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Review Article

Occupational safety and health in construction: a review of applications and trends

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Abstract: Due to the high number of accidents that occur in construction and the consequences this has for workers, organizations, society and countries, occupational safety and health (OSH) has become a very important issue for stakeholders to take care of the human resource. For this reason, and in order to know how OSH research in the construction sector has evolved over time, this article – in which articles published in English were studied – presents an analysis of research conducted from 1930 to 2016. The classification of documents was carried out following the Occupational Safety and Health Cycle which is composed of five steps: regulation, education and training, risk assessment, risk prevention, and accident analysis. With the help of tree diagrams we show that evolution takes place. In addition, risk assessment, risk prevention, and accident analysis were the research topics with the highest number of papers. The main objective of the study was to contribute to knowledge of the subject, showing trends through an exploratory study that may serve as a starting point for further research.

Key words: Accident, Construction industry, Health, Risk, Occupational safety

Introduction

In most industrialized countries, the construction industry is one of the most significant industries in terms of contribution to gross domestic product (GDP). It also has a significant impact on the health and safety of workers. The construction industry is both economically and socially important[1)]. In construction, workers perform a great diversity of activities, each one with a specific associated risk. The worker who carries out a task is directly exposed to its associated risks and passively exposed to risks produced by nearby co-workers[2)]. Building design, materials, dimensions and site conditions are often unique, which requires adaptation and a learning curve from site to site. Injuries may occur in a number of ways and at every juncture of the process[3)].

As a result of this situation there is a high frequency of accidents in construction, which makes it an unsafe industry. Degree of safety in this selected sector of the economy is not indicated by a single accident but by a set of accidents that have occurred within a specified time interval. Knowledge about the noticeable trends in accidents is required in order to assess the level of safety and also directions for changes[4)].

Occupational safety and health is an area concerned with the development, promotion, and maintenance of the workplace environment, policies and programs that ensure the mental, physical, and emotional well-being of employees, as well as keeping the workplace environment relatively free from actual or potential hazards that

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could injure employees[5]. However, the number of articles regarding OSH in construction was small until fifteen years ago. Since 2001 the number of OSH publications relating to construction has increased. From different perspectives and using different tools researchers have studied occupational hazards in construction. Sousa, Almeida, and Dias[6] state that there are several tools and methods to investigate and understand occupational accidents in the construction industry.

In a systematic review of construction safety studies, Zhou *et al.*[7] found that of all the research topics 44.65% were pertinent to safety management process, 20.27% to the impact of individual and group/organizational characteristics, and 33.03% to accident/incident data. The body of research on safety management process involves safety planning, safety monitoring, safety assessment, safety measurement, safety performance etc.

Taking into account the previously stated remarks, the aim of our paper was to review the literature and define current trends in research in occupational safety and health applied to the construction industry. Trends were obtained through chronological evolution. Thus, they can be properly analyzed and further research can be developed from them.

Methodology

Our literature search analyzed only peer-reviewed papers associated with occupational safety and health in construction, because the state-of-the-art of a discipline is defined in these forums; some very relevant articles from conferences were also considered, and the scope of the research was determined by the following parameters:

– Language: English.
– Period: from 1930 to 2016
– Key descriptors: occupational risk; occupational accident; occupational safety; occupational prevention; occupational health; occupational safety and health and construction
– Databases: Ebsco Host, Science Direct and Scopus. These were selected as sources of information due to their size and the quality of the publications found in them, however for future research other sources may be considered

The first problem needing to be addressed was how to suitably classify all the information. Occupational safety and health is not a homogenous issue; quite the opposite, there are many stakeholders involved. Besides, it can be considered a multi-stage process. This process approach has already been suggested by many authors in risk management, as traditionally applied to project management[8) which proposes a similar process based on four stages: identification, analysis, response, and control. Moreover, the OHSAS 18001:2007 Standard[9] proposes a cycle based on continuous improvement which comprises of: establish corporate policies, plan, implement and operate, check and correct, review, and improve. These steps are compatible with the ISO 9001:2008 quality management system[10]. Finally, Carvajal[11] proposed a five-step cycle: regulation, education and training, risk assessment, risk prevention, and accident analysis. A new Occupational Safety and Health Cycle that includes safety climate was developed, adapting the cycle suggested by Carvajal, which is created in phases of education and training, risk assessment and risk prevention (Fig. 1).

