Safety in construction?

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ABSTRACT: The available literature on Construction Safety is not very optimistic about the chances of evidence-based safety in the construction industry exerting a positive influence. Many articles indicate that the structures and processes that are designed to ensure safety in the industry are poor. Safety management systems do not work, or only partially, the business processes executed are fragmentary, it is not clear who is responsible for safety and parties lower in the construction hierarchy tend to be saddled with the consequences. Safety detracts from the primary production process and is seen as a bureaucratic burden. But there are some positive developments as well. Lists of prevalent accident scenarios and significant events are available and information is published on barrier failures. What is missing is a reliable exposure gauge of the relative importance of scenarios and the identification of pivotal events. The more clearly the cause-effect chains of accident processes can be recorded, the more specific the measures, solutions and interventions can be when it comes to avoiding or reducing the effects of accident scenarios. Audit methods have also been developed, such as the Safety Index, which can be used to not only negatively but also positively assess safety. Finally an approach that can best be described as 'frappez toujours' seems to yield noticeable results. In such cases it does not really matter what safety steps are taken. Simply highlighting the issue is a factor that can, in itself, have an effect.

1 INTRODUCTION

The building sector is a dangerous branch of industry. Frequently this is one of the first statements in many articles on construction safety; the same types of accident continue to occur time after time. Often building company managers point to major differences in the manufacturing and process industries, where safety programs seem to have an effect.

This review focuses on the question of whether or not it is possible to influence safety in the building sector. The building sector is quite an extensive concept. The review will therefore confine itself to the contract side, the design and the construction of building projects and to parties involved. The various phases of the building process, such as demolition, implementation and conceptual design will not be included in the review.

1.1 Organic structure

In the literature, construction companies are characterized as ones with an 'organic' structure. Such a structure is contrary to the mechanistic structure of companies that have a highly standardized production process, like manufacturing and process industries. The organic structure of companies manifests itself in its processes. Generally, though, there is a low level of standardized work performance and a culture of aversion to rules, procedures, and decision-making-including safety-all of which have very low priority in the organization. This characterization is drawn from studies in the construction sector in Europe, America, the Middle East, Asia and Australia (Helander, 1980; Jong et al. 1989; Kartam et al. 2000; Lee & Halpin, 2003; Lingard & Rowlinson, 1998; Lingard & Holmes, 2001; Loosemore & Lam, 2004; Pinto et al. 2011; Sawacha et al. 1999; Spangenberg, 2010; Tam et al. 2004; Teo et al. 2005; Wilson 1989). The construction industry is a political and market sensitive sector. The dynamics of the building process, the temporary nature of projects and the physical distance from a central organization means that relatively few construction workers are able to receive (safety) training and so develop loyalty more to fellow construction workers than to their company. The keen competition between companies creates a conflict between the primary process and any activities that threaten to cause delay. Safety is one of those activities and such factors as production bonuses, and danger money are thus counterproductive to safety. In addition, the costs of lack of safety are always shifted to the weakest party, the subcontractor (Jong et al. 1989; Donaghy, 2009; Priemus & Ale, 2010). The sector adheres to a rather rigid separation between design

and implementation/construction, which is not conducive to safety. If an accident occurs and if accident analysis is conducted (which is not always the case) then the results are limited to one direct cause—that of human behavior. In such a complex environment it is therefore certainly a challenge to improve safety. Scientific literature from 1980 onwards on safety management in construction provides a number of successful and less successful examples.

2 RESULTS, DETERMINANTS OF ACCIDENTS

2.1 Hazards, scenarios, central events, barriers

Descriptive epidemiology is an often-used method in the investigation of construction accidents, which draws on national, regional, company or project records of accidents or deaths. It is a type of research that is most prevalent in the United States. The results provide information on the hierarchy of central events, on barrier failures, on the general determinants of accidents, or on the specific determinants of accident scenarios.

For a long time hierarchy of central events in the construction industry remained unchanged (Baradan & Usmen, 2006; CWRP, 2007; Hinze et al. 1998; Horwitz & McCall, 2004; Huang & Hinze, 2003; Hunting et al. 1999; Lipscomb et al. 2000; López et al. 2008; Wang et al. 1999) (see Table 1).

This hierarchy resembles the results obtained from Dutch research (Ale et al. 2008; Aneziris et al. 2008). The contribution made by the different central events is presented in absolute figures or percentages. This demonstrates a major weakness in the safety domain. While national figures are presented as rates by standardizing the hours worked or the total population of construction workers, this is not an option for specific scenarios. Information is not yet available on the degree of exposure to specific scenarios.

Table 1. The hierarchy of central events.

