



Centre for
Construction Work Health and Safety

Safety in Design

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About RMIT Centre for Construction Work Health and Safety Research

The RMIT Centre for Construction Work Health and Safety provides leading-edge, applied research to the construction and property industries. Our members are able to work with organisations to analyse health and safety (H&S) performance and identify opportunities for improvement. We can develop and evaluate innovative solutions, provide specialised H&S programs or undertake other research-based consulting activities. Our work addresses real-world H&S challenges and our strong international linkages provide a global perspective to our research.

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Executive Summary

The construction industry performs poorly in health and safety (H&S) when compared to other industries. Many have argued that the role and position of designers enable them to influence decisions that can eliminate hazards before work commences at a construction site. However, implementing safety in design in the construction industry faces numerous challenges, arising from:

- a failure to distinguish between design of a structure/facility to be constructed, design of the construction process, and design of equipment used or installed during construction work
- a failure to acknowledge or address the complexity of design work in the construction industry, with an assumption that design is a simple and linear process, and
- a failure to appreciate the complex social environment and network of interrelated tasks involved in design, which creates problems when attempting to assign H&S responsibility to 'the designer'.

Research literature about safety in design identifies design as having the potential to reduce the risk of accidents in construction, although the strength of the link between design and H&S performance is still unclear. Nevertheless, safety in design has been demonstrated as viable and effective in improving site safety.

Higher level risk controls characterise safety in design. Recent Australian research shows higher level risk controls are most likely to be present when:

- H&S is considered by stakeholders in the design stage, and
- constructors are involved in the design stage.

Barriers to realising safety in design in the construction industry include:

- difficulty in applying a linear H&S risk management process in the dynamic design environment
- confusion about what aspect of a project is the focus of safety in design activity
- project complexity that gives rise to problems in ascribing responsibility for safety in design
- designers' knowledge and experience relating to construction in general and construction H&S specifically, and
- the construction industry's fragmented supply chain and project delivery processes.

Safety in design forms an integral component of Australian H&S policy and legislation. All state and territory H&S legislation requires some form of systematic approach to managing H&S risk associated with the design of structures (as well as plant and materials). Codes of practice provide risk management processes to assist duty holders to comply with these statutory requirements.

Outside Australia, the well-known UK Construction (Design and Management) Regulations (2007) (CDM 2007) establish detailed requirements for managing safety in design. These are more explicit about the mechanisms for integrating safety in design into project team decision making. For instance, they require the appointment of a person to the professional role of Project Health and Safety Coordinator. Evidence suggests CDM 2007 has contributed to changing the culture of the UK construction industry about safety in design, although CDM 2007 is still often viewed as a 'paper-based' exercise.

Apart from legal requirements, voluntary industry and research initiatives indicate a broad desire to implement safety in design in the Australian construction industry. These initiatives include best practice guides, numerous toolkits, decision-support tools, virtual prototyping, visualisation, and information modelling. However, further research is required to develop design aids that cope with the complex and dynamic nature of design in construction.

A survey of eleven members of the Australian constructor organisations provided an indication of current practices. Further details about the survey are provided in Part 4 of this report. The survey reveals that safety in design is a primary consideration in their activities. Respondents identified key success factors in implementing safety in design, including:

- the need for a safety-focussed design culture
- early consideration of H&S in a project’s life
- broad, timely stakeholder engagement in design
- effective information management, and
- the use of advanced technologies.

In Part 5 of this report, eight recommendations are made for implementing effective safety in design initiatives. The recommendations are listed below.

Recommendation 1	People with relevant knowledge and experience should be engaged in safety in design workshops and design reviews.
Recommendation 2	Project communication networks should be analysed and understood to remove blocks and ‘bottlenecks’ that might impede the free flow of information.
Recommendation 3	Involving key project participants in communication networks be used as a ‘leading indicator’ for assessing the quality and effectiveness of safety in design activities.
Recommendation 4	All stakeholders (both internal and external) whose influence could have a positive or negative H&S impact on safety in design be identified.
Recommendation 5	The interests of these stakeholders and their potential to influence H&S be assessed.
Recommendation 6	Those stakeholders with the potential to influence H&S be engaged in safety in design activities in an appropriate manner.
Recommendation 7	Safety in design be directly linked with design change management processes to ensure ongoing assessment and management of ‘emergent’ H&S risks.
Recommendation 8	Further research be carried out to develop and evaluate the use of knowledge intensive, integrated safety in design systems, using advanced technology such as BIM (Building Information Modelling) tools.

Part 1: Introduction

1.1 The H&S performance of the construction industry

The construction industry performs poorly in health and safety (H&S) relative to other industries.

In Australia, between 2007-08 and 2011-12, 211 construction workers died from work-related injuries. Over that period, the construction industry fatality rate was 4.34 fatalities per 100 000 workers, nearly twice the national rate of 2.29 (Safe Work Australia, 2012a).

Further, in the same period, construction accounted for a disproportionate number of serious workers' compensation claims. In 2011-12 the construction industry employed 9% of the Australian workforce, yet between 2007-08 and 2011-12 the industry accounted for 11% of serious workers' compensation claims. On average, for the period 2007-08 to 2011-12, 39 claims were made each day by construction industry employees who required one or more weeks off work because of work related injury or disease. The incidence rate of serious claims in the construction industry decreased by 38%, from 31.0 claims per 1,000 employees in 2000-01 to 19.1 in 2010-11. However, this rate remains higher than the rate for all industries (12.7), and was the fifth highest of all industries in 2010-11 (Safe Work Australia 2012a).

1.2 Safety in design

The most effective and durable means of creating a healthy and safe working environment is to eliminate hazards and risks during the design of new plant, structures, substances and technology and of jobs, processes and systems. This design process needs to take into account hazards and risks that may be present at all stages of the lifecycle of structures, plant, products and substances.

- Safe Work Australia 2012b, p.7

During the past decade, the safety of construction workers has become a major concern in the construction industry. This is due mainly to:

- high rates of fatalities and injuries in the construction industry compared to other industries around the world, and
- high direct and indirect costs associated with construction accidents.

Recently, government policy in Australia and elsewhere has given prominence to approaches that anticipate H&S hazards in the early stages of projects (Creaser, 2008). These policy settings are a response to the capacity at the project design stage of identifying and then eliminating or reducing the root causes of construction accidents related to processes, structures, and plant and equipment (Schulte, 2008).

Attempts to improve the effectiveness of H&S systems by using high level risk controls implemented at the design stage are referred to in various ways, such as 'safe design', 'prevention through design', 'safety in design', and 'design for construction safety'.

Gambatese and Hinze (1999) suggest that if designers address construction workers safety, common safety hazards can be eliminated and worker injuries reduced. Research seems to confirm that decisions made during a project's design stage can significantly influence H&S during the construction and subsequent stages of a building's lifecycle (Williams, 1998). Designers sometimes make choices (either implicitly or explicitly) about the methods of construction and materials used. Those choices can impact markedly on the H&S of those who build, occupy, maintain, clean, renovate, refurbish or eventually demolish buildings/structures (European Construction Institute, 1996; Hinze & Gambatese, 1994).

In construction, the concept of safety in design is defined as:

... modifications to the permanent features of the construction project in such a way that construction site safety is considered; attention during the preparation of plans and specifications for construction in such a way that construction site safety is considered; the utilization of specific design for construction safety suggestions; and the communication of risks regarding the design in relation to the site and the work to be performed (Behm, 2005, p. 590).

Promoting safety in design is a key action area in the Australian Work Health and Safety Strategy 2012-2022. The Strategy identifies construction as a priority area for action. Strategic outcomes to achieve by 2022 are:

- structures, plant and substances are designed to eliminate or minimise hazards and risks before they are introduced into the workplace, and
- work, work processes and systems of work are designed and managed to eliminate or minimise hazards and risks.

It is argued that designers are better positioned to make decisions that eliminate hazards before work commences at a construction site. Adopting this perspective has led to H&S legislation in all Australian states and territories which now specifies H&S duties for designers of buildings and structures. This means that responsibility for some aspects of H&S have been pushed up the supply chain and now rest with professional contributors in the planning and design stages. Behm (2005, p.608) notes:

While the constructor will always bear the responsibility for construction site safety, utilization of the [safety in design] concept allows design professionals to participate in enhancing site safety.

However, implementing safety in design in the construction industry presents a number of challenges. These arise because:

- there is a lack of clarity about what is being designed. Safety in design advocates often fail to distinguish between design of a structure/facility to be constructed, design of the construction process, and design of equipment being used or installed during construction work.
- there is a failure to acknowledge or address the complexity of design work in the construction industry. There is a tendency to assume that design can be decomposed easily into component parts and regarded as a simple, linear process. In fact, it is dynamic, iterative, and comprises a vast number of interrelated tasks.
- there are problems inherent in trying to ascribe H&S responsibility to 'the designer' – an abstract, undefined socio-technical role. In construction, design involves a network of tasks. It requires contributions from many specialist domains and involves a complicated 'web' of interorganisational relationships. Arguably, what is needed is a broader stakeholder understanding of H&S roles and responsibilities.