However, a shortcut in this Occupational Safety and Health Cycle could appear if regulations (either from the company or from public agencies) are not analyzed, improved on, or at least implemented; and later, if education and training is not provided.

A company that does not seriously apply an occupational safety and health management system may enter into a spiral of unsafeness, trying to take the easiest way out of the cycle, and making it shorter and shorter each time until a serious accident takes place. In any event, a "culture of construction safety" should be implemented; this is defined[12, 13] as the whole group of knowledge, habits, and behaviors that drive companies to the willing application of safety and health approaches and procedures in the construction industry. This is a good way to achieve a "climate of safety", which implies a subjective perception and evaluation of safety issues related to the organization, its members, structures and processes, based on experience of the organizational environment and social relationships[14].

For this article, the previous cycle was taken as an example of a logical and continuous process with feedback, which allowed for an analysis of the evolution of research in occupational safety and health in construction. Risk assessment comprises risk identification and analysis, as stated in traditional risk management literature. Likewise, risk prevention consists of response and control. In order to highlight the importance of setting objectives and of organizational learning through time, two previous steps and a final one are added. Regulation is included to emphasize the significance of corporate policies issued by companies on one hand, and laws and standards issued by public agencies on the other. Training and education reflects the impact that the former steps have upon the people involved if some improvement needs to take place. Finally, accident

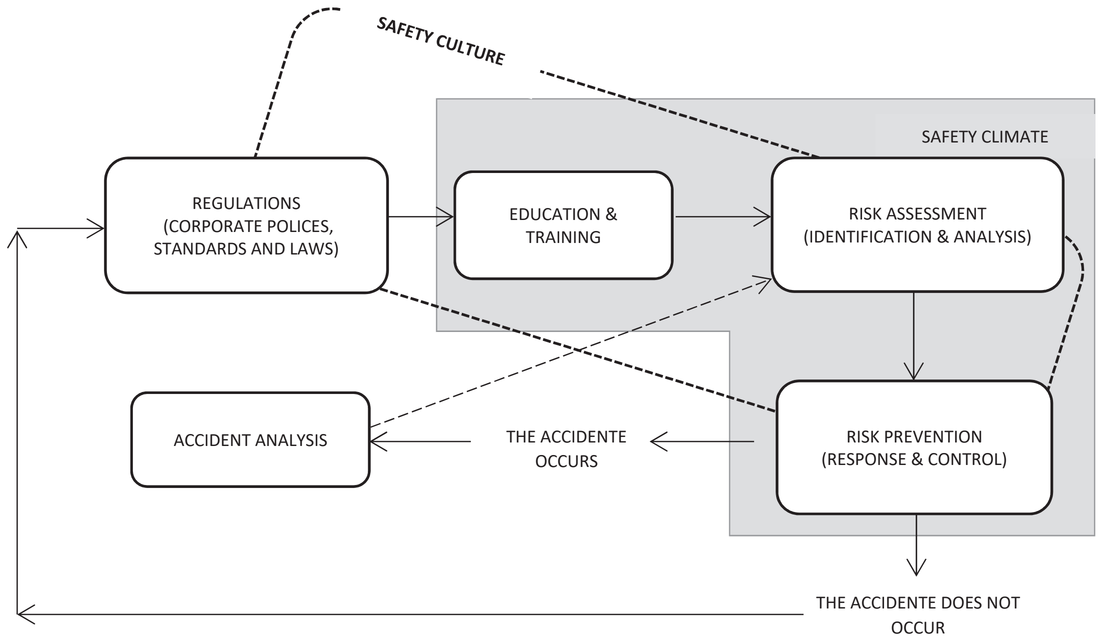

Fig. 1. Occupational Safety and Health Cycle. Adapted from Carvajal, G. I. (2008). ***Modelo de cuantificación de riesgos laborales en la construcción: RIES-CO*****. (Doctoral Thesis). Universidad Politécnica de Valencia, Valencia, España.**

analysis is needed to investigate the cause of accidents; thus, lessons can be learned and other accidents may be avoided in the future - obviously, this step is skipped if no accident occurs.