Central events
Falling from a height
Contact with falling or collapsing objects
Contact with electricity
Contact with moving machinery parts
Falling from a moving platform
Contact with hoisted, hanging, swinging objects
Hit by a vehicle
Squeezed between or against something Contact with objects thrown from a machine

Already for decades, the central event 'falling from a height' has topped the list. On the basis of national accident records, American research into construction safety publishes lists of failing accident barriers involving scaffolding, ladders and working on roofs (Cattledge et al. 1996; Halperin & McCann, 2004; Helander, 1991; Hsiao & Simeonov, 2001).

Research into the general determinants of accidents has determined the influence of race and age. For example, in North Carolina no difference in the incidences of accidents was found between African American and white workers (Wang et al. 1999). This research as well as that carried out by Lipscomb et al. (2000) from the same state indicated that living conditions do contribute to accidents, including alcohol and drug use. The age distribution of victims led to a subtle conclusion. Typically, the accident rates proved to be inversely proportional to the age of the victims: the younger group had more accidents. However, a closer analysis of the type of accidents showed reduced accident incidence with growing age but revealed also that younger workers are involved in significantly fewer serious accidents than older workers (Horwitz and McCall, 2004). According to these authors, younger construction workers will have a lower exposure to high hazards and thus a smaller chance of incurring more serious accidents.

2.2 Determinants: Direct and underlying factors, structure and process

The European studies of accidents occurring during construction work were initially based upon a more complex accident process than that seen in the United States. A differentiation was made between the types of factors affecting the accident process. Already in the 1980s research done in Finland correlated process disturbance and accidents (Niskanen & Saarsalmi, 1983). Process disturbances may be an indication of material flow or machinery disruptions during the construction process or of design adaptations that are only announced during construction. The Swedish AORU (Occupational Accident Research Unit) model is an example of such an approach. This model combines accident analysis with control measures sessions and with structured decisionmaking processes undertaken with stakeholders. The model was first developed in the early 1980s (Kjellén, 1983, 1984; Menckel & Kullinger, 1996) and distinguishes between the direct and underlying causal factors of accidents. Direct factors were defined as the combination of process disturbances, events and conditions that disrupted flawless and planned production, like interruptions in the control exercised over materials, equipment,

labor, technology and direct supervision. The underlying factors were the characteristics of the production system that affect direct factors and were related to various immediate and long-term decisions concerning the design and development of the production system with regard to all the physical, organizational and human resources.

Recent research done by HSE defined these distal factors in somewhat broader terms, as characteristics of construction projects; as the outcome of the wishes of the client and the decision-making process during design and project management. Table 2 provides examples of distal and proximal factors that affect the accident process (Manu et al. 2010).

Distal factors, unlike proximal factors, do not directly cause accidents and so they resemble the underlying factors seen in the Swedish AORU model. All the distal factors were listed for 100 different construction accidents (HSE, 2003) and, to a large extent; they fell outside the realm of the safety chain. Additionally, there was a lack of any type of safety management either among clients and their advisers or with the contracting companies. And the state of the material and equipment was below standard as was the standard of maintenance. In general there was a lack of interest in the topic of safety. Recently published research from Asia, Taiwan and Australia confirms these research findings (Cheng et al. 2010a; Lingard & Holmer, 2001; Mohamed, 1999). Safety has become too bureaucratic. With the slogan 'manage the risk, not the paper work' HSE calls for a return to the controlling of hazards and risks at construction sites (Donaghy, 2009; HSE, 2009).

Striking epidemiological study results have emerged in Scotland (Cameron et al. 2008). Between 1997 and 2002 the Scottish fatal accident rate among construction workers was 50% higher than that of England for the same period and the rate for major accidents was 15% higher. The

Table 2. Examples of distal and proximal factors in the accident process.

Distal factors	Proximal factors
Nature of the project, new construction—renovation, demolition	Uncertainty, complexity of threats
Construction method, conventional—prefab	Manual operations
Construction site, restrictions	Congestion
Project duration	Time pressure
Design complexity	Construction complexity
Subcontractors	Fragmentation workforce
Height, low—high rise	Working at a height

discrepancy can be explained by the different building organization structure (Fig. 2). In England more managers and experts were involved in construction projects where there was little exposure to construction hazards. Scotland, however, had a much 'flatter' organization, thus making the population exposed to danger relatively large; in other words, the accident rate denominator was very differently composed. An almost identical investigation was conducted in Denmark, during the construction of the Øresund Link, the link between Denmark and Sweden (Spangenberg et al. 2002, 2003). There too a remarkable difference could be seen between the nationalities present. The incidence of accidents leading to lost time among Swedish construction workers was a factor of four lower than that of Danish workers. Here the way in which the building process was organized was not the most likely explanation for the difference observed. The discrepancy was most probably attributable to the lower level of education of the Danish workers combined with the higher unemployment level seen in the Swedish construction industry and the less generous Swedish sickness benefits.

