Causal factors and connections in construction accidents

Stig Winge; Eirik Albrechtsen

Norwegian University of Science and Technology (NTNU), Department of Industrial Economics and Technology Management, NO-7491, Trondheim, Norway

Bodil Aamnes Mostue

Norwegian Labour Inspection Authority, Directorate of Labour Inspection, NO-7468, Trondheim, Norway

Abstract

The aim of this study was to add to the relatively sparse literature on accident causality in the construction industry by identifying frequent causal factors and connections between causal factors. Using the Construction Accident Causation (ConAC) framework, 176 relatively severe construction accidents investigated by the Labour Inspection Authority in 2015 were analysed. The seven factors most identified were (in rank order): (1) worker actions, (2) risk management, (3) immediate supervision, (4) usability of materials or equipment, (5) local hazards, (6) worker capabilities, and (7) project management. A set theoretic approach was used to identify causal connections between causal factors. Risk management, immediate supervision and worker actions were found to be key causal factors and strongly connected. The analyses identified seven causal factors consistently connected to worker actions, for example immediate supervision and local hazards. Immediate supervision was found to be strongly connected to both worker actions and risk management, underlining the importance of the supervisor controlling unsafe conditions/acts and planning the work to reduce risk. Strong connections were also found between risk management and immediate supervision, and between risk management and worker actions. Risk management and immediate supervision is to a large degree about planning and risk control at different levels, underlining the importance of risk being addressed at different levels and by different actors in construction projects.

1 Introduction

The construction industry is among the industries with the highest share of fatal occupational accidents. In Europe (EU-28), construction had the highest share of fatal occupational accidents in 2014 with one in five accidents (Eurostat, 2016). In Norway, the construction industry had the second highest share of fatal occupational accidents in 2016, also with one in five accidents (Statistics Norway, 2017). An increase in the annual number of fatalities and some major dramatic accidents led to an initiative from stakeholders in the Norwegian construction industry to establish a tripartite cooperation with a vision-zero-approach. The cooperation expressed a need for further knowledge on proximal and distal causal factors in construction accidents for developing preventive strategies.

Accident prevention begins with having a clear understanding of factors that play key roles in causation (Hinze et al., 1998). In a review of construction site safety literature, Khosravi et al. (2014) concluded that there is little research on the key causes and contributory factors of unsafe behaviours and accidents at construction sites. The aim of this study was to add to this literature by studying causal factors in 176 severe construction accidents in depth. The specific purposes were to identify (1) frequent causal factors in construction accidents, and (2) important connections between the causal factors.

Information about accident mechanisms and injury agents can be extracted from national injury statistics. Acquiring knowledge about distal causal factors is more problematic since national statistics do not '… generally permit detailed analysis of causes beyond the identification of the mechanism and agency of injury' (Cooke and Lingard, 2011, p. 279). The sample analysed in this study consists of all construction accidents investigated by the Norwegian Labour Inspection Authority (LIA) for one year (2015). These accidents were relatively severe, and the qualitative documentation of the accidents was sufficient to assess causal factors using a holistic system model.

2 Theoretical approach

Khanzode et al. (2012) divide accident causation theories into four generations as accident proneness theory, domino theories, injury epidemiology models, and system theories. Some accident causality research in construction have much in common with injury epidemiology models. The energy-barrier model (Gibson, 1961; Haddon, 1980) and the bowtie are important theoretical inspirations. Lipscomb et al. (2000) identified the 'external causes' of work related deaths (e.g. motor vehicle accidents) and 'major causes' of the frequent external causes (e.g. backovers). Papazoglou and Ale (2007) developed a logical model for quantification of occupational risk that allows the user to input relationships between events, corresponding probabilities for events and obtain at the end the quantified corresponding simplified event tree. In a Dutch study of construction accidents Ale et al. (2008) used the tool Storybuilder based on the bowtie to identify causes (e.g. barrier failures) and consequences of frequent accident types. A similar approach was used by Winge and Albrechtsen (2018) identifying frequent accident types and its barrier failures and consequences. The material used was the same as the 176 accidents analysed in this paper.

This study does not divide the accidents into accident types but study the sample of 176 accidents using a holistic system approach to identify relatively many causal factors and connections between factors at different organisational levels. We see this approach as complementary to the approach described above giving complementary advice for prevention. The causes found in accident analyses reflect the accident model used, the so called 'What-You-Look-For-Is-What-You-Find'-principle (Lundberg et al., 2009).

System models focus on both organisations, integrated safety systems, and interacting social and technical systems (Khanzode et al., 2012). Reason's Swiss cheese model (SCM) (e.g., Reason, 1997 and 2016; Reason et al., 2006) has had a major impact on the understanding of accident causation and prevention. In the SCM, major accidents depend on defence in depth, where each slice of cheese represents a fallible barrier. Gaps in the defences arise for two reasons, unsafe acts by 'sharp-enders', and latent conditions, for example, poor supervision, maintenance or training.

Many studies and literature reviews on construction safety emphasise that construction sites are technologically and organisationally complex (e.g., Mitropoulos et al., 2005; Pinto et al., 2011; Swuste et al., 2012; Lingaard, 2013). Lingard (2013) argue that in construction there is a specific need to manage the interests and influences of stakeholders, ensure compatibility among the components that make up a facility, and manage and coordinate the activities of different work crews and trades to ensure that workers, materials and equipment are constantly moving. This technological and organisational complexity is the reason for developing systemic accident frameworks specifically for the construction setting and studying interactions of distal and proximal factors in construction accident causation (e.g., Abdelhamid and Everett, 2000; Suraji et al., 2001; Leveson, 2004; Mitropoulos et al., 2005; Haslam et al., 2005; Manu et al., 2010; Priemus and Ale, 2010; Hale et al.; 2012; Khosravi et al., 2014).

Hale et al. (2012) developed a framework for identifying underlying causes of fatal construction accidents. The results showed '… a concentration of underlying factors associated with inadequacies in planning and risk assessments, competence assurance, hardware design, purchase and installation, and contracting strategy' (p. 2020). Khosravi et al. (2014) included 56 studies in a literature review to determine variables that influence unsafe behaviours and accidents on construction sites. The studies showed high evidence of association for organisation (e.g., safety climate/culture, information management, and policy/plan) and project management (e.g., commitment/support, management style and review/feedback). The studies also showed moderate evidence for the connections between accidents and supervision (e.g., effective enforcement, supervision style and communication), site condition (e.g., unsafe condition and hazardous operation), individual characteristics (e.g., attitude/motivation, psychological distress and age/experience) and contractor (e.g., size and subcontractor rate).

The framework chosen for this study was the Construction Accident Causation (ConAC) framework (Haslam et al. 2003; 2005). The ConAC framework was developed inductively through a combination of focus groups and a detailed study of 100 construction accidents. The framework was chosen for mainly three reasons. First, it builds on acknowledged accident theories and models, for example, an ergonomics systems approach (Haslam et al. 2003; 2005), and it '… adopts a similar framework to that presented by Reason (1997) but places it in the context of the construction industry' (Lingard and Rowlinson, 2005, p. 30). Second, the framework was used by other studies in different construction settings and countries (Cooke and Lingard, 2011: Lingard et al., 2013; Behm and Schneller, 2013), and the experiences were that the framework's terminology was 'sufficiently generalizable' and can be '… applied to a variety of construction accident consequences and yield numerous organizational learning opportunities at both the sharp end on site and the blunt end of project management or design' (Gibb et al., 2014 p. 457). Third, the methodology and operational definitions of the factors in the framework were documented by the original research and later studies and is hence easier to replicate.

3 Analysis framework

3.1 The ConAC framework and understanding of causality

The ConAC framework has previously had different names. We use the term ConAC as it is used in the paper by Gibb et al. (2014). The framework has three levels of factors (Figure 1): *Immediate* factors (e.g., worker actions) are influenced by *shaping* factors (e.g., supervision), and the shaping factors are influenced by *originating* factors (e.g., risk management). The shaping and immediate factors are divided into worker/team factors, site factors and material and equipment factors. The double arrows at the centre of the model represent multiple two-way interactions.