Articles were analyzed and classified in the Occupational Safety and Health Cycle, according to the suitability of their content according to each of the steps. Nevertheless, our goal was not to develop a bibliometric study, but to define chronological trends in research by using noteworthy articles to display the main milestones. Thus, in our second analysis of the papers, we chose only those significant articles that offered an added-value and could be used as references in a research trend. In this opportunity, the selection was developed by taking several aspects into consideration. Mainly, in order to be chosen, a paper must have enough qualitative references from other papers even if it does have many citations. Besides, we have rated the paper's degree of importance according to our assessment of the novelty of its ideas and the future influence of this particular manuscript on others. The analysis of the evolution of research was conducted following a logical sequence of ideas in the selected papers.

Results

Bibliographic analysis

In the first search we undertook, 285 articles were selected from 32 journals or proceedings. Papers chosen by journal and by time period are displayed in Table 1. It can be noted from this table that the number of papers has recently increased: in the period between 2001 and 2010, a total of 129 papers related to OSH in construction were published. This amounts to 45.3% of all articles included. Likewise, in the period between 2011 and 2016, a total of 57 papers were published. Although this period is shorter, it can be observed that the amount of published papers is greater than that of the periods prior to 2001. The Journal of Construction Engineering and Management is the one with the most articles selected, followed by Safety Science and the International Journal of Project Management.

Selected articles are displayed in Table 2 according to topic, showing absolute and relative values. Risk assessment is the most popular topic, appearing in 35.4% of the papers. Accident analysis and risk prevention each get more than 20% of the share.

It is surprising not to find many papers on regulations, either from the company's point of view (corporate policies) or from public agencies' point of view (standards and norms). Maybe the reason is that some articles deal not just with regulations, but also with other approaches to occupational safety and health; thus, they are categorized under other steps of the cycle, mainly risk assessment or risk prevention. In our study, we observed how research has influenced the development of laws and regulations by

Table 1. Selected articles per journal and per period

JOURNAL	1930 1970	1971 1980	1981 1990	1991 2000	2001 2010	2011 2016	TOTAL
Accident Analysis and Prevention			1	1	1	3	6
Construction Management and Economics			1	4	6	3	14
Engineering Construction and Architectural Management				4	7		11
International Journal of Project Management			3	11	11	2	27
Journal of Construction Engineering and Management/ Journal of the Construction Division	1	11	6	9	32	4	63
Journal of Construction Research					11		11
Journal of Management in Engineering			1	3	3		7
Journal of Occupational Medicine			1	2			3
Journal of Safety Research		1		2	5	2	10
Practice Periodical on Structural Design and Construction			1		10		11
Professional Safety			3	2	7		12
Reliability Engineering and System Safety					1	2	3
Risk Analysis			1		3		4
Safety Science/Journal of Occupational Accidents		3	8	5	15	11	42
Other (18)	1	2	1	10	17	30	61
TOTAL	2	17	27	53	129	57	285

Table 2. Selected articles per topic

	Regulations	Education & Training	Risk Assessment	Risk Prevention	Accident Analysis
Number	21	22	101	58	83
Percentage (%)	7.4	7.7	35.4	20.4	29.1

providing new forms and tools for risk assessment and for the implementation of preventive measures at the workplace. The analyzed papers propose measures to assess results achieved and to know whether regulations are being applied and if they are meeting the objectives for which they were created.

It is not so unexpected to discover that education and training get very little attention from researchers. Pietroforte and Stefani[15] already found that only 1.8% of the papers published in the Journal of Construction Engineering and Management from 1983 to 2000 were related to education and professional development. Furthermore, in their analysis of trends in project management, Crawford, Pollack, and England[16] selected forty-seven topics relevant to the field of project management; none of them was related to education and training. Because so few articles are found for these two steps, no research trends are developed for regulations and for education and training. Safety culture and safety climate are new factors that have also few publications. According to research on occupational safety and health applied to the construction industry, three main topics obtained from our previous bibliographic analysis are described: risk assessment, risk prevention, and accident analysis (which represent 85% of the total), and this paper focuses on those subjects.