1.3 Structure of the report

The report has five parts. An overview of each part is provided in the table below.

Part 1: Introduction	<p>Part 1 cites data on the Australian construction industry's rates of fatalities and serious worker's compensation claims.</p> <p>The safety in design concept is introduced, and an overview provided of difficulties in interpreting the concept in practice.</p>
Part 2: Safety in design	<p>Part 2 positions design in relation to models of accident causation. The research evidence linking design to construction accidents is presented and discussed.</p> <p>This part explores the potential to improve the quality of H&S risk control through adopting safety in design in construction projects.</p> <p>Research evidence is presented that highlights the importance of stakeholder engagement, and the early integration of construction knowledge into design decision-making.</p>
Part 3: Safety in design policy and practice	<p>Part 3 describes legislative and policy initiatives related to Safety in Design in the construction industry.</p> <p>The UK Construction (Design and Management) Regulations are reviewed, and lessons learned from the UK experience are articulated.</p> <p>Voluntary approaches to addressing safety in design in the construction industry are reviewed.</p> <p>Finally, a critical review is presented of various documented tools and approaches that support safety in design.</p>
Part 4: Safety in design in Australian construction	<p>Part 4 describes the results of a survey of safety in design best practice conducted among member organisations of the Australian Constructors Association. Key findings and examples of good practice are described.</p>
Part 5: Recommendations and conclusions	<p>Part 5 presents recommendations about appropriate methods and tools to assist in implementing safety in design in the Australian construction context. Recommendations are based on the body of evidence in the literature.</p>

Part 2: Safety in design

2.1 Design as a causal factor in construction accidents

Efforts to prevent occupational injury and illness are likely to be shaped by assumptions made about how injuries and illnesses occur. Hopkins (2005) identifies two broad sets of assumptions, which he terms 'blaming the victim' and 'blaming the system'.

'Blaming the victim' explains occupational injury and illness in terms of the characteristics of workers that make them particularly susceptible.

Alternative explanations of occupational injury and illness focus on social, technological and organisational causes – these explanations 'blame the system'. The social relationships that underpin production – such as the pressure to maintain production, and bonus or piece-rate payment schemes – are seen as playing a key role in encouraging workers to ignore safe work practices. The physical/technological environment is also recognised as a source of occupational injury and illness – in many industries it presents unusual (and sometimes extreme) hazardous conditions. Organisational breaches of occupational health and safety legislation, and codes, are common features of many incidents that lead to occupational injury or illness. In their most comprehensive expression, 'blaming the system' approaches accidents as system failures in which accidents are explained as a complex interaction of plant and equipment, management systems and procedures, people and other human factor considerations.

The design of workplaces and work systems has been identified as a causal factor in a number of causation models which attempt to trace accidents back to their 'root causes'.

Reason's 'Swiss cheese' Model

Reason (1997) devised a generic model of accident causation. Known as the 'Swiss cheese' model, it is depicted in Figure 2.1. It is not specific to the construction industry. However, it has provided a key reference point for construction industry accident causation models (such as the Constraint-Response Model discussed in the next section of the report). The power of Reason's model is that it reveals how accidents occur through the combined effect of organisational, local workplace and individual factors.

Reason's systems-based model supports analysis of how human error is induced by organisational factors such as:

- how workplaces or systems are designed
- budget allocation
- communication
- planning
- scheduling, and
- unwritten rules about acceptable practices within the company.

Workplace accidents can be traced back to these organisational and workplace factors, which Reason terms 'latent condition pathways'. The pathway is an alignment of gaps or holes in organisational systems. Cumulatively, these gaps produce the circumstances for adverse safety outcomes. Circumstances which may result in accidents in local workplaces, such as construction sites, can arise because of management practices, priorities and decisions that lead to unrealistic work schedules, poor maintenance, under staffing, low pay, poor supervisor-worker ratios, ambiguous or unworkable procedures, or conflicting goals. These latent conditions interact with human behaviour – such as cutting corners, or prioritising delivery of materials over an unsafe work practice – to produce human error.

Reason suggests that while many unsafe acts occur, only some unsafe acts result in accidents because systems have built-in defences. It is when the defences fail that organisational accidents occur.

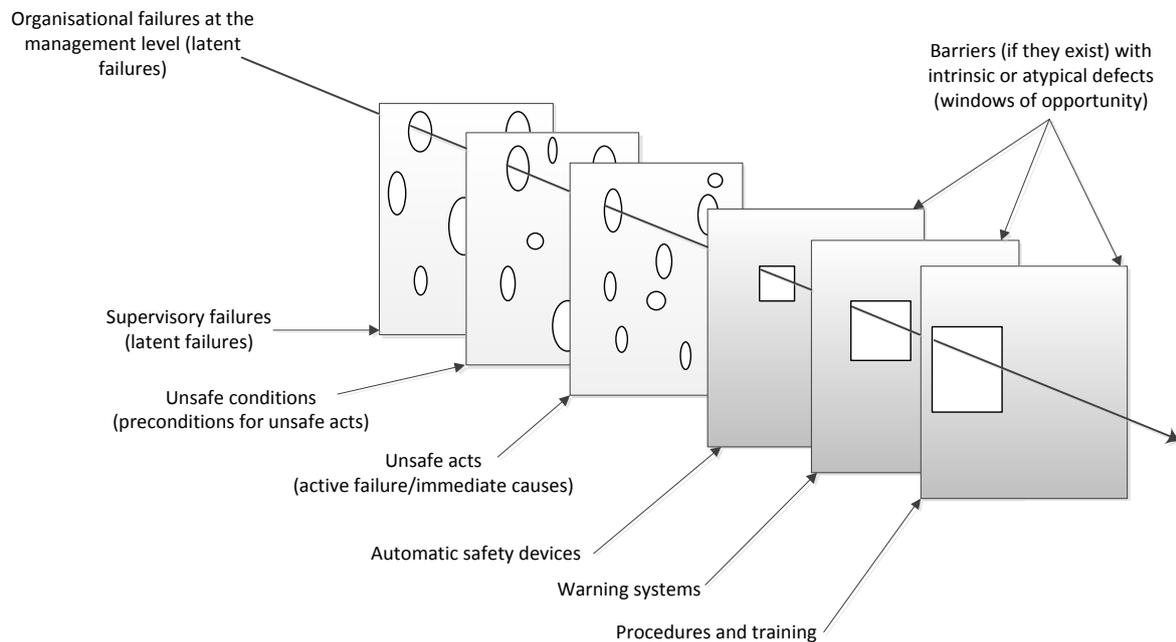


Figure 2.1: 'Swiss cheese' accident causation model (Reason, 1997)

The Constraint-Response Model

Suraji et al. (2001) describe the complex interaction of factors that contribute to the occurrence of construction site accidents. They propose a Constraint-Response accident causation model (see Figure 2.2). The model holds that the parties involved in each stage of the construction project lifecycle (conception, design, and construction) experience constraints on their decision making. Their responses to these constraints, in turn, constrain the actions of participants in the subsequent stages. Ultimately, unless carefully managed, the cumulative effect of constraints and responses will be experienced as hazardous site conditions, inappropriate work practices, or unsafe actions at the construction site. Thus, accident causes can be traced back from the immediate site level conditions, actions and practices, to the planning and control activities of site supervisors and managers, to subcontractors' constraints and responses, to principal contractors' constraints and responses, and to the constraints and responses experienced by designers and clients in the design and project conception stages (Suraji et al., 2001).

The Constraint-Response causation model recognises 'project design constraints' (for example, conflicting project objectives, technical difficulties, time constraints) as contributing factors in the causal chain of events leading up to a construction accident. Designers' responses to these constraints then become constraints experienced by the management team during the construction stage of the project – for example, a design that may be difficult and/or expensive to construct safely. These constraints accumulate as work flows from one stage to the next. The cumulative impact of the constraints may result in undesired events and outcomes, including accidental injury (Suraji et al., 2001).