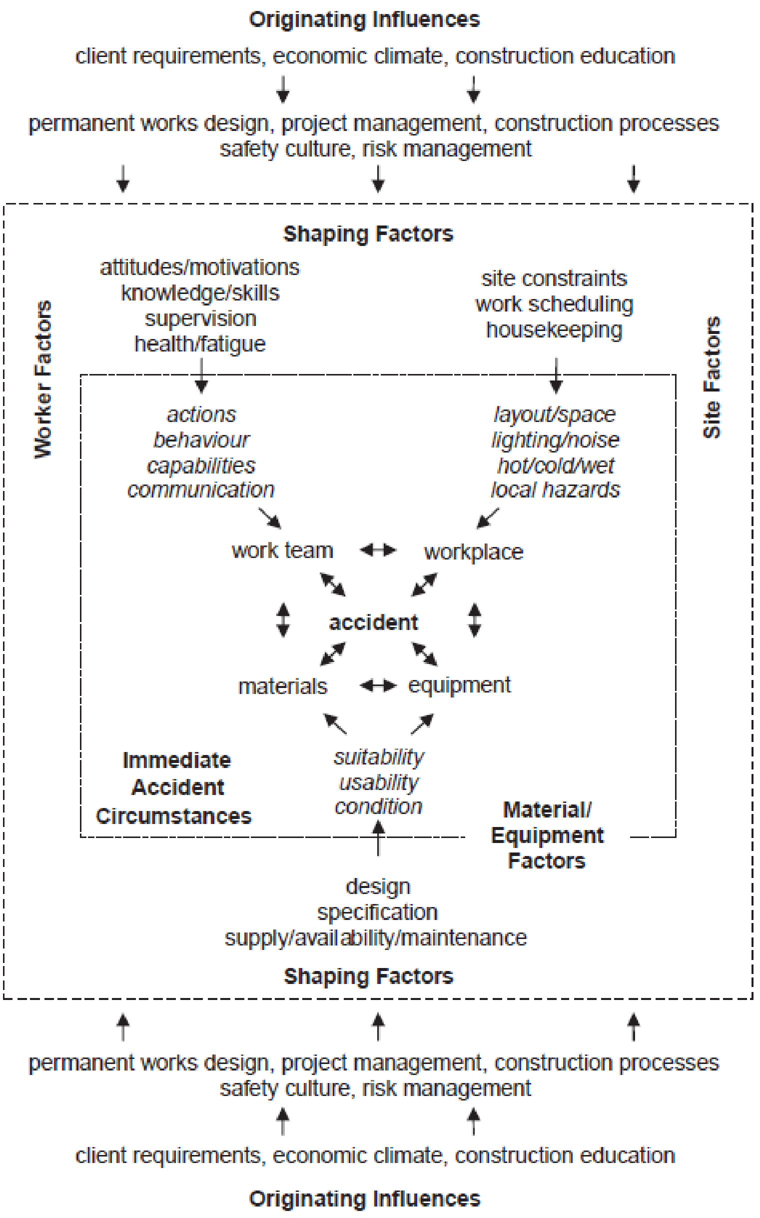

Figure 1. The Construction Accident Causation Framework (Haslam et al., 2003; 2005).

The understanding of causality in the SCM, and implicitly in many other accident models, is that accidents in complex systems occur through the interaction of multiple factors, where each may be necessary but where they are only jointly sufficient to produce the accident' (Reason et al., 2006; Hopkins, 2014). No failure, human or technical, is *sufficient* alone to cause an accident. According to Reason et al. (2006) the proximal factor (e.g., errors and violations) is the causal factor in an accident, while a latent condition is '… not necessarily a cause, but it is necessary for a causal factor to have an impact. Oxygen is a necessary condition for fire; but its cause is a source of ignition' (Reason et al., 2006, p. 7). This understanding of causality is also implicit in the ConAC model: 'All accidents are multi-causal, with a rare combination of factors needing to coincide to give rise to an incident.

Underlying each of the causal factors are a range of influences determining the extent to which they undermine safety' (Haslam et al., 2003. p. 58).

3.2 Operational definitions of the ConAC factors

Like Cooke and Lingard (2011) and Behm and Schneller (2013), we also found it problematic that the classification of factors was open to interpretation. Behm (2009) and Behm and Schneller (2013) developed operational definitions guided by previous research by Haslam et al. (2003; 2005). This study has used these definitions and added some clarifications based on how the terms are operationalised in this study (Table 1). This study does not include the outer originating factors in the framework due to lack of information in the material. The factors included are the same 23 factors that Gibb et al. (2014) used when comparing the material from UK, Australia and USA.

Table 1. Operational definitions of the 23 factors used in this study. Based on Haslam et al. (2003; 2005), Behm (2009), Behm and Schneller (2013), and this study.

	Factors	Description
Worker and work team	Worker actions and behaviours	Includes all acts at the 'sharp end' that have an impact on the accident, such as mistakes, unsafe acts, violations of procedures, taking shortcuts, etc. Included are unsafe acts by the injured workers themselves and other worker actions that contributed to the accidents.
	Worker capabilities	Did the worker/team have adequate *training* to know how to do the job, use the equipment, and identify hazards and risks associated with the work, etc.? Training is context-specific, dealing with procedures or rules for undertaking particular tasks or activities.
	Communication	Lack of, or poor, communication at work group level, supervisory level or the organizational level and between organisations. Includes poor command of the language and lack of safety communication from supervisors. Includes the written as well as the spoken word.
	Attitudes and motivations	Attitudes towards safety. Motivation: prizes for safety performance, disciplinary measures, financial incentives, priced work, payment methods, bonuses, etc.
	Knowledge and skills	Did the worker/team have the *education* to know how to do the job, use the equipment, and identify hazard and risks associated with the work, etc. Compared to 'worker capabilities', education imparts a higher level of knowledge and skills, which is transferable to different situations.
	Immediate supervision	The supervisor is a key individual in accident prevention, having daily contact with staff and the opportunity to control unsafe conditions and acts likely to cause accidents and plan the work in a manner to reduce risk and identifiable hazards. The assessment is based on (1) inadequacies in *controlling* unsafe conditions and acts likely to cause accidents, and (2) *plan* the work in a manner to reduce risk and identifiable hazards.
	Worker health/fatigue	Worker health/fatigue
Workplace	Local hazards	Hazards and risks that are specific to the site, which should have been identified or somehow managed or planned to avoid or minimize.
	Site layout and space	Includes the ground and area where the work is performed, and the immediate adjacent area if contributing to the accident, and the relationship to the hazards and risks of the tasks.
	Work environment	The work environment includes wet conditions, thermal stressors, lights, noise, and other physical, climatic factors involved in influencing the factors involved in the incident.
	Housekeeping	Disorderly condition of trucks, equipment, materials, waste, etc
	Work scheduling	Poor required pace of the work, work sequencing, scheduling pressures, and other factors affecting the safety and health of workers in relation to work preparation and arrangement.
	Site constraints	The space in which the work is performed. Includes the relationship of equipment and the work team to identifiable hazards.
Materials/equip	Condition	Unsafe condition of materials/equipment
	Usability	Lack of/limited functionality of the materials/equipment or lack of materials/equipment themselves
	Suitability	Materials/equipment utilized not suitable for the job and task to be performed. Materials/ equipment used for other types of work than meant for.

	Design and specification	Poor designs and specifications of materials and equipment
	Supply and availability	Poor supply and availability of materials and equipment
Originating	Permanent works design	Permanent features of the equipment and buildings that influences the incident. It also includes temporary structures (temporary works) built for the tasks and projects. Includes information about underground and overhead utilities in the planning of projects/tasks.
	Project management	The safety oversight of the intricacies of the project and tasks. Includes contractor arrangements, subcontracting, labour supply, work scheduling, time management, time pressures and individuals taking it upon themselves to do jobs/tasks.
	Construction processes	Improper methods statements or absence of method statements if there should have been one developed and communicated. Inadequate or lack of verbal instructions when they should have been given or more thoroughly planned. Includes improper tools for the job or using tools not suitable for the job.
	Safety culture	Safety culture is the way things are done in and around the organisation and can be at different levels: organisational, divisional, and group (work team). This study assessed safety culture based on descriptions of five of the factors in the ConAC framework used as indicators: worker actions; communication; attitudes/motivations; supervision; and risk management.
	Risk management	Includes: Improper, or a lack of formal or informal, risk assessments, work method statements, job hazard analyses; improper incident investigation (which includes not learning from past mistakes and/or failures); poor identification of proper remedial actions in respect of identified risks; lack of, or poor employee consultation and participation in identification of hazards and risks; conditions where recognizable hazards were not identified; and situations where recognizable risks were not properly anticipated and identified.