Trends in risk assessment

For the topic of risk assessment, the search started with Fine's seminal article "Mathematical evaluation for controlling hazards"[17], in which a formulation to quantify risks is proposed. It is based on three factors that define risk: probability of the accident happening, personnel exposure to the risk, and consequences of the accident (or severity). From his approach, three basic lines of research were identified: management of occupational safety and health, quantifying occupational risk through modeling, and quantifying risk through probability analysis. They are displayed in Fig. 2.

Al-Bahar and Crandall[18] applied traditional risk management approaches to the construction industry to obtain a useful strategic tool for managers. Mohamed[19] introduced the influence of management and risk systems at the workplace. Koehn and Datta[20] analyzed ISO Standards (9000 for quality, 14000 for environment, and 18000 for safety and health), and proposed an integrated system for construction companies. Sparer and Dennerlein[21] created and evaluated different approaches for establishing rewards based on a threshold score, for use in safety incen-

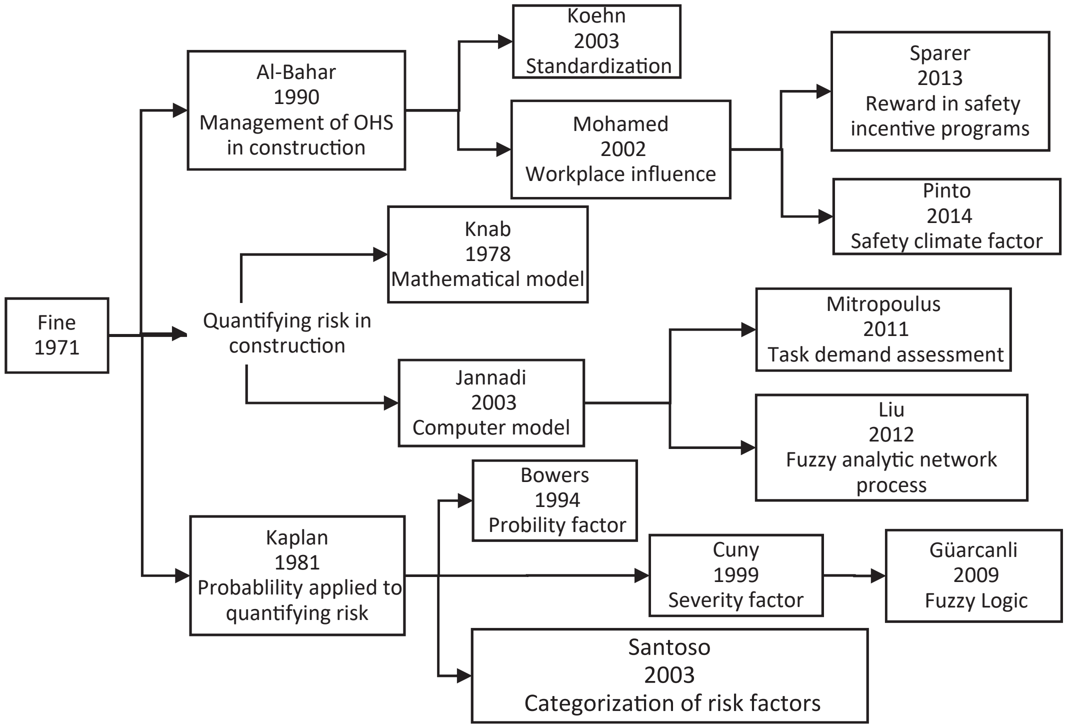

Fig. 2. Trends in risk assessment.

tive programs. Pinto[22] introduced safety climate variables within the calculation of the level of risk in a Qualitative Occupational Safety Risk Assessment Model (QRAM).

On the issue of quantifying risk through modeling, Knab[23] put forward a mathematical model based on insurance premiums. Whereas Jannadi and Almishari[24] developed a computer model based on Fine's formulation. Mitropoulos and Namboodiri[25] developed a technique for measuring the safety risk of construction activities according to the characteristics of the activity and independent of the workers' capabilities, and Liu and Tsai[26] proposed a fuzzy risk assessment method which related hazard types with construction items and hazard causes with hazard types.