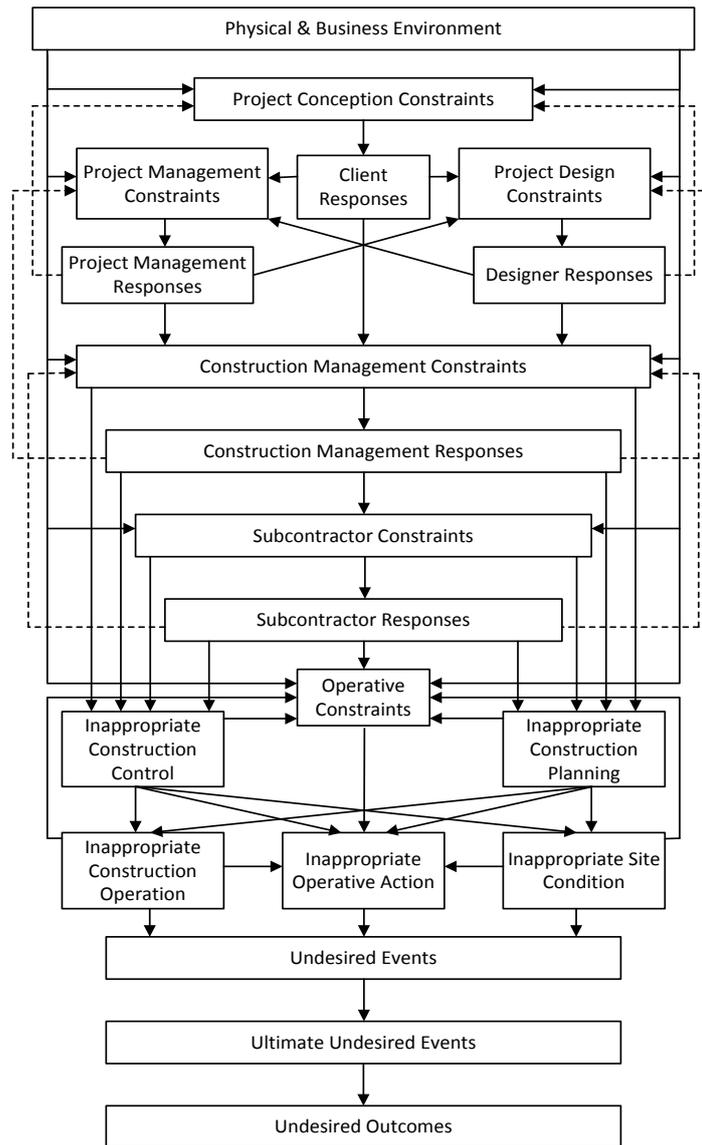


Figure 2.2: Constraint-Response Model (Suraji et al., 2001)

The Construction Accident Causality (ConAC) Model

On behalf of the UK's Health and Safety Executive, a 2003 report prepared by Loughborough University and the University of Manchester Institute of Science and Technology (UMIST) sought to test a holistic model of accident causation by carefully investigating the causes of 100 construction accidents. The research team obtained information from people involved in accidents, including the victims and their supervisors, to describe the processes of accident causation in construction. Based on their analysis, they developed a construction accident causality (ConAC) model. Figure 2.3 shows the ConAC model.

The ConAC model identifies originating influences affecting accidents in construction as including:

- client requirements
- features of the economic climate
- prevailing level of construction education
- design of the permanent works
- project management issues
- construction processes, and
- the prevailing safety culture and risk management approach.

Deficiencies in the risk management system were apparent in almost all the 100 accidents studied. This represents a significant management failure.

Project management failures were also commonly reported, most of which involved:

- inadequate attention to coordinating the work of different trades, and
- managing subcontractors to ensure that workers on site had the requisite skills to perform the work safely.

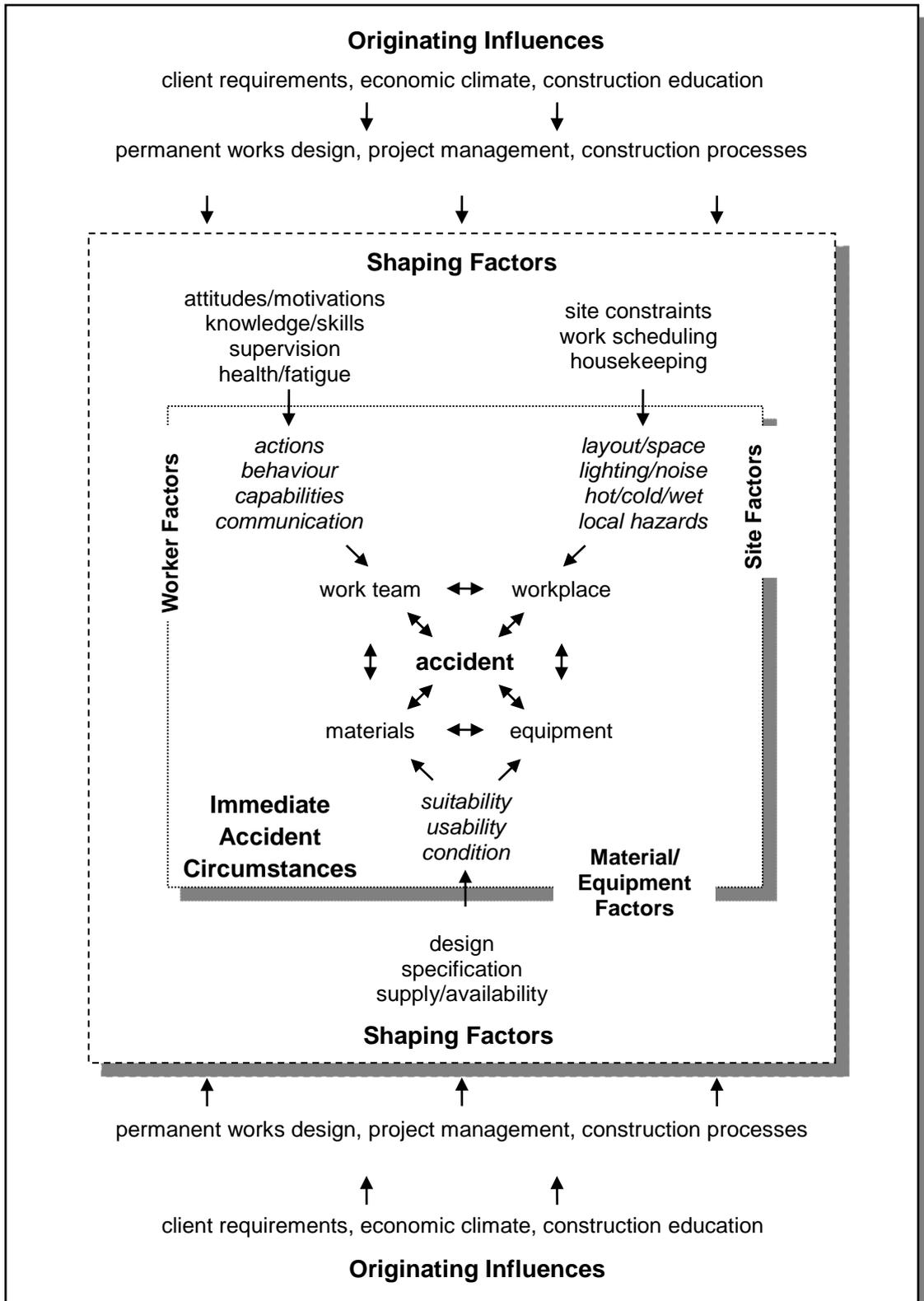
The next level of contributing causes identified in the ConAC model is termed 'Shaping factors'. This level includes issues such as:

- the level of supervision provided
- site constraints
- housekeeping
- work hours
- the state of workers' health and fatigue, and
- poor communication within work teams.

The ConAC model identifies the most immediate contributing causes of workplace accidents as:

- the suitability, usability and condition of tools and materials
- the behaviour, motivation and capabilities of individual workers, and
- features of the physical site environment, such as layout, lighting and weather conditions.

The ConAC model acknowledges that construction accidents occur as a result of a complex process, involving proximal causes as well as factors that are upstream of the construction work.



**Figure 2.3: The ConAC model of construction accident causation
(Haslam et al., 2003b, p.59)**

The Constraint-Response and ConAC models adopt a similar framework to that presented in Reason’s (1997) ‘Swiss Cheese’ model. However, the construction industry provides the context for the Constraint-Response and ConAC models. Consequently, they address directly some of the unusual organisational features of construction (such as producing a bespoke product for a particular client, separating design and construction, and the extensive use of lengthy subcontracting chains). Haslam et al. (2005) found that in almost 50% of cases, a change to the permanent works design could have reduced the level of risk that preceded an accident.

Table 2.1 summarises the accident models introduced above, and provides an overview of the extent to which design is described as a causal factor in construction accidents.

Table 2.1: A review of different models of accident causation

Model and reference	Application area	Comments
Swiss Cheese Model	Generic	<p>The model originated from Reason’s early work in psychological error mechanisms. It is widely accepted in different fields.</p> <p>It indicates the complexity of accident causation. The value of the model for construction is that it draws attention to both:</p> <ul style="list-style-type: none"> • proximal construction site circumstances, and • the importance of upstream organisational factors in contributing to accident causation. <p>The model supports the notion that upstream project decision makers (including designers, clients, and their professional advisors) must participate in the network of those who are responsible for ensuring safe construction activities.</p>
James Reason (1997)		
Constraint-Response Model	Construction	<p>The model recognises that upstream project constraints shape upstream decisions, including design decisions. These decisions impact on decisions made downstream in the project lifecycle, and so influence the causation of undesired events and outcomes.</p> <p>The model supports collaborative actions to enhance construction safety by holding everybody in the project’s interorganisational network responsible for promoting safety.</p> <p>The model highlights the effectiveness of upstream controls for dealing with high level conditions that contribute to accident causation – for example:</p> <ul style="list-style-type: none"> • poor design, and • failing to incorporate construction safety as a project objective in conception and design phases. <p>The model reflects:</p> <ul style="list-style-type: none"> • the complex structure of the accident causation process, and • how the accident causation process is produced by interacting factors. <p>However, the model takes a generic approach to construction safety. It does not differentiate between design of the construction process and design of the outcome (structure or building).</p>
Suraji et al. (2001)		

Model and reference	Application area	Comments
ConAC model Loughborough University and UMIST (2003)	Construction	<p>The model recognises ‘permanent works design’ and ‘construction process design’ as originating upstream factors shaping downstream circumstances and conditions, which, in turn, lead to accidents.</p> <p>The model supports collaborative actions to enhance construction safety by holding parties involved in the project interorganisational network responsible for promoting safety.</p> <p>The model recognises that the accident causation process is produced by a range of complex, interacting factors that flow from multiple sources.</p> <p>The model’s focus is on both:</p> <ul style="list-style-type: none"> • accidents in the construction stage, and • contributing upstream factors.