2.3 Design

The relationship between design and safety is obvious. Considerable attention has been given to this topic (see for instance Priemus & Ale, 2009; Spangenberg, 2010; Swuste et al. 2010). Perrow (1984) published one of the first systematic reviews on the relationship between design and accidents/ disasters in high-risk systems. If systems meet certain requirements, then accidents and disasters will be inevitable and cynically these came to be termed 'normal accidents'. Such normal accidents continue to happen as, for instance, an accident analysis recently presented by the Dutch Safety Board of a normal accident involving a nonmobile, peak less trolley tower crane bears out (OVV, 2009; Swuste, 2013).

Literature on the impact that design and the design process have on accidents in the construction industry has been rather sparse. The contribution that design can make to construction safety was determined by taking a selection of 224 fatal construction accidents. A group of experts reviewed the accidents and concluded that 42% were causally related to the design (Behm, 2005).

The American program on 'Designing for Construction Worker Safety' and 'Prevention through Design' (Behm, 2005, 2008; Gambatese et al. 2005, 2008) revealed the limited corporation between designers and contractor, the rigid separation between design and execution. Furthermore safety was no topic of discussion, and knowledge on safety was rudimentary both by architects and engineers.

2.4 Determinants, perception, safety climate

Once safe behavior becomes a topic, the safety culture, or safety climate of any given organization also receives frequent mention. No research has been published on safety culture in the construction sector. On the other hand, safety climate surveys have been conducted. These safety climate surveys are mainly based on questionnaires. This method has some major disadvantages. Researchers made claims about behavior without presenting information on the safety structure and processes. Frequently, researchers lack information on fieldwork and simply rely on databases or on questionnaires that have been returned but fail to take note of other details about the workplaces and companies. Another drawback is the questionnaire itself, which often amounts to an evaluation of how the management cares for its employees. This in itself may be interesting but it says little about culture or climate (Guldenmund, 2007).

Dedobbeleer & Beland (1991) found that the perception of safety among American construction workers revolved around one central theme: that of involvement, which applied both to management and to workers. Management became involved whenever frequent attention was paid to safety instructions, meetings and providing safe equipment for the workers. The involvement of workers emerged from their participation in safety programs, auditing sessions and sessions designed to find solutions to hazards and risks. Similar results were found in a number of other studies, including in the surveys done by Dingsdag et al. (2008), Australia, Larsson et al. (2008) and Törner & Poussette (2009). Sweden. Mohamed et al. (2009), Pakistan and in the conclusions drawn by Meliá and colleagues (2008) when they compared England, Spain and Hong Kong. The attention to the matter received from management and the way in which safety was organized in a company had direct and positive impacts on supervisors and that, in turn, reflected on the workers. Subsequently the safety awareness behavior of individual construction workers is directly influenced by the group. Hong Kong was the only place where this kind of correlation could not be established. According to the authors, the explanation lies in the turnover of contractors and sub-contractors, and this is significantly higher in Hong Kong than in other countries.

2.5 Determinants, costs

In American publications the cost of accidents is often mentioned as an argument to convince management of the importance of safety on construction sites (see for instance Waerher et al. 2007). Traditionally capitalizing on safety has been an important topic (see, for example, Van Gulijk et al. 2009; Swuste et al. 2013). Again in the 1980s it was seen as a major motivator for employers in an industry where long-term safety problems tended to be overshadowed by short-term technical problems (Helander, 1980). Studies showed a direct relationship between project financing and safety (Arboleda & Abraham, 2004; Hinze & Radboud, 1988). Big projects that were 'under-budgeted' had a higher incidence of accident rate when compared to projects where these problems were not relevant. Similar results were also found in Taiwan (Cheng et al. 2010b). However, for big contractors, the costs of accidents are barely perceptible which means that the financial argument hardly enters into their decisions (Laufer, 1987).

2.6 Determinants, laws and regulations

In American proposals for 'Designing for Construction Worker Safety' and 'Prevention through Design' (Behm, 2005, 2008; Gambatese et al. 2005, 2008) it was shown that decisions taken at the beginning of the construction process will have a major impact on construction site safety. Everyone will be agreed on that point. According to authors, there are quite a few barriers frustrating the implementation of safety in design. Laws and regulations are not a stimulus and neither is the insurance system. Architects and clients are not interested in such matters and will even be put off by the prospect of potential liability claims. Authors conclude that in general safety is seen as a topic for contractors and the construction team, and not for designers and clients.