3.3 Previous use of the ConAC framework

The ConAC framework was developed through a combination of focus groups and a detailed study of 100 construction accidents by Haslam et al. (2003; 2005). Worker actions/behaviours were identified in 49% of the accidents. Explanations for unsafe acts were: safety being overlooked in the context of heavy workloads and other priorities; taking shortcuts to save efforts and time; and inaccurate perception of risk. Underlying the worker actions/behaviours were inadequate safety knowledge. Risk management was identified in 84% of the accidents. Haslam et. al. (2005) concluded that '… there is a pervasive failure of the industry to engage in effective risk management' (p. 413). The failures of risk management typically were lack of, or inadequate, risk assessments.

Cooke and Lingard (2011) used the ConAC framework to analyse 258 fatal construction accidents in Australia based on coronial investigations. The preliminary analysis suggested that many investigations focussed on immediate factors and '… may not identify the extent to which these immediate factors arise as a result of shaping factors or originating influences' (p. 284). Frequent factors identified were mainly immediate factors, for example, worker actions/behaviour, site layout/space and suitability of materials and equipment.

In a study of 10 fatal accidents involving excavators, Lingard et al. (2013) found that it was possible to identify immediate factors in most cases, shaping factors in only a few cases and originating factors in none of the cases. The immediate factors included unsafe work methods/actions, aspects of the site layout and the condition of mobile plant. The shaping factors included on-site communication issues, design of work processes and the specification/suitability of plant for the site location and/or activity being performed.

Behm and Schneller (2013) used the ConAC model interviewing employees, witnesses, supervisors and safety engineers in 27 construction accidents. The most frequent factors found were (in rank order) (1) risk management, (2) worker actions and behaviour, (3) worker capabilities including knowledge and skills, (4) local hazards, (5) project management and (6) attitude and motivation. They also analysed if the factors were correlated to other factors in the framework and found that worker actions were negatively correlated with worker capabilities, indicating that these factors acted independently. Further, they found that worker actions were correlated with attitudes and motivations, attitudes and motivation were correlated with safety culture, worker actions were correlated with availability of equipment and materials, site conditions were correlated with work scheduling and work scheduling was correlated with construction processes.

Gibb et. al (2014) compared the results on 23 of the ConAC factors from research in the UK, Australia and USA, and found similarities and dissimilarities in the ranking of factors between the three studies. Differences were explained by differences in, for example, accident severity, researcher background, use of primary versus secondary data and types of hazards. The average percentage of each factor from the studies showed that the most frequent immediate factors were worker actions, suitability of materials/equipment and worker capabilities. The most frequent shaping factors were knowledge/skills and attitudes/motivations, and the most frequent originating factors were risk management, project management and permanent works design.

4 Material and methods

4.1 Study sample

The study sample consists of 176 construction accidents investigated by the Norwegian Labour Inspection (LIA) in 2015. The same sample is used and described in more detail in another paper identifying frequent accident types and barrier failures (Winge and Albrechtsen, 2018). This sample gives sufficient descriptions of the accident sequence as well as a sufficient number of recent accidents. The study sample is limited to accidents investigated by the LIA for one whole year, 2015. In 2015, LIA carried out investigations of 189 construction accidents, involving 210 companies. Seven of the 189 accidents were excluded from the sample since they did not take place during construction work or at constructions sites, and six accidents were excluded due to lack of sufficient information about the accident. Hence, the main study sample is 176 accidents involving 184 injured persons, of which four were fatalities.

According to the Norwegian Work Environment Act, occupational accidents that lead to fatal or severe injuries must be reported to the police and the LIA. Severe injury here means any harm (physical or mental) that results in permanent or prolonged incapacitation. There is guidance on LIA's website describing nine characteristics that indicate severe injury, including injuries to the head, skeleton, or internal organs; loss of a body part; poisoning; unconsciousness; metabolism/frost injury; hypothermia; and injuries that lead to hospitalisation (Labour Inspection Authority, 2018). When the LIA is notified of an accident, it decides whether to complete an investigation based on assessments of potential severity and available inspectors. The criteria for selecting accidents for the study sample included:

1. At least one construction company involved
2. Occurred during construction work
3. Inspected by the LIA in 2015

Construction accident statistics normally do not include workers employed by non-construction companies that are injured in construction accidents, for example, hired workers employed by temporary employment agencies. Criteria 1 and 2 above ensured that these workers were included in the sample.

An investigated accident can involve many documents and normally consists of the notification of the accident, accident reports from the LIA and the company, and letters between the LIA and companies involved in the accident. When an accident is reported by mail or phone to the LIA, basic information about the accident is collected to decide whether an investigation is going to be carried out. During the investigation, the inspectors collect information to investigate if there have been any violations of the law and to describe the course of events. After the investigation, the inspectors produce an investigation report that in most cases includes a description of the accident sequence, causal factors and violations of the law when identified. In most cases, the investigated company is decreed to produce an accident investigation report and a plan including measures to prevent similar accidents.

The amount of information available on the accidents varies significantly. Some accidents in this sample consisted of only one document, others consisted of up to 50 documents. Some accidents were sparsely described, and six accidents were excluded due to lack of sufficient information. Other accidents had rich descriptions and were investigated by professional accident investigators.

This study includes all data collected from the reporting of the accident and the entire process related to the investigation. Four analysts were engaged in finding relevant documents and extracting relevant information from the accident documentation for entry into a text file, consisting of 84,000 words.

4.2 Identifying causal factors

The method for using the ConAC framework was inspired by the methods described by Behm and Schneller (2013), adapted to the secondary data used in this study:

1. Identify immediate circumstances (e.g., worker actions)
2. Identify the shaping factor(s) associated with the immediate factor (e.g., supervision)
3. Identify originating influence(s) influencing the shaping factor(s) (e.g., risk management)
4. Repeat the sequence for each immediate circumstance

A spreadsheet used by Behm and Schneller (2013) was used to describe how each factor was linked to the accident. Originating influences may appear more than once in a single incident if there are multiple deficiencies.

Like the other studies using the ConAC framework, the researchers coded the accidents and their related factors based on their judgement of 'reasonable confidence' that a factor was present in an accident (Haslam et al. 2005). The outer originating influences are rarely clearly identifiable in incident investigations (Haslam et al. 2005). Therefore, like Behm and Schneller (2013), this study did not attempt to trace incident influences to these outer originating influences in the framework. This study uses the same 23 factors Gibb et al. (2014) used when comparing the Australian, UK and US studies.

Four analysts studied the documents related to the accidents. To ensure internal validity, quality assurance measures were carried out in five steps:

1. The first author studied the previous studies in depth and gave training to the others.
2. A few accidents were analysed according to the method described above by the analysts jointly before the accidents were divided among the analysts for reading documents and coding.
3. There were regular meetings of the analysts where accidents and factors were discussed.
4. After all of the accidents had been assessed and coded, two analysts divided the accidents in two groups and carried out quality assurance of the coding of all of the accidents (not accidents they had originally coded).
5. During analysis of the accidents, the first author compared the coding and recoded where there were discrepancies in the coding.

4.3 Approach for identifying connections between causal factors

Reason et al. (2006) state that it '… is now broadly recognised that accidents in complex systems occur through the concatenation of multiple factors, where each may be necessary but where they are only jointly sufficient to produce the accident' (p. 2). This study uses a set theoretic approach that allows for assessing necessity and sufficiency of conditions in data sets (Ragin, 2006 and 2008; Goertz and Mahoney, 2012; Schneider and Wagemann, 2012). The term 'causal condition' is used generically in this paper to refer to an aspect of a case that is relevant in some way to the explanation of the outcome (see Ragin, 2008).

It is not possible to assess necessary and sufficient conditions for accidents as such, since binary variables are necessary to do that, and there are no 'non-accidents' in this material. However, it is possible to assess necessary and sufficient conditions for causal factors in the ConAC framework, for instance, conditions that can explain worker actions and local hazards. In this approach the 'independent variable' is called *condition* (X), and the 'dependant variable' is called *outcome* (Y).