2.2 The link between design and H&S outcomes

Early research investigating safety in design in the construction industry sought to establish an empirical link between design activity and H&S outcomes, specifically the occurrence of accidents, injuries or fatalities. This research largely involved retrospectively analysing the causes of accidents to assess whether design was a cause. Retrospective analyses contribute to building the case for safety in design. However, they have limitations. It may not be warranted to conclude that there are direct links between design decisions and a workplace accident. A researcher may attribute a direct link even though the relationship is tenuous – an outcome that Lundberg et al. (2009) termed ‘what-you-look-for-is-what-you-find’. Retrospective analysis alone cannot illuminate the relationship between implementing safety in design and achieving improved H&S outcomes.

In 1991, the European Foundation for the Improvement of Living and Working Conditions reported that better decision making during construction planning and design stages could have eliminated, reduced, or avoided 60% of construction fatalities analysed. This statistic was cited widely by proponents of safety in design in the construction industry. However, this interpretation of the analysis was contentious because it failed to distinguish between:

- design of the permanent structure or facility being constructed, and
- design of the construction work processes involved in the accidents.

This important distinction recognises the difference between *product design* (the building/structure to be built), and *process design* (the organisation of work and methods used to construct the building/structure). The European Foundation for the Improvement of Living and Working Conditions cited research by Lorent (1987) who included in the figure of 60% both product design (design of the architectural choices, materials and equipment specifications), and process design (the organisation of works and activities).

In the United Kingdom, Haslam et al. (2003) and Gibb et al. (2004) investigated the causes of 100 non-fatal construction industry accidents. Selected accident reports were given to a group of experts who were asked to comment on the extent to which the accident could have been avoided if an alternative design of the structure/facility had been chosen. The experts were also asked: ‘What could designers have done to reduce the risk?’ The study showed that in 47% of the cases, the experts believed the likelihood of the accident could have been reduced had different design

decisions been made in relation to the permanent works. The authors concluded that permanent works design should be considered a contributing factor in the occurrence of construction accidents.

In the USA, Behm (2005) reviewed 224 fatality reports from the National Institute for Occupational Safety and Health's fatality assessment control and evaluation (FACE) database. He considered the accident to be design related if any of the following three criteria were met.

Criterion 1	The permanent features of the construction project were a causal factor in the incident
Criterion 2	Any of the design suggestions identified in previous studies could have been implemented to prevent the incident
Criterion 3	Modification of the design or the design process could have prevented the incident

Behm's criteria focused exclusively on permanent works and final product design (building/structure). The criteria did not include construction process design, or the design of plant and equipment. Behm reports that design was a causal factor in 42% of fatal accidents reviewed. Behm (2005) also proposed 30 new design suggestions and concluded that safety in design can:

- positively affect the safety of construction workers during initial construction work and subsequent maintenance, renovation, and repair work, and
- reduce risk across all types of construction projects.

The results of Behm's (2005) study were further validated by Gambatese et al. (2008). An expert panel composed of construction industry professionals reviewed a subset of the 224 fatality cases used in the previous study. The panel judged whether the design was a contributing factor to the incident. A link between the incident and the design was considered if any of the following criteria were met.

Criterion 1	If the permanent features of the project could have been modified to prevent or reduce the risk
Criterion 2	If the construction plans and specifications could have been prepared in a different way to avoid the incident
Criterion 3	If the construction safety risks related to the design could have been communicated to the constructor to avoid the accident

Criterion 2 suggests that contributing factors to downstream accidents could arise from both:

- construction work process design
- the design of the permanent features of the building/structure.

Criterion 3 supports the view that communication (or collaboration) problems between designers and constructors can influence H&S.

Gambatese et al. (2008) report that in 71% of the fatalities investigated, the panel's responses confirmed Behm's findings of a significant link between H&S and design and construction.

The researchers further concluded that:

- the expert panel members, who were all knowledgeable of the engineering and construction industry, recognised that the 'design for construction safety' concept was a viable method to reduce safety risk on construction sites.
- in particular, those expert panel members with a safety and health background agreed with the findings of previous research. These panel members were trained to identify the causes of accidents, and possessed a genuine understanding and acceptance of the benefit that safe designs can have on H&S.
- panellists with construction, design, and academic backgrounds expressed a moderate to fair level of agreement (63-73%) with previous research (Gambatese et al., 2008).

In Australia, Driscoll et al. (2008) reported that 44% of construction fatalities were 'design-related', although they acknowledge that 'informational difficulties' made it difficult to ascertain whether these fatalities could be attributed to:

- the permanent design of the building/structure
- the design of plant/equipment, or
- the design of the process of construction, including temporary works.

Cooke and Lingard (2011) further examined data in the National Coroners' Information System to explore the causal pathways leading from the design of a permanent building/structure to the immediate circumstances surrounding fatal accidents in the construction industry. They reported that design of the permanent structure could be identified as a contributing factor in 14% of fatal construction accidents in the analysis. Using the ConAC model of accident causation, Cooke and Lingard examined the 'pathways' leading from design of the permanent structure to the fatal accident. Thus, shaping factors and immediate circumstances were explored for each case. Consistent with the view that workplace accidents are the result of a complex interaction of multiple causes, design decisions resulted in a variety of different shaping factors and immediate circumstances. However, the most frequently occurring pathways were between design of the permanent structure through design of the work process, and unsafe actions and/or the use of equipment unsuitable for a task (see Figure 2.4 below).

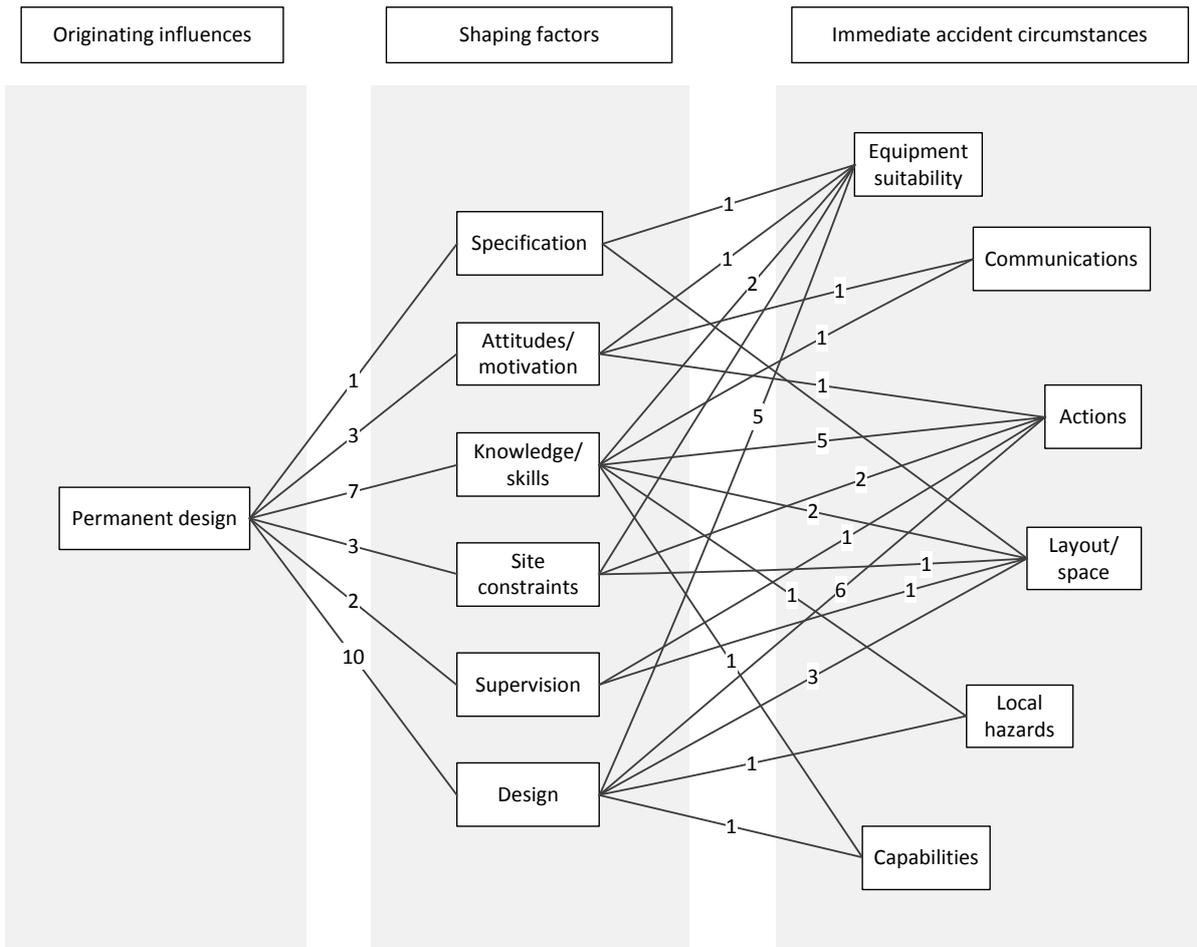


Figure 2.4: Relationship between shaping factors and immediate causes traced back to the originating factor of ‘permanent works design’ (Cooke and Lingard, 2011).