On the other hand, Kaplan and Garrick[27] followed Fine's assumptions to calculate the probability factor of his formulation. Using this work as reference, Cuny and Lejeune[28] analyzed the severity factor. Then, to solve the problem of uncertain and insufficient statistical data Gürcanli and Müngen[29] used fuzzy logic. Bowers[30] approached the probability factor by using quantitative data (e.g., historical ratios) or qualitative data (e.g., interviews). Santoso *et al.*[31] identified, analyzed, and categorized potential risk factors in construction.

In summary, three main branches of research were identified: management of occupational safety and health in construction, risk quantification through modeling, and probability applied to risk quantification. From them, twelve active lines of research were highlighted, and a representative paper for each was pointed out.

Trends in risk prevention

Heinrich's seminal article[32] is the starting point of the two other topics: risk prevention and accident analysis. He suggested the concept of risk prevention based on historical accident statistics, and focused on cost reduction due to the adoption of prevention techniques. Fifty years later, Helander[33] discussed several interesting issues: high accident ratios, increasing costs due to accidents, lack of research, and inexperience in implementing policies and plans; unfortunately, many of these problems still remain in today's construction industry. From this line of thought on risk prevention, three main trends were outlined, one concerning business strategy, and the other two regarding the main phases of the project life cycle: design and construction. They are displayed in Fig. 3.

Business strategy to achieve better safety performance in construction was introduced in work by Jaselskis, Anderson, and Russell[34]. Their article analyzes the main factors that lead to success in occupational safety and