3 RESULTS, INTERVENTIONS

3.1 *Examples of interventions, hazard, risk analysis and audits*

Various research groups have developed audit systems to measure barrier quality (see for instance Guldenmund et al. 2006), or to link hazard analyses to probability of consequences, or to possible solutions. One of these audit systems is TR safety observation method on building construction'. This audit was developed by the Finnish Institute of Occupational Health (Laitinen & Kiurula, 2002; Laitinen & Ruohomäki, 1996; Laitinen et al. 1999; Mattila et al. 1994). The abbreviation 'TR' is a Finnish acronym for construction site. The audit has the advantage of not addressing safety only as a list of negative reviews, and the results of this audit serves as a starting point for safety discussions within the company on items with a positive or negative score. The method has been tested and validated, and a high positive score on the TRaudit is associated with a low accident rate on the respective sites (Laitinen & Paivarinta, 2010).

The Risk Management Toolbox for construction is another audit, and will provide safety a more prominent position during managements' decision-making (Zalk et al. 2011). This model is based upon the principle of control banding, a principle familiar from the domain of occupational hygiene (Zalk, 2010), and it combines the results of a given risk analysis with possible solutions and control measures. It is especially the combination of risk analysis and control measures that is a strong point of this model and which is thus also a support to management in the construction branch.

3.2 Examples of interventions, direct and underlying factors, structure and process

In literature interventions were described, which were both extensive, and influenced the safety structure and processes within companies. The first one is AORU, mentioned earlier. The intervention drives on an active participation of workers, both during analysis, and during generating solutions. This resembles strongly a participatory ergonomics approach, which advocates an active input of workers and management representatives in ergonomic research.

Another extensive example are the so-called 'zero accident' approaches as exemplified by a safety studies from the United States and Canada (Hinze & Raboud, 1988; McDonald et al. 2009). In both examples, sufficient safety expertise was present, subcontractors received safety training, and both safety communication and behavior modification programs were executed during construction where order and cleanliness in the workplace were seen as important issues. Finally building sites were only accessible to authorized personnel. Both studies showed an incidence of lost time accidents that was well below the national average.

In the early 1990s a similar approach was adopted in the process industry in The Netherlands when the phenomenon of Safety Health and Environmental Checklist Contractors was introduced (Veiligheid gezondheid en milieu Checklist Aannemers—VCA). VCA trains and certifies contractors to conduct maintenance work and building activities at sites in the chemical and oil industries. The certificate is compulsory for contractors and aims to guarantee an acceptable level of safety. The introduction of VCA has led to a dramatic decrease in the number of reported accidents amongst contractors (Jeen & Swuste, 2009; Jongen & Swuste, 2008).

Finally the impact of a national campaign to stimulate safety management in construction is worth mentioning. In the United States an extensive research program was set up, leading to the formation of the Center to Protect Workers' Rights in 1990. To that end an extensive national infrastructure was set up, including dozens of organizations designed to improve working conditions in construction. Regional and national conferences brought together key decision-makers and initiated a comprehensive program with the appropriate funding. Gradually the national rates of absenteeism and lost-time accidents were seen to decrease by 20% for no apparent reason, other than that this might well have been prompted by national initiatives and a focus on the topic of construction safety (Ringen & Stafford, 1996).

3.3 Examples of interventions, design

The application of a technique to predict accident scenarios and central events during building activities, originates from the process industry. Here the 'Hazard and Operability Study (HAZOP)' is a well-known technique which makes use of group sessions to detect all possible scenarios leading to the central event 'loss of containment'. Design drawings are routinely checked for relevant combinations of guide words and process parameters. Guide words indicate possible malfunctions, such as no/not, more, fewer, simultaneously, etc. The process parameters are indications of potential hazard, like those linked to pressure, flow or temperature. For the construction sector, loss of containment only has a limited degree of application and is replaced by 'loss of control'. The technique can be used to detect all types of faults and disturbances in the material flow of a building site and to determine whether this can give rise to accidents. For this purpose the process parameters need to be adapted to the research question. The technique was applied to road workers' accidents during work (Swuste et al. 2000). The relevant technology for the construction sector is still in its experimental stages.