South African research undertaken by Smallwood (1996) also explored industry stakeholders’ beliefs about the link between design and construction H&S. Smallwood reports that almost half of 71 general constructors interviewed identified design as an aspect or factor that negatively affects H&S performance in their work activities. In comparison with other influences on H&S, design was ranked as having the greatest impact on H&S.

By providing evidence from the analysis of past construction accidents, the studies cited above provide preliminary evidence for the existence of a link between design work in the construction industry and H&S. The results suggest that considering construction H&S when making decisions in the design stage of a construction project provides potentially promising outcomes for improving workers’ health and safety.

However, construction site work conditions and processes are complex and dynamic in nature. Accident causality on construction sites, and therefore risk reduction, is complex and multifaceted. The objective strength of the link between design and H&S performance is still unclear, and remains a subject of debate. Researchers have been justifiably cautious about quantifying the potential for safety in design to produce improved H&S outcomes in construction. For example, Gibb et al. (2004) choose their words carefully when stating that design modifications had the potential to reduce the risk of almost half of the construction accidents they analysed, but might not necessarily have prevented those accidents from occurring. Further, in focusing on outcomes (that is, accidents),

retrospective analyses tell us little about current safety in design initiatives and tools, or their potential impact on future H&S performance in the construction industry.

Research in 'live' projects is helpful for better understanding the relationship between considering H&S at the pre-construction stage and actual H&S performance.

2.3 Safety in design and the quality of risk control

Technological versus behavioural risk controls

The hierarchy of control (HOC) is a widely accepted approach to controlling workplace risks or hazards (see, for example, Manuele, 2006). The HOC classifies hazard control measures into five levels of effectiveness. Level 5 is the most effective method of control. Level 1 is the least effective method of control.

Level 5	Eliminate a hazard altogether. Most effective because a hazard is removed physically from the work environment.
Level 4	Substitution of a hazard. Something that produces a hazard is replaced by something less hazardous.
Level 3	Engineering controls. People are isolated from hazards.
Level 2	Administrative controls. These include safe work procedures, or using job rotation to limit exposure to a hazard.
Level 1	Personal protective equipment. This is the least effective control because it is the least reliable. See, for example Lombardi et al.'s (2009) analysis of barriers to using eye protection.

Levels 3, 4 and 5 are technological risk controls. They involve changes to the physical work environment.

Levels 1 and 2 are behavioural risk controls. They seek to alter how individuals and teams undertake their work.

It is often argued that safety in design will increase opportunities to implement higher order (technological) controls for health and safety risk (see, for example, Gangolles et al., 2010). However, until recently there has been little empirical evidence to support this claim.

The time/safety influence curve

Studies in the construction industry have often observed that the opportunities to reduce H&S risks are highest at the beginning of a project and diminish as the project progress (Toole, 2007). Swuste et al. (2012) comment that the design phase of construction projects offers the greatest potential to positively influence safety. This argument is linked to Szymberski's (1997) concept that it is ideal for construction safety to be a prime consideration in the conceptual and preliminary design phases of projects. The theoretical curve in Figure 2.5 shows:

- the relationship between a project's progression through its composite phases (such as concept design, detailed design, procurement, construction) and the ability to influence H&S, and
- that the ability to influence safety deteriorates rapidly as the project passes through the pre-construction stages. At the commencement of construction, the ability to influence safety is very low.

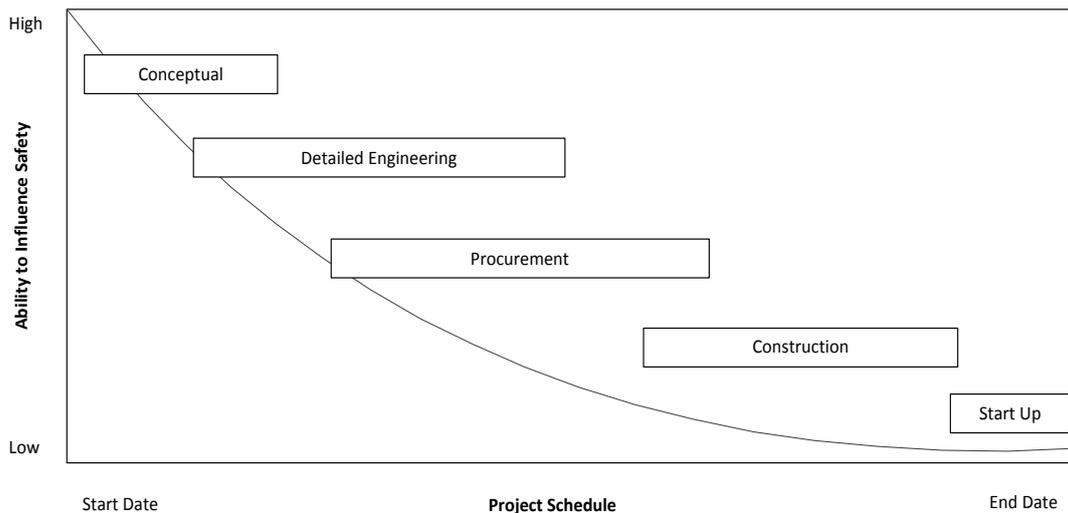


Figure 2.5: The time/safety influence curve (adapted from Szymberski, 1997)

Though widely cited and almost universally accepted, until recently little evidence existed to support the time/safety influence curve. Recent research by the Centre for Construction Work Health and Safety at RMIT University tested the proposition that considering H&S early would produce better outcomes.

This research formed part of an international benchmarking study of safety in design. Data were collected from a total of 23 construction projects – 10 in Australia and New Zealand, and 13 in the USA. In each project, specific elements or components of the building (or other facility) were selected. The total number of elements in the analysis was 43. Elements included roof structures, sewerage systems, retaining walls, a pedestrian bridge, and foundation systems. Project stakeholders involved in planning, designing and constructing the buildings (or other facilities) were interviewed. Interviews explored design decisions made for each element, the construction process for the element, and the way H&S hazards were controlled during construction. Interviews also explored the timing and sequence of key decisions about each element and the influences that were at play as design decisions were made. A total of 288 interviews were conducted (185 in Australia, and 103 in the USA). The average number of interviews per feature of work was 6.7. For each building (or facility) element, a score was generated that reflected the quality of H&S risk controls implemented during construction. This score was based on the HOC.

Each HOC level was given a rating ranging from 1 (personal protective equipment) to 5 (elimination). The risk controls implemented for hazards presented by each feature of work were assigned a score on this 5 point scale. In the event that no risk controls were implemented, a value of zero was assigned. Using these values, the mean HOC score for each feature of work was generated.

The point in time was recorded at which a risk control solution was identified; that is, whether this occurred in the project's pre-construction or construction stage. For each building/facility element, the number of H&S solutions selected during the pre-construction stage was expressed as a percentage of the total number of safety solutions for that element – the percentage reflected the extent to which H&S was considered early in the project lifecycle.

Table 2.2 shows the mean HOC scores for cases by industry sector, project type and country. Australian cases in the analysis had significantly higher average HOC scores than the US cases.

Table 2.2: Mean HOC scores by country, project delivery method, and industry sector

Case descriptor	Mean HOC score	Standard deviation
Country		
United States	2.48	.311
Australia	3.69	.671
Delivery method		
Collaborative	3.36	.632
Accelerated	2.98	.820
Design-bid-build	2.71	.602
Design and build	3.38	.233
Sector		
Heavy engineering	3.33	.844
Residential	3.02	.777
Commercial	2.72	.649
Industrial	3.13	.807

Figure 2.6 shows:

- the relationship between the extent to which health and safety risk controls were considered and decided upon before construction commenced (that is, in the planning or design stages of the project), and
- the quality of risk control outcomes (that is, the average HOC score).

A positive relationship was found, meaning that the greater the proportion of H&S risk controls that were identified and chosen before construction commenced, the better the quality of H&S risk controls. This relationship was also statistically significant (Lingard et al. 2013a).