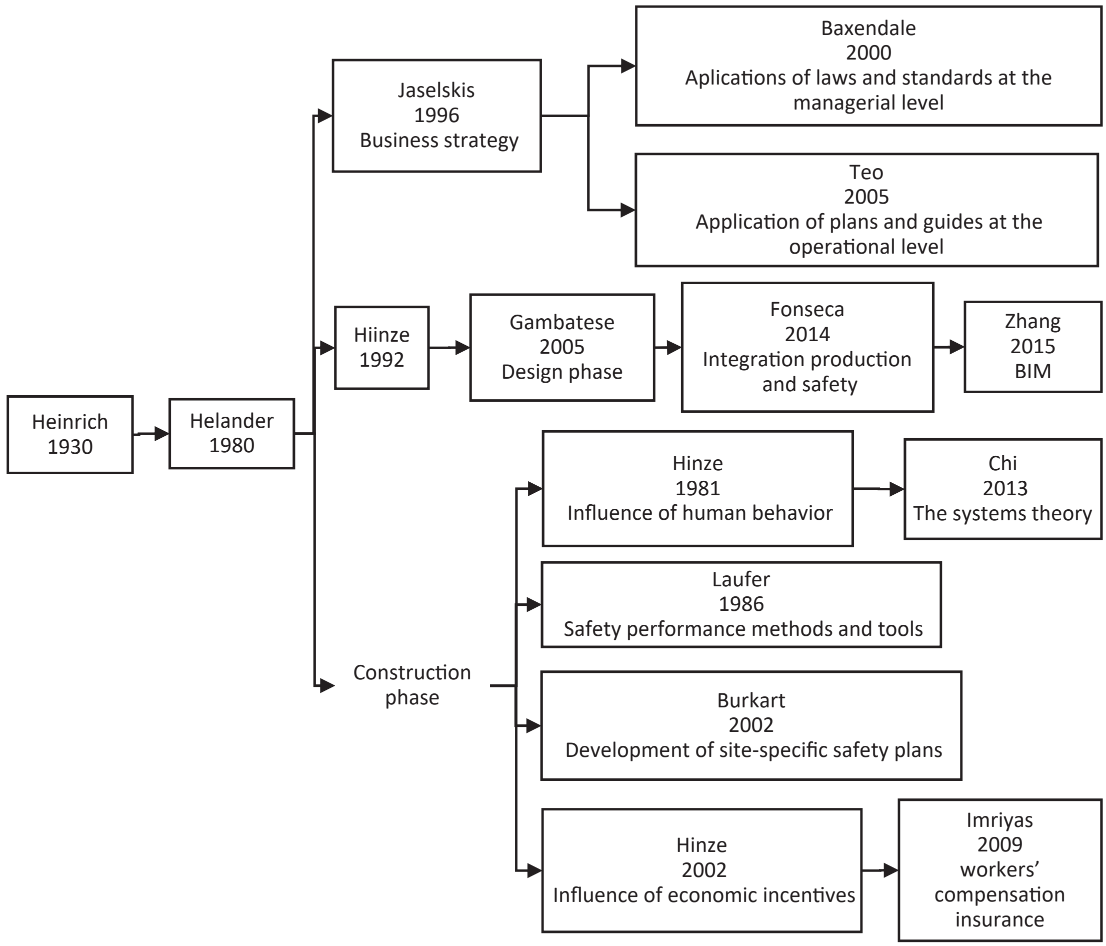

Fig. 3. Trends in risk prevention.

health in the construction industry. Two branches are developed from this idea, depending on the emphasis of the implementation: laws and standards at the managerial level[35)] and plans, guidelines and checklists at the operational level[36)].

Hinze and Wiegand[37)] were the first to show the importance of safety prevention in the design phase. They state the important role of designers in occupational safety and health because the success of construction works depends on their decision-making. Gambatese *et al.*[38)] deepened this idea through several interviews, revealing keys for successful implementation of designing for safety. Fonseca *et al.*[39)] proposed a model of risk prevention integrating production and safety through three different levels of anticipation (analysis of design, planning/scheduling of services and implementation). One year later, Zhang *et al.*[40)] applied Building Information Modeling BIM-based safety to fall hazard identification and prevention in construction safety planning.

Nevertheless, most work produced on the topic of risk prevention focuses on the construction phase. Many authors explore different approaches. Hinze[41)] analyzed human behavior in risk prevention and Chi and Han[42)] analyzed 9,358 accidents that occurred in the U.S. construction industry between 2002 and 2011 and incorporated systems theory into Heinrich's domino theory to explore the interrelationships of risks. Laufer and Ledbetter[43)] assessed the efficiency of several safety tools used in the construction workplace through surveys; according to these authors, simultaneous methods should be used to achieve better levels of safety. Burkart[44)] called for site-specific safety plans, adapted to each workplace, and useful and reliable for every stakeholder.

Along another line, Hinze[45)] analyzed the influence of economic incentives, concluding that low-value incentives, combined with good prevention tools, are more successful, and Imriyas[46)] developed a workers´ compensation insurance (WCI) premium-rating model for building projects.

Summing up, our exploration detected ten lines of research within risk prevention in construction. Three of