A design analysis provides a simple description of a manufacturing process—or a construction process—using three hierarchically ordered concepts: the production function (what should be produced), the production principle (how) and the production form (in what way) (Manu et al. 2010) The production principle includes the key determinants of the potential accident scenarios. This is not only important for the analysis phase but also for potential solutions. Scenarios and central events can be predicted on the basis of information linked to the production principle. This kind of design analysis has been successfully applied to hand operated pneumatic drills of the type used to remove concrete from the heads of foundation piles. Alternative production principles, like remote controlled cracking of piles have been successfully introduces, reducing scenarios related to handarm vibrations, to accidents and to dust and noise exposure to acceptable levels (Swuste et al. 1997).

3.4 *Examples of interventions, perception, behavior*

The focus on the training, competence and awareness of construction workers, supervisors, foremen and the broader 'management support' team is a recurring topic in a number of studies (Abdelhamid et al. 2000; Aksorn & Hadikusumo, 2008; Baradan et al. 2006; Carter & Smith, 2006; Kines et al. 2010; Lipscomb et al. 2000; Paas & Swuste, 2006). Finnish and Danish studies go one step further. General safety training has little effect, but job training and discipline teaches builders to consciously deal with specific work hazards and risks (Laukkanen, 1999; Spangenberg, 2010).

The impact of behavioural-based safety programs was measured on a limited number of construction sites in England and in Hong Kong, using the same study approach (Duff et al. 1994; Lingard & Rowlinson, 1998). By staggering the introduction of the behavioural interventions the effect Independent auditors who were not involved in construction reviewed the level of safety several times a week. On English sites these interventions had a clear and significantly positive effect on the audit scores but after the interventions ended the effect disappeared. The results were less positive in Hong Kong. Only scores on order and cleanliness correlated positively with interventions, as solutions for this scenario lay within the workers' ambit. Also here the effect rapidly disappeared after the intervention stopped. The authors attributed the temporary effect of the interventions to the limited support from management.

3.5 *Examples of interventions, procedures, laws and regulations*

According to Helander (1991), who reviewed the quality of safety barriers of scaffolds and ladders, procedures, laws and regulations are significant barriers conducive to reducing the central event of 'falling from a height'. The author claimed, ergonomic redesign could reduce many accidents. In line with Helander's argument, OSHA introduced additional legislation in 1998. The relevant regulations relate to the special requirements concerning fall protection and harness belts. An analysis

of the fall accidents during the 1990-2001 period did not show that this legislation had a demonstrable effect, either in the numbers of accidents. or regarding the type fall scenarios (Halperin & McCann, 2004; Huang & Hinze, 2003). To explain this, the authors pointed to the strong economic growth seen in the industry since 1995. This has led to a significant influx of unskilled construction workers. Before the effects of legislation can be felt the authors state that more safety training and education is first needed. Another national study into the influence that the OSHA has had on safety standards for scaffolding that was introduced two years earlier, in 1996, showed a different picture. The stipulations lay down requirements for the strength and dimensions of scaffolding and for fall protection. Both the fatality level and the time lost due to accidents did decrease significantly in the 5-year period after introduction (Yassin & Martonik, 2004). A restrictive policy involving more frequent inspections, higher fines for noncompliance, and higher accident costs did lead to a better implementation of the standards.

4 CONCLUSION AND DISCUSSION

Is it possible to influence safety in the building sector? This is the central question behind this survey. The main causes of accidents during construction, the central events, are known. Descriptive epidemiology has established a list giving a hierarchy of central events (Table 1) and between countries there is consensus on this list. The available literature also provides insight into the barrier failures that lead to accidents. With all this knowledge available why, as many publications indicate, is it so difficult to improve safety in this particular industry and why do many construction workers consider risk to be a natural occupational hazard?

The various studies often highlight the elements 'structure' and 'processes'. Generally these elements of the management system are poorly developed in terms of safety. 'Construction is different' is what is often stated. 'Different' in this case is a reference to the special characteristics of the construction and building process, all of which makes safety past, present and future a rather complex issue (Swuste et al. 2012).

There is always, however, the danger that companies will put a lot of energy into programs designed to improve safety-conscious behaviour among workers without paying attention to the safety structure and processes of the organization. This will inevitably lead to resistance. Often restricting people's radius of action is a source of irritation, a thing that is particularly evident among experienced workers, who can be frustrated by trivial rules that sometimes interfere with their expertise (Hale & Swuste, 1998).

From a scientific point one can question if more safety research will provide more insight in accident processes in this sector. Most likely it is not, and it makes sense to put academic attention to decision making processes, and to address the topic of responsibilities on safety. In many countries specific knowledge centres for construction safety are established, producing easy-to-use tools and very customer's friendly methods to persuade the sector for more safety. Maybe we should stop these efforts, and ask questions sociologists did in the 1970s, like Barry Turner (1978) 'why do organisations fail'.

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