Set-theoretic connections are often illustrated by Venn-diagrams (Figure 2) where each circle represents cases with a given characteristic. For instance, X can represent accidents with poor risk management, and Y can represent accidents with poor worker actions. Figure 2 illustrates different combinations of sufficiency and necessity.

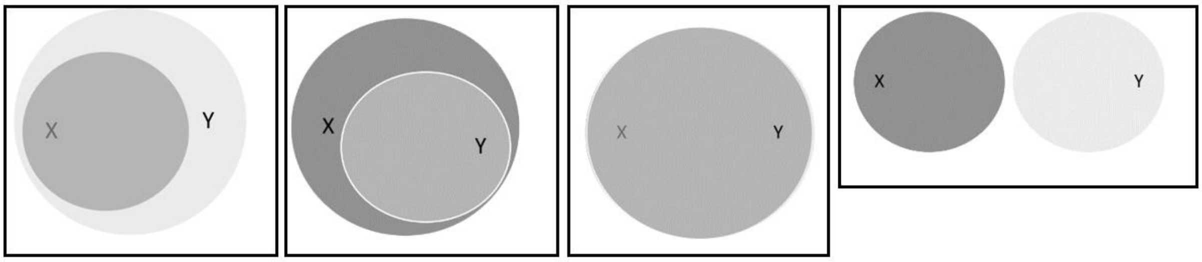

Figure 2. Venn diagrams illustrating (from left to right) (1) X as a sufficient condition (if X, then Y), (2) X as a necessary condition (if Y, then X), (3) X as a sufficient and necessary condition, and (4) no connection.

A condition (X) is *sufficient* if, whenever it is present across cases, the outcome (Y) is also present (If X, then Y). Sufficient conditions can produce the outcome alone, but there are also other conditions with this capability. For binary variables, the assessment of sufficiency and necessity of conditions are carried out in two-by-two tables. If a condition is sufficient, there are cases in cell B and no cases in cell D (Figure 3).

The logic behind necessary conditions can be viewed as the mirror image of that for a sufficient condition (Schneider and Wagemann, 2012). A condition (X) is necessary if, whenever the outcome (Y) is present across cases, the condition (X) is also present. A necessary condition must be present for the outcome to occur. If a condition is necessary, there are cases in cell B, and no cases in cell A (Figure 3). Table 2 summarises the strategies for assessing sufficiency and necessity.

	X=0	X=1
Y=1	A	B
Y=0	C	D

Figure 3. Two-by-two table

Table 2. Description of sufficient and necessary conditions

Type	Description	Logic	Capacity	Examine cases that share same;	Attempt to identify their shared;
Sufficient	Whenever the condition is present, the outcome is also present	If X, then Y	Can produce the outcome alone	Conditions (X)	Outcome (Y)
Necessary	Whenever the outcome is present, the condition is also present.	If Y, then X	Must be present for the outcome to occur	Outcome (Y)	Conditions (X)

In data sets, connections between factors are rarely perfectly consistent. Some cases will usually deviate from the general patterns so that conditions can be quasi-necessary or quasi-sufficient (Legewie, 2013). Consistency and coverage are parameters used to assess how well the cases in a data set fit a relation.

The calculation of consistency is described in Table 3 and in an example in the results section. *Consistency* resembles significance in statistical approaches where 0 indicates no consistency and 1 indicates perfect consistency. The consistency value for conditions should be higher than 0.75 (Schneider and Wagemann, 2012). If a relation is established to be consistent, the coverage should be calculated. *Coverage* assesses the degree to which a condition accounts for instances of an outcome, or empirical relevance (Ragin, 2008). The analogous measure in statistical models would be R2, the explained variance contribution of a variable (Thiem, 2010), with values between 0 and 1.

Table 3. Assessing consistency and coverage for sufficient and necessary conditions. Based on Ragin (2008) and Schneider & Wagemann (2012).

Sufficiency				Necessity			
	X=0	X=1	Coverage		X=0	X=1	Consistency
Y=1	A	B	B/(A+B)	Y=1	A	B	B/(A+B)
Y=0	C	D	-	Y=0	C	D	-
Consistency	-	B/(B+D)	-	Coverage	-	B/(B+D)	-

Behm and Schneller (2013) analysed correlations (*phi*) for each pairing of all factors in the ConAC framework. Correlations and set theoretic connections indicate different types of connections.

Therefore, correlations (*phi*) are included in the tables in the results section along with the assessment of consistent connections.

5 Results

5.1 Background data

Table 4 shows background data for injured persons and the accidents in the main study sample.

Table 4. Background data for the 176 accidents/184 injuries in the main study sample in percentages

Age of injured workers (%) (n=184)		Nationality of injured workers (%) (n=184)		Construction type (%) (n=176)		Accident type (%) (n=176)		Potential fatality of accident (%) (n=176)	
15-19	8	Norway	62	Building	41	Fall	48	Fatality	2
20-24	14	Other Nordic countries	6	Refurbishment	20	Hit by object	24	Likely	47
25-39	30	Eastern Europe	26	Civil Engineering	15	Cut by sharp object	13	Possible	26
40-54	34	Other European countries	6	Engineering Construction	14	Squeezed, caught	6	Not possible	25
55-67	13	Non-European countries	1	Other	9	Electricity	4	Total	100
67<	1	Total	101	Total	100	Other	5		
Total	100					Total	100		

The average age of the injured person was 38 years; 64% of the injured were between 25 and 55 years of age, and 22% were younger than age 25. Only three injured workers were women. Thirty-eight percent of the injured persons had foreign citizenship, most of them from Eastern Europe. ‘Building’ was the most frequent construction type and nearly half of the accidents involved a fall from height. The material did not always provide information about the conditions of employment, but at least 18 % were hired workers and 9% were apprentices or hired for a summer job.

A method used by Haslam et al. (2003) was also used in this study to indicate potential fatality. Information from the accidents was used to evaluate alternative outcomes and to assess the outcome if the injured person had been in a slightly different location or if a different part of the body had been involved. *Likely fatality* required only a minor change in circumstances and *possible fatality* required a number of circumstances to change. There were four fatalities in this material (2%); 47% were assessed to be *likely* fatalities, 26% *possible* fatalities, and 25% were *not possible* fatalities.

5.2 Causal factors

Figure 4 summarises factors identified using the ConAC framework (Haslam et al. 2003; 2005). In total, 1.039 causal factors were identified in the 176 accidents, an average of 5.9 factors per accident. There were on average 2.7 immediate factors, 1.8 shaping factors and 1.5 originating factors per accident. The left side of the figure shows that worker and team factors were identified in 90% of the accidents, site factors in 55%, material and equipment factors in 56%, and originating influences in 66% of the accidents.

The right side of the figure shows the percentage of accidents where the detailed factors were identified. Seven of the factors were identified in more than 30% of the accidents: the immediate factors worker actions, worker capabilities, usability of materials or equipment and local hazards; the shaping factor immediate supervision; and the originating factors project management and risk management. These seven factors are important in the analysis of connections between factors in section 5.3. and is therefore described in more detail below.