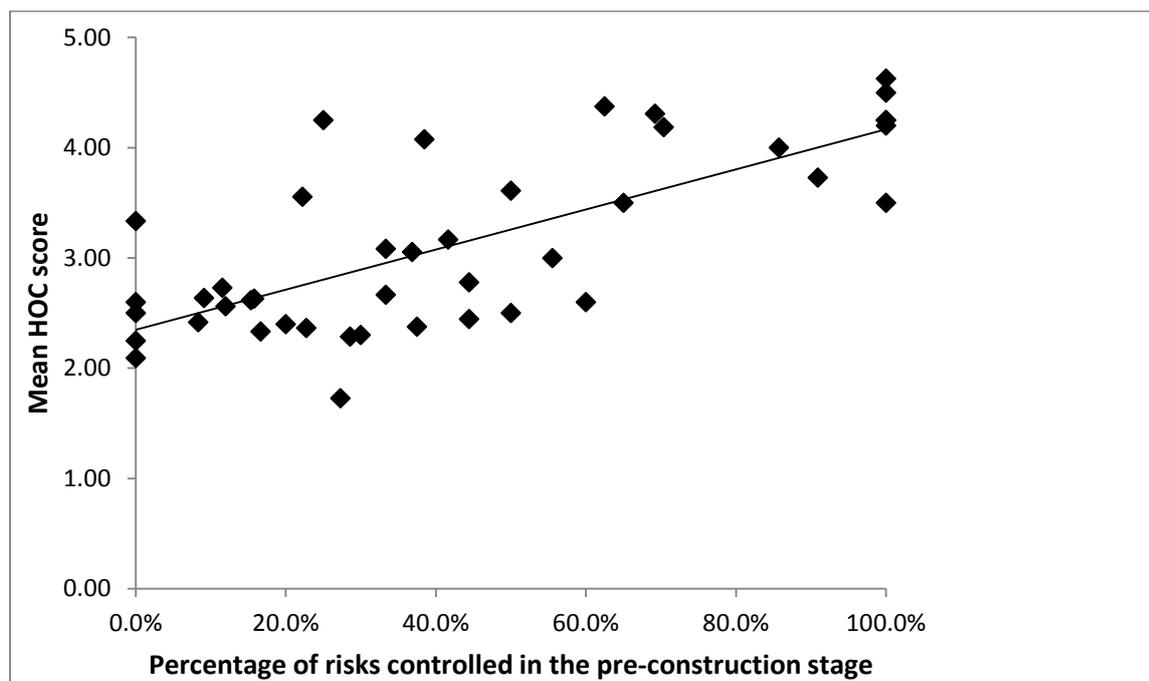


Figure 2.6: Relationship between pre-construction H&S decision making and quality of H&S risk control outcomes

This research provides some evidence for the link between:

- considering H&S early (in pre-construction stages of the project lifecycle), and
- implementing higher order controls for H&S risk.

The research confirms the benefits of considering construction workers' H&S when making decisions about the design of buildings (and other facilities).

Early constructor involvement

There are considerable benefits to involving constructors early in design decision making because of their centrality to the web of actors who participate in construction activity. Song et al. (2009) identified three primary benefits:

- constructors have specialised training, knowledge and experience in applying construction materials and methods
- they are in the best position to provide advice about H&S hazards/risks and ways to mitigate them in construction activities
- they are responsible for a project's construction operations – they have a strong motivation and interest in ensuring work is performed with minimal risk to health and safety.

The Australian-US safety benchmarking study described above investigated whether involving constructors in decision making during the project design stage produced better H&S risk control outcomes. To investigate this, a technique known as social network analysis was used. Social network analysis is an analytical tool that studies the exchange of information between people who make up a network. Social network analysis was used to map the social relations between project participants in each of the Australian case studies. The constructors' position of 'centrality' in the social networks was quantified. 'Centrality' refers to the extent to which a person is connected to other people – that is, the ratio of the number of relationships the person has relative to the maximum possible number of relationships they could have. Degree centrality is sometimes used as an indicator of the power or influence a person has within a network. In the case study projects, the constructors' centrality was measured during the design stage of the project. The relationships between members in a social network can be mapped to produce a 'sociogram'. The resulting diagrams provide a graphic representation of the position and importance of participants within a network.

The cases were split into those with:

- high HOC outcomes in which predominantly technological risk controls were implemented, and
- low HOC outcomes in which predominantly behavioural controls were implemented.

The design stage centrality scores for the constructor were compared between high HOC cases and low HOC cases. There was a statistically significant difference:

- in the high HOC cases, the constructors' design stage centrality was 14.2
- in the low HOC cases, the constructors' design stage centrality was only 5.4.

These results demonstrate how the effective transfer of construction knowledge to design decision makers can enable improved H&S risk control outcomes (Lingard et al. 2013b).

Case Study: Design and construction of steel columns and roof structure at a food processing and storage facility

An initial concept design was developed on behalf of the client to accommodate operational requirements for the facility. The concept design included a steel framed structure consisting of three spine trusses supported by five rows of steel columns. To maximise useable floor space, the columns were positioned in the middle of product stacks rather than at the ends of the rows.

The Design and Construction contractor suggested eliminating one row of columns. This design alternative required fewer columns to be lifted and manoeuvred into place, reducing H&S risks associated with lifting operations. The contractor also suggested revising the roof design by using trussed rafters connecting to the main spine trusses, instead of using steel 'I' beams as rafters. Fabricating rafter trusses was slightly more expensive, but these trusses weighed less than I beams and could be manufactured offsite. The reduced weight of the roof enabled the use of smaller sections for supporting columns. It also made erecting and installing the roof quicker and easier.

All supporting columns were fitted with a bearing plate allowing trusses to be supported temporarily while connections at each end were bolted. This reduced the need for propping and manual handling associated with installing and dismantling props. It also freed the area around the columns and under the trusses of any obstacles or trip hazards that props may have caused. At the same time, this design solution reduced the extent of work required at height to connect the trusses to the columns, and reduced the H&S issues associated with suspended loads. As the client's engineer commented:

[The constructor has] got quite a good, what I call a bearing type detail, so you can actually put the trusses up and have them take the gravity load away before you start trying to put the bolts in. And that's one of the major concerns [on another similar project] is that we should have picked it up when we did the structural check, but of course we just checked the structure rather than checking the buildability.

The structure was designed so that erection could be done in self-supporting sections. This allowed the builders to start at one end of the building and move progressively along the length of the building. This method enabled the constructor to ensure that crane lifts were within safe reach tolerances, without having to extend the crane's arm over already constructed portions of the structure. To ensure the constructability of the facility before the start of construction work, the main constructor involved subcontractors to review the design and erection/installation sequences. The resulting safety in design solutions resulted in an HOC score of 4.2.

Figure 2.7 is a sociogram that shows the pre-construction social network for this project. The data revealed relatively high normalised degree-centrality (14.46) for the constructor. As the sociogram depicts, the construction contractor had direct links with the majority of other network participants. The network pattern shows that the constructor took advantage of direct information ties with suppliers and subcontractors (steel erectors and concreters). These suppliers and subcontractors possess practical knowledge about constructability and would be responsible for executing the construction tasks. Their engagement in decision making enabled the constructor to benefit from their specialised knowledge in proposing practical and safer design solutions which, in turn, improved the quality of H&S risk control.

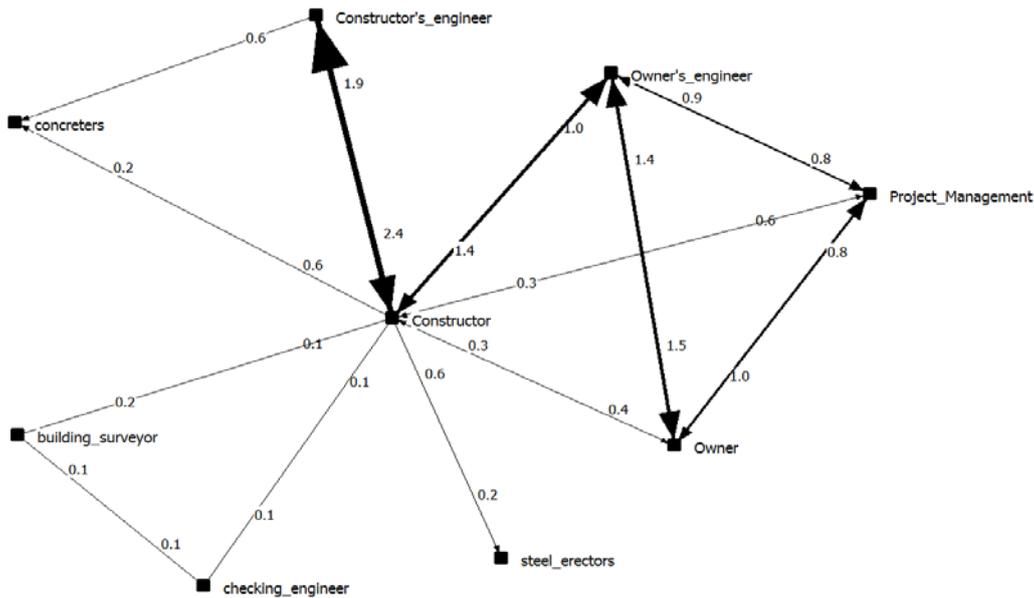


Figure 2.7: Sociogram for the steel column and roof design at a food processing and storage facility

The sociogram shows three groups:

1. On the right hand side of the network are key demand-side stakeholders, including the owner, owner’s engineer and project manager.
2. On the left hand side of the network are key supply-side stakeholders, including the concreters and steel erectors.
3. Also on the left hand side of the network are stakeholders who supply design related information and services to the network – the checking engineer and building surveyor.