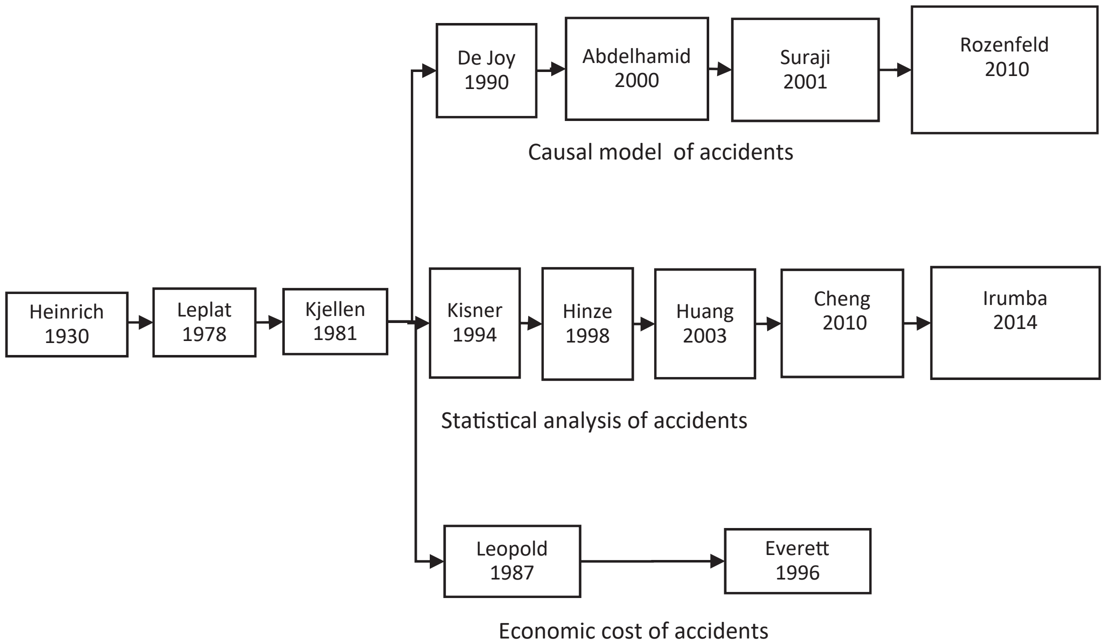

Fig. 4. Trends in risk analysis.

them deal with business strategy, three with the design phase, and six others with the construction phase.

Trends in accident analysis

Accident analysis (or accident investigation, as it could also be called) makes it possible to determine the what, how, and why of an accident; thus, in the future, similar accidents can be avoided based on the lessons learned. This topic also originates from Heinrich's work (1930). He considered accident statistics as the baseline for any analysis of occupational safety and health. Many years later, Leplat[47)] approached the principle of accident causation, discussing the relationship between accidents and the work in progress at the time of the accident. Kjellen and Larsson[48)] proposed a conceptual model to investigate accidents across two levels: the sequence of facts about an accident, and factors affecting work at the time of an accident. From these articles, three main branches are displayed in Fig. 4.

The first branch deals with different models of workplace accident causation. DeJoy[49)] focused on human factors. Abdelhamid and Everett[50)] reviewed different techniques and offered a theoretical explanation for root causes of accidents. Suraji *et al.*[51)] described a global model for the project cycle. Rozenfeld *et al.*[52)] developed a structured method for hazard analysis and assessment for construction activities called Construction Job Safety Analysis (CJSA).

The second branch is about the statistical analysis of accidents. Kisner and Fosbroke[53)] analyzed injuries from 1980 to 1989 in the United States. Hinze *et al.*[54)] supported by Occupational Safety and Health Administration (OSHA) data from 1985 to 1995, categorized accident causes and sources of injures. Huang and Hinze[55)] also examined OSHA data on construction worker's accidental falls from 1990 to 2001. Cheng *et al.*[56)] used data mining to establish the cause–effect relationships within occupational accidents in construction in Taiwan during the period 2000–2007. Finally, Irumba[57)] investigated the causes of construction accidents in Kampala, Uganda using ordinary least squares regression and spatial regression modeling.

The last branch evaluated occupational accidents in terms of their cost. Leopold and Leonard[58)] assessed several British construction firms to analyze accident costs in relation to their insurance premiums. On the other hand, Everett and Frank[59)] showed a comparative study on the actual costs of accidents and injuries in the construction industry.

The main lines of research in accident analysis can be summarized within three topics: causal model of accidents, statistical analysis of accidents, and economic cost of accidents.

Conclusions

Our paper sought to establish current research trends in occupational safety and health in the construction industry. We described an "Occupational Safety and Health Cycle" based on traditional risk management approaches with five basic steps: regulations, education and training, risk assessment, risk prevention and accident analysis. Because of a scarcity of articles in the first two steps, no trends were proposed for regulations, education or training.

Three main branches (i.e. management of occupational safety and health in construction, risk quantification through modeling and probability applied to quantifying risk) were outlined within the topic of risk assessment, which is the topic with the highest amount of publications, and were subsequently broken up until obtaining the twelve current trends. Likewise, three main branches (business strategy, focus on the design phase and focus on the construction phase) were obtained for risk prevention. These were in turn split into the ten current trends. Finally, there were three solid trends within accident analysis: a causal model of accidents, their statistical analysis, and their economic cost.

The findings of this study show the following future subjects as trends of research and implementation in OSH in construction: rewards in safety incentivization programs; increasing the usage of information technology tools; production process automation; implementing proactive measures rather than reactive measures; integrating quality, environmental and OSH management system standards and using technological tools to train workers.

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