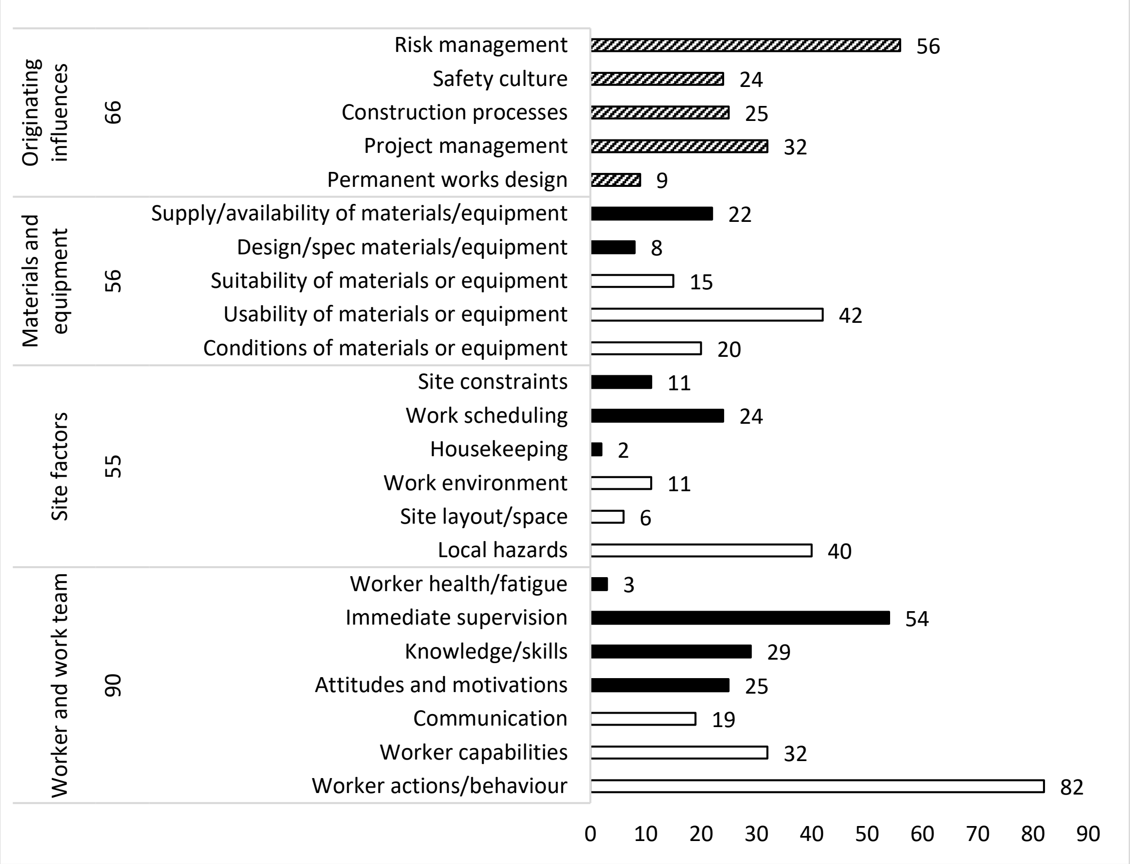

Figure 4. Percent of causal factors identified in 176 accidents (several factors possible for each accident). (White=immediate factors. Black=Shaping factors. Stripes=Originating influences).

5.2.1 Worker actions and behaviours

Worker actions includes all acts at the ‘sharp end’ that have an impact on the accident, such as mistakes, unsafe acts, violations of procedures, taking shortcuts, etc. Included are unsafe acts by the injured workers themselves and other worker actions at the ‘sharp end’ that contributed to the accidents. Worker actions was identified to be a factor in 145 accidents (82%). Subcategories of poor worker actions were identified inductively. Some accidents had more than one of these characteristics, others had none. The most frequent categories found were (in rank order) (1) using wrong type/use of equipment, (2) working at heights without adequate safeguarding, (3) staying in a danger zone, (4) choosing a wrong working method or skipping a phase in the sequence of the operation, (5) not securing scaffolding or working platforms correctly/sufficiently, (6) not communicating to other workers or companies about hazards and danger zones, and (7) not securing materials or structures properly. In 25 accidents (24% of the worker actions-accidents), other workers than the injured worker contributed to the accident. Often, combinations of actions by the injured worker and other workers contributed to the accident. In some accidents, many actions by several workers led to the accident.

5.2.2 Worker capabilities

Worker capabilities is about workers not knowing how to do the job, use the equipment and identify hazards and risks associated with the work. Worker capabilities was identified to be a factor in 56 accidents (32%). The most frequent categories found were (in rank order) (1) lack of competence related to the use of machinery or equipment, (2) young and/or inexperienced workers, and (3) workers lacking sufficient general safety competence.

5.2.3 Immediate supervision

Immediate supervision refers to the supervisor (1) having daily contact with staff and the opportunity to *control* unsafe conditions and acts likely to cause accidents, and (2) *planning* the work in a manner to reduce risk and identifiable hazards. There was great variation in the size and type of the construction work and hence the role of the supervisors. Immediate supervision in total was identified to be a factor in 95 accidents (54%). Of these, inadequacies in controlling unsafe conditions and actions were judged to have been involved in 68 accidents (38%). Further, inadequacies in planning the work in a manner to reduce risk and identifiable hazards were judged to have been involved in 51 accidents (29%).

5.2.4 Local hazards

Local hazards are hazards that are specific to the site and that should have been identified and managed. Included are hazards related to more or less fixed installations like platforms and scaffolding. Local hazards were identified to be a factor in 71 accidents (40%). The most frequent categories found were: inadequate barriers on walkways, platforms, roofs and scaffoldings structures; holes and openings in building structures; and loose or rotten roofs and floors.

5.2.5 Usability of materials or equipment

Usability of materials and equipment refers to lack or limited functionality of materials/equipment. Usability of materials and equipment was identified to be a factor in 72 accidents (42%). The most frequent deficiencies were scaffolding and platforms lacking adequate barriers and poor condition of scaffolding floors. A factor in many of the fall accidents was that fall arrest equipment was not available or that opportunities for attaching the fall arrest equipment was lacking. In many accidents where saw was involved, the saw lacked a push stick and the worker used the hand instead.

5.2.6 Project management

Project management refers to the oversight of the intricacies of the project and tasks and contractor arrangements, subcontracting, labour supply, work scheduling, time management, time pressures, and individuals taking it upon themselves to do jobs/tasks. Project management was identified to be a factor in 57 accidents (32%). The most frequent problems were related to unclear organisational structures and responsibilities, cooperation and communication between workers and companies, lack of control on actors and worker behaviour in the project, time pressure and new types of jobs unfamiliar to the work team.

5.2.7 Risk management

Risk management refers to improper risk assessments, not learning from past failures, poor identification of remedial actions and poor employee consultation and participation in identification of hazards and risks. Risk management was identified to be a factor in 98 accidents (56%). The most frequent categories of deficiencies in risk management in this research were (1) poor systematic health and safety work/internal control, (2) poor routines for assessing risk in working operations, (3) not following the safety and health plan and (4) poor or lacking risk assessments. There were combinations of such deficiencies in most of the risk management accidents.

5.3 Connections between factors

In this section, conditions and outcomes of frequent causal factor are analysed. There is an abundance of possible connections between the 23 factors in this material but all are not theoretical plausible. Table 5 shows connections that are: theoretically plausible (cf. Figure 1); consistent (> .75); empirically relevant (coverage > .30); involve the most frequent factors; and do not include factors that include same type of characteristics. The calculation of consistency and coverage is explained in section 4.3 and in an example below.

Table 5. Connections between factors in rank order by coverage (empirical strength) (N=176). n=cases where both factors are present. Consistency > .75. Coverage > .30. S/N=Sufficient/Necessary. Correlations (*phi*).

Condition (X)	Outcome (Y)	n.	Consistency	Coverage	S/N	R.*	Sig.
Risk management	Immediate supervision	77	.79	.81	S&N	.553	.000
Immediate supervision	Worker actions	86	.91	.59	S	.231	.002
Risk management	Worker actions	86	.88	.59	S	.158	.036
Project management	Immediate supervision	49	.86	.52	S	.444	.000
Usability of materials or equipment	Worker actions	66	.89	.46	S	.152	.044
Local hazards	Worker actions	59	.83	.41	S	n.s.	n.s.
Immediate supervision	Work scheduling	38	.90	.40	N	.410	.000
Risk management	Construction processes	37	.84	.38	N	.330	.000
Worker capabilities	Worker actions	51	.91	.35	S	.156	.039
Project management	Worker actions	50	.88	.34	S	n.s.	n.s.
Risk management	Work scheduling	33	.79	.34	N	.258	.001
Knowledge/skills	Worker actions	46	.90	.32	S	n.s.	n.s.

*Correlations (phi): $p < .05$. Strength R: weak (0-.0.3), moderate (0.3-0.6), and strong (0.6-1.0). n.s. = Not significant.