The Design and Construction contractor is the central actor connecting these three groups. In this central position, the contractor:

- identified constructability issues before construction commenced, and
- drove the redesign of various components which still met the owner’s operational requirements for the facility, and which complied with regulatory requirements.

2.4 Implementation issues for safety in design

The viability of safety in design in the construction

In Australia, there is now a legislative imperative to implement safety in design in the construction industry. Legislation and requirements relating to safety in design will be discussed in Part 3 of this report. In the US, safety in design is not required by H&S legislation, leading US researchers to examine industry perceptions about its viability. Although the viability of safety in design is now widely accepted in Australia, the US research highlights some concerns that design professionals have expressed about the tension between safety in design and other design objectives.

Gambatese et al. (2005a) argue that the viability of implementing safety in design in the construction industry is subject to two conditions (see Figure 2.8):

1. The feasibility of implementation: the factors that impact implementation on a project should not prohibit, or substantially limit, its implementation.
2. The effectiveness in producing desired outcomes: the outcomes of implementation should be beneficial so that they provide sufficient motivation for the industry to implement the concept.

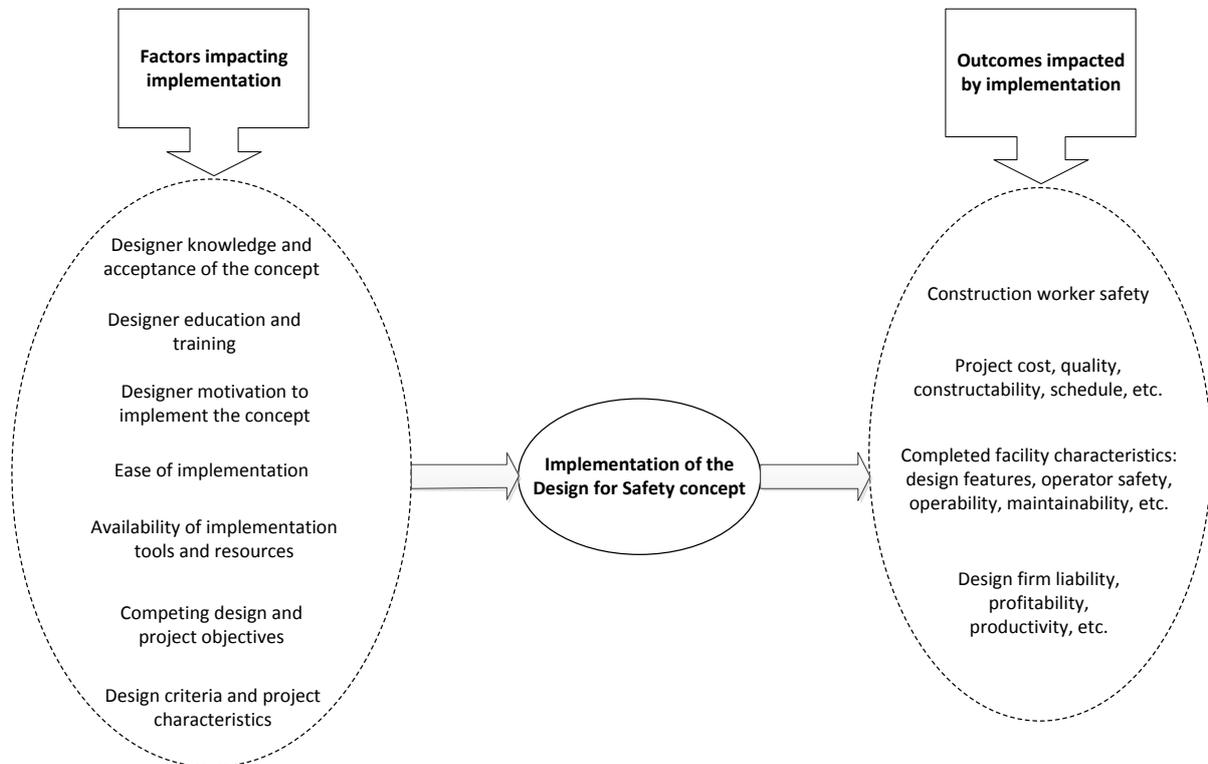


Figure 2.8: Design for safety concept implementation factors and impacts (Gambatese et al., 2005a)

In their pilot study investigating the feasibility and practicality of designing to improve construction workers' safety, Gambatese et al. (2005a, 2005b) interviewed 19 architects and design engineers in the US. They focused their study on four key aspects:

1. Designers' knowledge and acceptance of the 'design for construction safety' concept.
2. Designers' ability to address safety in design.
3. Feasibility of implementing promising safe designs.
4. The likely impacts resulting from implementing safe designs.

The results of their interviews indicated that almost half the professionals considered safety in design to be feasible in the construction industry:

- 47% of the designers indicated that they already make design decisions that improve construction worker health and safety
- 42% indicated that they had previously made modifications to a design in the design phase to eliminate a potential safety risk that would impact construction worker health and safety.

However, when the design professionals were asked to rank a set of project criteria in order of importance/priority, construction safety was ranked lowest (Gambatese et al., 2005a). The authors concluded that the designers interviewed foresee that implementing safety in design will have negative impacts on other project criteria, such as cost, schedule, design creativity, and liability exposure. For example:

- 74% of participants stated that designing for safety would increase project costs
- 47% stated that designing for safety would lead to schedule delays and lowered productivity
- 21% of designers expressed concerns that implementing safety in design would decrease project quality through limiting creativity.

These perceptions are likely to act as barriers to adopting safety in design. However, they may not reflect the true situation. Earlier research by Gambatese et al. (1997) reported that implementing safety in design, and eliminating safety problems during the construction stage of a project, would have a positive impact on construction cost, schedule, productivity, and quality. In particular, they noted that eliminating the need to provide temporary safety controls during construction potentially could result in overall cost savings or improved productivity.

Similarly, Hecker et al. (2005) report several examples in which design changes improved both H&S and the speed of construction. These include:

- raising the ceiling height in the utility area of an electronic component manufacturing facility to provide more space and height for workers, and to reduce ergonomic hazards and other issues related to material handling and access
- increasing the height of a parapet to create a 'walkable' ceiling, and
- designing built-in anchorage points for a fall protection system to reduce the risk of workers falling from height (Hecker et al., 2005).

Gambatese et al. (2005a) further contend that if the entire lifecycle of a project is considered, initially costly design changes become long term benefits as a result of lower construction costs, and improved safety during the operation and maintenance stages of a building (or other facility).

These are positive assessments about the feasibility of implementing safety in design in the construction industry. However, research reveals some significant structural impediments to implementing safety in design early in the life of a construction project.

Criticism has been levelled at some of the safety in design solutions suggested by researchers, including Hecker et al. (2005), and Hinze and Gambatese (1994). Atkinson and Westall (2010) note that many design modifications implemented to improve H&S in construction represent fairly modest solutions. They cite examples of fixing rails or anchor points for fall arrest devices which do not eliminate the inherently dangerous activity of working at height. Similarly, Mroszczyk (2006) argues that designing a fall protection system is not an optimal safety in design outcome. Rather, designers should seek ways to eliminate or significantly reduce the need to use fall protection systems during construction; for example, by eliminating or reducing the need to work at height or providing an alternative and safer means of working at height.

There is some likelihood that safety in design solutions implemented at the construction stage will default to behavioural risk controls (levels 4 and 5 on the Hierarchy of Control) rather than to eliminating hazards altogether (Hopkins, 2006). Atkinson and Westall (2010) suggest that if design modifications are left until the construction stage of a project, then it is likely that designers will accept suboptimal modifications – at this stage, risk control decision making largely devolves to the actors who participate in the construction activity. As Swuste et al. (2012) noted, the safety consequences of key design decisions are locked in once construction commences. Consequently, the scope to implement safety in design is constrained.

