuzzy-Analytical Hierarchy Process and a Quantitative Technique—A Case Study for the Greek Construction Sector. *Saf. Sci.* **2019**, *112*, 96–104. [CrossRef]
53. Glass, G.V. Primary, Secondary, and Meta-Analysis of Research. *Educ. Res.* **1976**, *5*, 3. [CrossRef]
54. Borenstein, M.; Hedges, L.V.; Higgins, J.P.T.; Rothstein, H.R. A Basic Introduction to Fixed-Effect and Random-Effects Models for Meta-Analysis. *Res. Synth. Methods* **2010**, *1*, 97–111. [CrossRef]

55. Zidane, Y.J.-T.; Andersen, B. The Top 10 Universal Delay Factors in Construction Projects. *Int. J. Manag. Proj. Bus.* **2018**, *11*, 650–672. [CrossRef]
56. Hu, K.; Rahmandad, H.; Smith-Jackson, T.; Winchester, W. Factors Influencing the Risk of Falls in the Construction Industry: A Review of the Evidence. *Constr. Manag. Econ.* **2011**, *29*, 397–416. [CrossRef]
57. Nadhim, E.; Hon, C.; Xia, B.; Stewart, I.; Fang, D. Falls from Height in the Construction Industry: A Critical Review of the Scientific Literature. *Int. J. Environ. Res. Public Health* **2016**, *13*, 638. [CrossRef]
58. Tong, R.; Wang, L.; Cao, L.; Zhang, B.; Yang, X. Psychosocial Factors for Safety Performance of Construction Workers: Taking Stock and Looking Forward. *Eng. Constr. Archit. Manag.* **2021**, *30*. [CrossRef]
59. Newaz, M.T.; Davis, P.R.; Jefferies, M.; Pillay, M. Developing a Safety Climate Factor Model in Construction Research and Practice. *Eng. Constr. Archit. Manag.* **2018**, *25*, 738–757. [CrossRef]
60. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *BMJ* **2009**, *339*, 332–336. [CrossRef]
61. Kokkini, A.A. Risks and Risk Control Measures on Building Construction Sites: The Workers' Perspective. Master's Thesis, Hellenic Open University, Patras, Greece, 2020.
62. Papadatou, G. Factors Causing Occupational Accidents in Construction and Prevention Measures. Master's Thesis, Hellenic Open University, Patras, Greece, 2021.
63. Ritsa, O. Safety and Health in Engineering Projects. Master's Thesis, Hellenic Open University, Patras, Greece, 2019.
64. Tsianas, B. Safety of Underground Utilities Engineering Works in an Urban Environment. Master's Thesis, Hellenic Open University, Patras, Greece, 2020.
65. Kapelakis, G. Health and Safety during the Construction and Operation of Building D of the Hellenic Open University. Master's Thesis, Hellenic Open University, Patras, Greece, 2020.
66. Kotsalos, C. The Role of Worker Training in Reducing Occupational Accidents at Workplaces. Master's Thesis, Hellenic Open University, Patras, Greece, 2020.
67. Touloupi, F. Investigating the Relationship between Labour Productivity in Construction Projects in Relation to Health and Safety Conditions. Master's Thesis, Hellenic Open University, Patras, Greece, 2020.
68. Pantos, M. Factors Affecting Safety and Hygiene in Technical Works and the Response of Human Resources to Preventive Measures. Master's Thesis, Hellenic Open University, Patras, Greece, 2019.
69. Marazioti, M. The Role of the Human Factor in the Challenge of Occupational Accidents in Technical Projects. Master's Thesis, Hellenic Open University, Patras, Greece, 2019.
70. Pigounaki, C. Economic Crisis and Occupational Accidents in Construction Projects: Evidence from the Greek Reality. Master's Thesis, Hellenic Open University, Patras, Greece, 2018.
71. Theodorakopoulos, G. Safety Management Systems in Construction Projects. Master's Thesis, Hellenic Open University, Patras, Greece, 2016.
72. Alamanos, N. The Impact of Continuous Training in the Field of Safety and Hygiene: The Case of Metro Construction Sites. Master's Thesis, Hellenic Open University, Patras, Greece, 2017.
73. Papastathakis, A. Investigation to Ensure Safe Working Conditions in Construction and Industrial Installations. Master's Thesis, Hellenic Open University, Patras, Greece, 2018.
74. Charitonidou, A. Occupational Risk Assessment of Employees in Constrcution Companies in Western Macedonia—Subjective Perception of Employees. Master's Thesis, Hellenic Open University, Patras, Greece, 2015.
75. Tzegkas, S. Health and Safety in Formwork and Concrete Laying Construction Crews. Master's Thesis, Hellenic Open University, Patras, Greece, 2010.
76. Koulinas, G. Occupational Safety Risk Assessment Using the Analytical Hierarchy Process. Master's Thesis, Hellenic Open University, Patras, Greece, 2017.
77. Bougelis, G. Occupational Risk Assessment Using Risk Registers and FEAHPFTOPSIS Multi-Criteria Decision Making Methods—Application to a Gas Plant Construction Site. Master's Thesis, Hellenic Open University, Patras, Greece, 2021.
78. Vroudas, P. Risk Assessment in Construction Projects Using Accident Statistics. Master's Thesis, Hellenic Open University, Patras, Greece, 2016.
79. Fekos, D. Hazard Analysis and Risk Assessment in Occupational Safety and Health Using a Combination of Probabilistic and Causal Methods—Application to Construction Sites. Master's Thesis, Hellenic Open University, Patras, Greece, 2018.
80. Panagiotopoulos, A.P. Analysis of Occupational Accidents in the Construction Sector. Master's Thesis, Hellenic Open University, Patras, Greece, 2020.
81. Katsolas, P. Evolution of Occupational Accidents in Construction. Master's Thesis, Hellenic Open University, Patras, Greece, 2018.
82. Mylona, S. Safety Management in Technical Telecommunications Projects. Network Works and Installation of Mobile Telephone Base Stations. Master's Thesis, Hellenic Open University, Patras, Greece, 2019.
83. Hedges, L.V. Meta-Analysis. *J. Educ. Stat.* **1992**, *17*, 279–296. [CrossRef]
84. Neyeloff, J.L.; Fuchs, S.C.; Moreira, L.B. Meta-Analyses and Forest Plots Using a Microsoft Excel Spreadsheet: Step-by-Step Guide Focusing on Descriptive Data Analysis. *BMC Res. Notes* **2012**, *5*, 52. [CrossRef] [PubMed]
85. Holt, G.D. Asking Questions, Analysing Answers: Relative Importance Revisited. *Constr. Innov.* **2014**, *14*, 2–16. [CrossRef]

86. Higgins, J.P.T. Measuring Inconsistency in Meta-Analyses. *BMJ* **2003**, *327*, 557–560. [CrossRef] [PubMed]
87. Zhao, D.; Lucas, J. Virtual Reality Simulation for Construction Safety Promotion. *Int. J. Inj. Contr. Saf. Promot.* **2015**, *22*, 57–67. [CrossRef]