Worker actions was identified in 145 accidents (82%). Table 5 shows that seven factors were identified as ‘sufficient’, but not ‘necessary’, conditions for worker actions. The connection between immediate supervision (X) and worker actions (Y) is used for illustration. Table 6 and Figure 5 shows that most (91%) of the immediate supervision-accidents (X) are also worker actions-accidents (Y). This gives support to the logical argument ‘if X, then Y’, or if poor immediate supervision, then poor worker actions. X covers most (59%) of Y, indicating that the empirical relevance (coverage) is strong. The 59 accidents (41%) that are not X, indicate that X is not *necessary* for Y and that there must be other conditions that can also explain Y, which is confirmed in Table 5. Four of the factors also show a positive correlation, indicating a symmetric relationship between the factors.

Table 6. Connection between ‘poor immediate supervision’ (condition) (n = 95) and ‘poor worker actions’ (outcome).

	Not poor immediate supervision (X = 0)	Poor immediate supervision (X = 1)	Tot.	Coverage
Poor worker actions (Y = 1)	A: 59	B 86	145	0.59
Not poor worker actions (Y = 0)	C: 22	D: 9	31	-
Tot.	81	95	176	-
Consistency	-	0.91	-	-

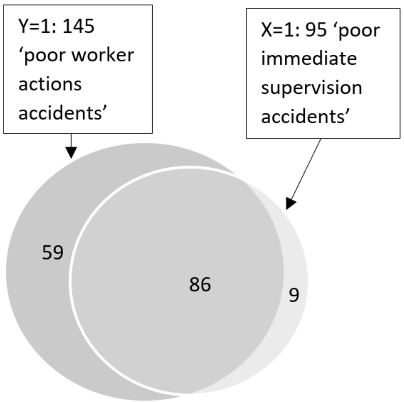

Figure 5.Venn diagram illustrating the connection between 'poor immediate supervision' (X) (n = 95) and 'poor worker actions' (Y) (n = 145).

Local hazards were identified in 71 accidents (40%). Table 5 shows that worker actions was identified as a 'necessary', but not 'sufficient', condition for producing local hazards. This supports the argument that poor worker actions must be present for local hazards to occur, but only together with other conditions. The results also show that 'site constraints' is 'sufficient', but not 'necessary', for producing local hazards, but the empirical relevance (coverage) is relatively low.

Usability of materials or equipment was identified in 74 accidents (42%). Worker actions was identified as a 'necessary' condition for producing usability of materials/equipment.

Immediate supervision was identified to be a factor in 95 accidents (54%). Immediate supervision is a shaping (intermediate) factor in the ConAC framework and can be a condition as well as an outcome. Table 5 shows that risk management is both a 'sufficient' and 'necessary' condition for immediate supervision. This indicates that poor risk management is almost always present when poor immediate supervision is present, *and* that when poor immediate supervision is present, poor risk management is also present. The results also show that project management is 'sufficient' for poor immediate supervision. Immediate supervision can also be a condition, and the results indicate that immediate supervision is a 'sufficient' condition for 'worker actions' and 'necessary' for work scheduling.

Risk management was the originating factor identified most frequently. Table 5 shows that risk management is both 'sufficient' and 'necessary' condition for poor immediate supervision, 'sufficient' for poor worker actions, and 'necessary' for seven factors. Project management was the second most originating factor identified. The results show that poor project management is a 'sufficient' condition for poor immediate supervision and poor worker actions.

6 Discussion

6.1 Frequent causal factors and connections

By studying 176 construction accidents in depth, we aimed at contributing to the knowledge of causal factors in construction accidents and connections between causal factors. Figure 6 simplifies and summarises the seven most frequent causal factors identified, and causal conditions that are consistent and empirically relevant. The term 'causal condition' is used generically to refer to an aspect of a case that is relevant in some way to the explanation of the outcome (Ragin, 2008). The discussion emphasises the three factors most identified in this study: worker actions, immediate supervision, and risk management.

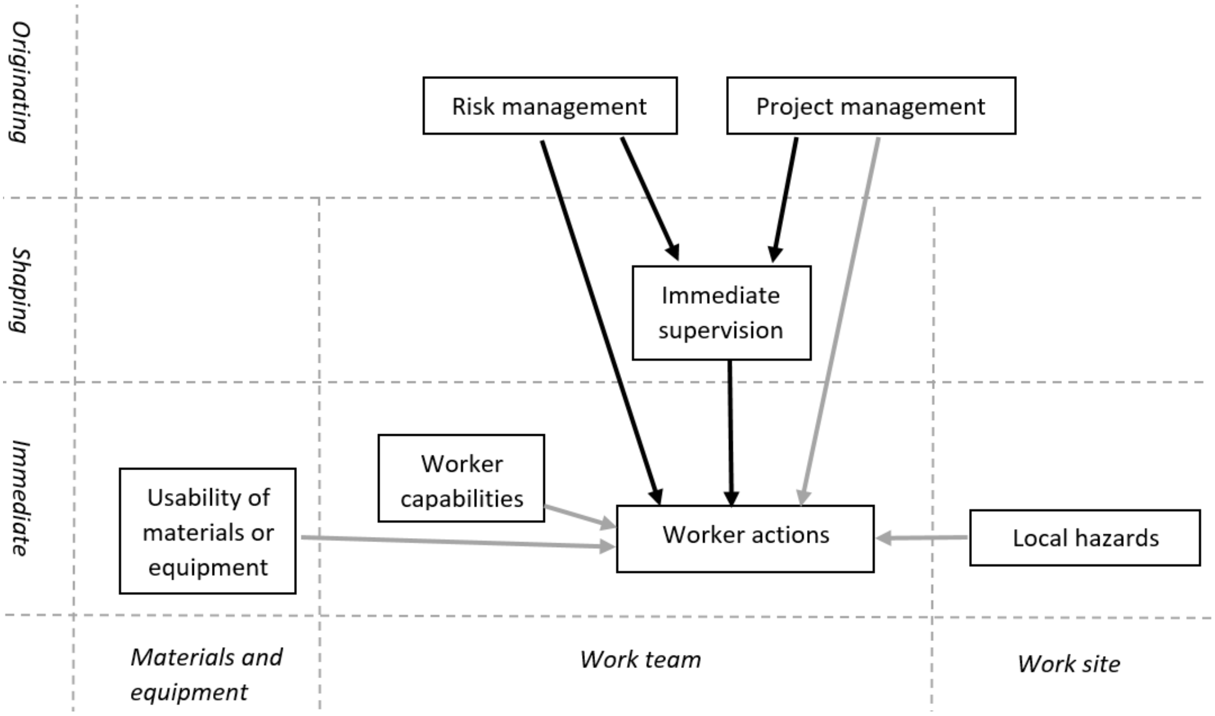

Figure 6. Factors consistently connected to poor worker actions (coverage > .3) and poor immediate supervision, and connections between these factors. Black arrows indicate strong connections (coverage > .5).

6.2 Worker actions

Depending on operational definitions, it is often concluded that 'human error' is a determining factor in 70-80% (Rasmussen, 1997) or 80-90% (Phillips, 2005) of accidents. Worker actions was identified to be a factor involved in 82% of the accidents in this study. This is more than that reported in other studies using the ConAC framework in the UK (49%), Australia (53%) and USA (63%) (Gibb et al., 2014).

Today, it is widely acknowledged that ‘human error’ is largely a result of the system humans are part of (Reason, 1997) and symptomatic of trouble deeper within a system (Dekker, 2017). Implicit in the works of Rasmussen (1997), Reason (1990) and in the ConAC framework (Haslam et al. 2005), is the involvement of human factors and ergonomic factors. The results in this study suggest that worker actions were influenced by many conditions, most notably immediate supervision, risk management, usability of materials or equipment, local hazards, worker capabilities and project management. The result is broadly consistent with many other studies. In the inductive process of developing the ConAC framework it was found that worker actions were shaped by attitudes/motivations, knowledge/skills, supervision and health/fatigue (Haslam et al., 2005). Behm and Schneller (2013) found that worker actions were positively correlated with attitudes/motivations and availability of equipment/materials, and negatively correlated with worker capabilities, indicating that these factors acted independently. Interviewing victims of construction accidents in Hong Kong, Choudry and Fang (2008) identified 11 factors influencing worker’s safety behaviour at construction sites, for example management, experience, performance pressure, working environment and training. In a literature review on construction safety, Khosravi et al. (2014) concluded that the causes of unsafe behaviours and accidents appear to be multifactorial, and generally related to society, organization, project management, supervision, contractor, site condition, work group, and individual characteristics.

One contribution of this study is the use of a set theoretic approach which makes it possible to assess sufficiency and necessity of conditions (Ragin, 2008). The understanding of causality in the SCM, and implicitly in many other accident models, is that accidents in complex systems occur through the interaction of multiple factors, where each may be necessary but where they are only jointly sufficient to produce the accident (Reason et al., 2006; Hopkins, 2014). When studying sets of accidents, it is possible to assess sufficiency and necessity of connections between factors. The results in this study indicate that ‘poor worker actions’ was the outcome of many ‘sufficient’ conditions. ‘Sufficient’ conditions can produce the outcome alone, at the same time as there are other conditions that have this capability, so-called multiple causation or equifinality (Goertz and Mahoney, 2012). This have practical implications for prevention. The results suggest that to reduce the number of construction accidents, it is necessary to ensure the quality of each of these ‘sufficient’ conditions.

Ideally, hazards should be eliminated before they are present (Haddon, 1980). However, the situation at many construction sites today is that construction workers must tackle several hazards daily. The human is usually considered a hazard, but humans can be heroes as well, whose behaviours can avoid hazards leading to accidents (Reason, 2008). Most hazards will not lead to injuries because they are observed and addressed by people’s behaviours (Jørgensen, 2016). Lingard and Rowlinson (2005) state that the human element is particularly important in a labour-intensive industry, such as the construction industry. Strategies for reducing unsafe acts should therefore include multiple measures including eliminating and interrupting the injury process, manpower recruitment and planning, education and training, an ergonomics/human factors approach, as well as behavioural measures.

6.3 Immediate supervision

Immediate supervision was the factor thirdly most identified in this study, and one of the factors strongly connected to worker actions (Figure 6). Immediate supervision was identified more often in this study (54%) compared to the studies in UK (13%), Australia (16%), and USA (30%) (Gibb et al., 2014). The results showed inadequate immediate supervision in *controlling* unsafe conditions and actions on site and in *planning* the work in a manner to reduce risk and identifiable hazards.

Immediate supervision is a shaping (intermediate) factor in the ConAC framework, and Figure 6 illustrates that immediate supervision is an outcome of the originating factors risk management (‘sufficient’ and ‘necessary’) and project management (‘sufficient’), and the immediate factor worker actions (‘sufficient’). The results are broadly consistent with other studies. Rowlinson et al. (2003) concluded that the foreman is the key interface between worker and management and plays a key role in ensuring that safety management systems operate effectively. Mohamed (2002) concluded that the more aware of occupational health and safety (OHS) supervisors are, the more positive is the OHS climate. Choudry and Fang (2008) found that management involvement and toolbox talks were found to be the most effective factors for site safety, and that workers feel more comfortable with supervisors who care for their safety. Kines et al. (2010) found that coaching construction site foremen to include safety in their daily verbal exchanges with workers had a significantly positive and lasting effect on the level of safety. In a literature review, Khosravi et al. (2014) found that effective enforcement, worker-supervision communication, and good supervision style had moderate evidence of negative association with unsafe behaviours and accidents. This study and the studies described above show the importance of the supervisor/foreman being the connection between workers and management, and in controlling and planning the work to prevent unsafe conditions and acts.

6.4 Risk management

Risk management was the originating factor most identified in this study (56%), and in the studies in the UK (84%), Australia (21%), and USA (67%) (Gibb et al., 2014). The most frequent categories of deficiencies in risk management in this research were poor or lacking risk assessments, poor routines for assessing risk in working operations, inadequate systematic health and safety work/internal control, and not following the safety and health plan. There were combinations of such deficiencies in most of the risk management accidents. The results are similar to those of Haslam et al. (2005) who found that the failures of risk management typically were lack of, or inadequate, risk assessments. Hale et al. (2012) also found failures in planned risk control at the workplace level and planning and risk management at the 'delivery systems' level. These inadequacies are largely about inadequacies in risk management at different levels and underline the importance of risk being addressed at different levels by different actors (Hale et al., 2012; Rasmussen and Svedung, 2000).

Risk management was found to be both a 'sufficient' and 'necessary' condition for poor immediate supervision in this study, suggesting that it can produce poor immediate supervision alone, and that it 'almost always' produces poor immediate supervision. This is not surprising, since the supervisor plays a key role in risk management in many construction projects as described above. Risk management was also found to be a 'necessary' condition for construction processes and work scheduling indicating causal connections to the planning and scheduling of the work operations. The results are not surprising, since accidents '… invariably involve an inadequately controlled risk, indicative of a management failing' (Haslam et al, 2005, p. 413). Risk management in this study is an example of what Reason (1997) call a latent condition that '… can increase the likelihood of active failures through the creation of local factors promoting errors and violations' (p. 11). Latent conditions like poor risk management can contribute to a number of different other causal factors and accidents.

6.5 Limitations

There are some limitations in using this framework and material. First, the framework used and the factors included will influence the outcome. Lundberg et al. (2009) has expressed this as 'What-you-look-for-is-what-you-find. Second, like Cooke and Lingard (2011) and Behm and Schneller (2013) we found that the classification of the factors was open to interpretation. Differences in results from different studies using the ConAC framework can be explained by, for example, differences in accident severity, researcher background, use of primary versus secondary data and types of hazards (Gibb et. al., 2014). The operational definitions created by Behm and Schneller (2013) were used and described in more detail and with examples from this study to increase internal validity. Third, the data used in this study, like in the Australian study (Cooke and Lingard, 2011), are secondary and some factors were difficult to assess due to little information. The outer originating factors in the framework were excluded and there was little information about some factors, for example, permanent works design and worker health/fatigue and housekeeping, which are clearly underreported in this material. Moreover, it was easier to identify factors at the sharp end on site than at the blunt end of, for example, project management or design. Fourth, the methods used for assessing connections between factors do not necessarily confirm causation. In the analysis, connections were established from an immediate factor to a shaping factor, and from the shaping factors to originating factors, as described in section 4.1. However, there are many connections in the data set that are not validated in this way. To establish likely causal connections, it is necessary to study each connection in depth using other methods like for example process tracing (e.g., Goertz and Mahoney, 2012; George and Bennett, 2005). A suggestion for future research is to study in depth the causal processes between factors that are strongly connected, such as risk management, immediate supervision and worker actions.

7 Conclusion

The purpose of this study was to add to the relative sparse literature on accident causality in the construction industry. The ConAC framework and its terminology were found to be good tools for identifying and assessing causal factors in construction accidents. Despite some limitations concerning methods and material, the study revealed some strong and repeated patterns of frequent factors and connections between factors that provide valuable insight into construction accident causality. The results can be used for prioritising and developing preventive measures at different levels in the construction industry. This study and previous studies show that many construction accidents are multi-causal, and that different combinations of factors are present in different accidents. Strategies for reducing unsafe acts and accidents must also be multifactorial. All factors are, however, not equally important, and this study suggest that worker actions, immediate supervision and risk management are key causal factors in construction accidents and accident prevention.

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1 References

Abdelhamid, T. S., & Everett, J. G. (2000). Identifying root causes of construction accidents. Journal of Construction Engineering and Management, 126(1), 52-60.

Ale, B. J., Bellamy, L. J., Baksteen, H., Damen, M., Goossens, L. H., Hale, A. R., ... & Whiston, J. Y. (2008). Accidents in the construction industry in the Netherlands: an analysis of accident reports using Storybuilder. Reliability Engineering & System Safety, 93(10), 1523-1533.

Behm, M., & Schneller, A. (2013). Application of the Loughborough Construction Accident Causation model: a framework for organizational learning. Construction Management and Economics, 31(6), 580–95.

Behm. M. (2009). Relevancy of Data Entered into Riskmaster. NC DOT Research Project 2009-10 (Oct. 10, 2017): https://connect.ncdot.gov/projects/planning/RNAProjDocs/2009-10FinalReport.pdf

Bellamy, L. J., Ale, B. J., Geyer, T. A. W., Goossens, L. H., Hale, A. R., Oh, J., ... & Whiston, J. Y. (2007). Storybuilder—A tool for the analysis of accident reports. Reliability engineering & system safety, 92(6), 735-744.

Choudhry, R. M., & Fang, D. (2008). Why operatives engage in unsafe work behavior: Investigating factors on construction sites. Safety Science, 46(4), 566-84.

Cooke, T., & Lingard, H. (2011). A retrospective analysis of work-related deaths in the Australian construction industry. In: Egbu, C. and Lou, E. C. W. (Eds.), Proceedings 27th Annual ARCOM Conference, Bristol, 5–7 September, Association of Researchers in Construction Management, Reading, pp. 279–88.

Dekker, S. (2017). The Field Guide to Understanding 'Human Error'. CRC Press.

Eurostat. (2016). Accident at work statistics. http://ec.europa.eu/eurostat/statistics-explained/index.php/Accidents_at_work_statistics (extracted 19 February 2018).

George, A. L., & Bennett, A. (2005). Case studies and theory development in the social sciences. MIT Press.

Gibb, A. Lingard, H., Behm, M., & Cooke, T. (2014). Construction accident causality: Learning from different countries and differing consequences. Construction Management and Economics, 32(5), 446-59.

Gibson, J., 1961. The contribution of experimental psychology to the formulation of the problem of safety. In Jacobs, H.H., (Ed.), Behavioural Approaches to Accident Research. Association for the Aid of Crippled Children, New York.

Goertz, G., & Mahoney, J. (2012). A tale of two cultures: Qualitative and quantitative research in the social sciences. Princeton University Press.

Haddon, W. (1980). The basic strategies for reducing damage from hazards of all kinds. Hazard Prevention 16(1), 8-12.

Hale, A. R., Walker, D., Walters, N., Bolt, H. (2012). Developing the understanding of underlying causes of construction fatal accidents. Safety Science, 50(10), 2020-7.

Haslam, R. A., Hide, S. A, Gibb, A. G. F., Gyi, D. E., Atkinson, S., Pavitt, T. C., Duff, R., Suraji, A. (2003). Causal factors in construction accidents, HSE Report RR156, HMSO, Norwich.

Haslam, R., Hide, S., Gibb, A., Gyi, D., Pavitt, T., Atkinson, S., Duff, A. (2005). Contributing factors in construction accidents. Applied Ergonomics, 36(3), 401–51.

Hinze, J., Pedersen, C., & Fredley, J. (1998). Identifying root causes of construction injuries. Journal of Construction Engineering and Management, 124(1), 67-71.

Hopkins, A. (2014). Issues in safety science. Safety Science, 67, 6-14.

Jørgensen, K. (2016). Prevention of “simple accidents at work” with major consequences. Safety Science, 81, 46-58.

Khanzode, V. V., Maiti, J., & Ray, P. K. (2012). Occupational injury and accident research: A comprehensive review. Safety Science, 50(5), 1355-67.

Khosravi, Y., Asilian-Mahabadi, H., Hajizadeh, E., Hassanzadeh-Rangi, N., Bastani, H., Behzadan, A. H. (2014). Factors influencing unsafe behaviors and accidents on construction sites: A review. International Journal of Occupational Safety and Ergonomics, 20(1), 111-25.

Kines, P., Andersen, L. P., Spangenberg, S., Mikkelsen, K. L., Dyreborg, J., Zohar, D. (2010). Improving construction site safety through leader-based verbal safety communication. Journal of Safety Research, 41(5), 399-406.

Labour Inspection Authority (2018). Reporting accidents and severe injury (May 29, 2018): https://www.arbeidstilsynet.no/kontakt-oss/melde-ulykke/melding-av-ulykker-og-alvorlig-skade/

Legewie, N. (2013). An introduction to applied data analysis with qualitative comparative analysis. In Forum Qualitative Sozialforschung/Forum: Qualitative Social Research (Vol. 14, No. 3).

Leveson, N. (2004). A new accident model for engineering safer systems. Safety Science, 42(4), 237-70.

Lingard, H., & Rowlinson, S. M. (2005). Occupational health and safety in construction project management. Taylor & Francis. London and New York.

Lingard, H. (2013). Occupational health and safety in the construction industry. Construction Management and Economics, 31(6), 505-14.

Lingard, H., Cooke, T., & Gharaie, E. (2013). A case study analysis of fatal incidents involving excavators in the Australian construction industry. Engineering, Construction and Architectural Management, 20(5), 488-504.

Lundberg, J., Rollenhagen, C., & Hollnagel, E. (2009). What-you-look-for-is-what you-find: The consequences of underlying accident models in eight accident investigation manuals. Safety Science, 47(10), 1297–311.

Manu, P., Ankrah, N., Proverbs, D., Suresh, S. (2010). An approach for determining the extent of contribution of construction project features to accident causation. Safety Science, 48(6), 687-92.

Mitropoulos, P., Abdelhamid, T. S., & Howell, G. A. (2005). Systems model of construction accident causation. Journal of Construction Engineering and Management, 131(7), 816-25.

Mohamed, S. (2002). Safety climate in construction site environments. Journal of Construction Engineering and Management, 128(5), 375-84.

Papazoglou, I. A., & Ale, B. J. (2007). A logical model for quantification of occupational risk. Reliability Engineering & System Safety, 92(6), 785-803.

Phillips, R. (2005). Behavioural safety management. In Lingard, H., & Rowlinson, S. M. (Eds.), Occupational health and safety in construction project management. Taylor & Francis, London and New York.

Pinto, A., Nunes, I. L., & Ribeiro, R. A. (2011). Occupational risk assessment in construction industry–Overview and reflection. Safety Science, 49(5), 616-624.

Priemus, H., & Ale, B. (2010). Construction safety: An analysis of systems failure: The case of the multifunctional Bos & Lommerplein estate, Amsterdam. Safety Science, 48(2), 111-22.

Ragin, C. C. (2006). Set relations in social research: Evaluating their consistency and coverage. Political Analysis, 14(3), 291-310.

Ragin, C. C. (2008). Redesigning social inquiry: Fuzzy sets and beyond (Vol. 240). Chicago: University of Chicago Press.

Rasmussen, J. & Svedung, I. (2000). Proactive Risk Management in a Dynamic Society. Swedish Rescue Services Agency.

Rasmussen, J. (1997). Risk management in a dynamic society: A modelling problem. Safety Science, 27(2/3): 183-213.

Reason, J. (1990). Human Error. Cambridge University Press.

Reason, J., (1997). Managing the Risks of Organizational Accidents. Ashgate Publishing, Surrey.

Reason, J. (2008). The Human Contribution: Unsafe Acts, Accidents and Heroic Recoveries. CRC Press.

Reason, J. (2016). Organizational Accidents Revisited. CRC Press.

Reason, J., Hollnagel, E. & Paries, J. (2006). Revisiting the Swiss Cheese Model of accidents, Project Safbuild. EEC Note No. 13/06, Eurocontrol: European Organisation for the Safety of Air Navigation.

Rowlinson, S., Mohamed, S., & Lam, S. W. (2003). Hong Kong construction foremen's safety responsibilities: A case study of management oversight. Engineering, Construction and Architectural Management, 10(1), 27-35.

Schneider, C. Q., & Wagemann, C. (2012). Set-theoretic methods for the social sciences: A guide to qualitative comparative analysis. Cambridge University Press.

Statistics Norway (2017). Accidents at work: https://www.ssb.no/helse/statistikker/arbulykker/aar (extracted 19 February 2018).

Suraji, A., Duff, A. R., & Peckitt, S. J. (2001). Development of causal model of construction accident causation. Journal of Construction Engineering and Management, 127(4), 337-44.

Swuste, P., Frijters, A., & Guldenmund, F. (2012): Is it possible to influence safety in the building sector?: A literature review extending from 1980 until the present. Safety Science, 50(2), 1333–43.

Thiem, A. (2010). Set-relational fit and the formulation of transformational rules in fsQCA. COMPASSS Working Paper Series, 61 [online]: https://ecpr.eu/Filestore/PaperProposal/0f5605a5-bb78-4bc4-b2be-541bd9ac089b.pdf (extracted 13 February 2018).

Winge, S. and Albrechtsen, E. (2018). Accident types and barrier failures in the construction industry. Safety Science, 105, 158-66.