Additional problems arise when basing the case for safety in design on a net reduction in cost over the lifecycle of a building or facility – for example, by arguing that safety in design will produce an overall reduction in the operational and maintenance costs. Lingard et al. (2013) report several cases in which design decisions that were made to increase safety in the operational stage of a building (or other facility) actually increased the degree of H&S risk to which workers were exposed in the construction stage. They argue against making the oversimplified assumption that actions taken to design out safety hazards or reduce risks in one stage of the lifecycle of a building (or other facility) will naturally and inevitably reduce risk in all stages of the lifecycle. This is a particularly important consideration in construction in which design professionals are often engaged by the client and respond to the client's brief. Designers are well versed in designing for operational and public safety. However, they may be less knowledgeable and experienced in designing for construction workers' H&S. Given the relatively short duration of the construction stage relative to the operational life of a building (or other facility), there may be a tendency to privilege operational and public safety, and to focus less attention on the implications of design decisions for H&S during the construction stages. For example, although design professionals might consider safety in their designs, research shows the beneficiaries of their efforts traditionally are the end users of the facility or building rather than those who undertake the construction and maintenance works (Hecker & Gambatese, 2003). These problems can be overcome by ensuring that:

- a genuine lifecycle approach to safety is adopted in design, and
- design decisions are informed by construction (and H&S) knowledge.

Overall, the research supports the viability of safety in design in the construction industry. However, there is no 'real world' evidence that supports the long term benefits and effective outcomes from implementing safety in design. Gambatese et al. (2005b) argue that in the US context (in which safety in design is not legally mandated), implementing safety in design will depend on general acceptance of the concept by design professionals. This, they argue, will require:

1. identifying and improving factors that support and motivate designers to adopt safety in design, and
2. removing barriers to implementing safety in design.

Safety in design capability

Despite the growing momentum surrounding safety in design, practical implementation difficulties have been observed in construction projects. Partly this relates to design professionals' level of safety in design knowledge and competency. Designers are the final implementers of the 'design for safety' concept. Their knowledge and acceptance of the concept has a great impact on implementing the 'design for safety' concept in practice (Gambatese et al., 2005a).

US research suggests many design professionals have limited knowledge about safety in design. Gambatese et al. (2005a) propose this may result from a lack of formal education about construction H&S, and designers' limited work experience on construction sites. Gambatese et al. (2005) report that design professionals who have limited knowledge and/or experience in implementing safety in design were much more likely to perceive safety in design as related to increased project costs, schedule problems, and reduced design quality. These assumptions are likely to reduce design professionals' motivation and willingness to implement safety in design. Gambatese et al. (2005a) also report that of six project criteria, US-based design professionals ranked safety as the lowest priority. According to this study, design professionals' concerns about legal liability were one of the main impediments to their willingness to address construction workers' H&S in design decision making.

Gambatese and Hinze (1999) report that construction professionals who frequently visit and spend time at construction sites can identify and suggest more meaningful safety in design 'solutions' than professionals who were predominantly office based and engaged in little site based work.

Brace et al. (2009), who reviewed the causes of fatalities in the UK construction industry, wrote that:

... many designers still think that safety is 'nothing to do with me,' although there are a small cohort who want to engage and are having difficulty doing this because they do not fully understand what good practice looks like (p. 12).

Their observations are concerning given that the UK's Construction Design and Management Regulations were implemented almost 20 years earlier. Donaghy (2009) responded by proposing that accrediting bodies impose a requirement that H&S is integrated into the education programs of designers and others engaged in delivering construction projects. Similarly, in the US almost 90% of contractors surveyed by Gambatese et al. (2008) believed that including H&S as a requirement in the education of architects and design engineers would improve H&S in construction.

Industry supply chain fragmentation

A feature of the construction industry is vertical segregation between the various participants responsible for initiating, designing, producing, using, and maintaining facilities. As Atkinson and Westall (2010) point out, vertical segregation can impede the industry's capability for effectively implementing safety in design. The division between design and construction functions can:

- hinder the development of shared project goals (Baiden & Price, 2011), and
- negatively impact project outcomes (Love, Gunasekaran & Li, 1998).

A causal factor in construction fatalities, according to Donaghy's (2009) recent review of H&S in the UK construction industry, is the separation of, and poor communication between, design and construction functions. Hare et al. (2006) cite several mechanisms that substantially assist with integrating H&S into project planning and design decision making:

- two-way communication between designers and constructors
- the early involvement of the constructor
- participation in health and safety workshops, and
- collaborative brainstorming.

In some instances, specialty subcontractors hold valuable construction/H&S knowledge. Franz et al. (2013) have presented case study data suggesting that in comparable projects, better H&S outcomes are achieved when specialist contractors are involved early.

Improved buildability is often claimed to result from collaborative or integrated approaches to project delivery and that, by implication, H&S is also enhanced (Bresnan & Marshall, 2000; Kent & Becerik-Gerber, 2010). However, some researchers caution that the implied link is not straightforward:

- Ankrah et al. (2009) observe that the procurement method will not generate, as a matter of course, a positive cultural orientation to H&S
- Atkinson and Westall (2010) point out that integrated project delivery is no guarantee of improved safety outcomes.

The contract typically defines the roles, responsibilities, and liabilities of different parties involved in a construction project (Gambatese et al., 2005a). For instance, traditional project delivery methods tend to isolate the designers by viewing them as a stand-alone entity. In this environment, the designers assume that there is no benefit to them from making their designs 'safer.'

In contrast, there are other forms of contract that encourage more involvement of designers in addressing workers' safety, especially those forms in which the owner requires that specific issues regarding safety are addressed, or those which more equally specify responsibilities and liabilities for various parties. For example, the design-build method provides more motivation for designers to address construction safety in their designs. This delivery method creates a partnership between the design and construction teams, closing the gap between these two parties. This facilitates the use of construction knowledge at the design stage and encourages designers to address construction issues (including safety hazards) in their designs (Gambatese et al., 2005a).

Hinze and Wiegand (1992) provide evidence for this. The results of their survey from large design firms in the US revealed that the designers who addressed construction worker safety during the design phase tended to work in design-build firms where both the design and construction teams are components of the same firm.

The research suggests two related but distinct points:

- integrated project delivery is more likely to foster conditions that support the incorporation of H&S into construction project planning and design activities, and
- tangible H&S improvements are more likely to stem directly from enhanced communication and information exchange between project participants.

Project complexity

Significant challenges have beset attempts to specify and operationalise designers' responsibilities for H&S in the construction industry. Complexity is at the heart of these challenges.

Baccarini (1996) has defined complexity as 'consisting of many varied inter-related parts, operationalised in terms of high levels of differentiation and interdependency' (p.202).

There are two kinds of project complexity, as outlined in Table 2.3.

Table 2.3: Sources of complexity in construction projects

Organisational complexity	Characterised by: <ul style="list-style-type: none"> • a significant division of tasks • multiple organisational units and/or hierarchical levels • multiple specialisations, and • many interdependencies between organisational elements.
Technological complexity	Characterised by <ul style="list-style-type: none"> • multiple diverse inputs, outputs, tasks or specialities, and • many interdependencies between technologies, tasks or inputs.

Design work exhibits high degrees of both organisational and technological complexity. This complexity is evident in three domains, each of which is elaborated below: first, the structure of work (collaborating parties); second, the structure of information (knowledge transactions); and third, the structure of governance (contractual arrangements) actually in place (Lingard et al., 2007).

1. *The structure of work*

Safety in design is often described and defined relatively simply. However, the operating context for safety in design is intricate. Distinguishing elements of the construction design process include:

- complex interorganisational relationships
- subclustering
- information dependencies, and
- considerable division of labour.

Researchers often fail to:

- appropriately differentiate the design functions applied at each stage in delivering a building, and
- recognise that control and influence over design frequently rests with parties other than the principal designer or architect.

Construction design teams are 'temporary, multidisciplinary and network-based organizations' (den Otter & Emmitt, 2008, p122). Design entails:

- a network of tasks that rely on contributions from a range of specialists, and
- the activation of a complex 'web' of inter-organisational relationships.

It is difficult to sustain the view that design decisions are the sole preserve of 'the designer' – an abstract, undefined socio-technical role. In the construction industry, suppliers and subcontractors are often the parties that display innovation and independent decision making in designing and manufacturing specialised building components (Gray & Flanagan, 1989; Slaughter, 1993). Construction is characterised by increasing product complexity and specialist contractors are often responsible for the detailed design of specific building elements (Haviland, 1996). Wright et al. (2003) concede that safety in design solutions are often driven by building systems manufacturers rather than by principal design consultants.

Lingard et al. (2012; 2013) have presented a series of in-depth Australian construction industry case studies. The case study analysis reveals that external project stakeholders (for example, regulatory bodies and local authorities) played substantial roles in shaping design decisions, and influenced design decisions that had a positive impact on the H&S of construction workers.

2. *The structure of information*

Construction design work is complex and iterative. It is not simple and linear. Responsibility for a multitude of component parts is difficult to pinpoint.

Design tasks are situated in complex, interconnected networks that require active engagement from many specialists. The design process depends on information exchange and frequent, detailed interactions among specialists to ensure that a building/structure's components are compatible – they must fit together. Austin et al. (2000) analysed four typical building designs. They found that the building design process encompassed 7-10 iterative loops, each involving 5-30 interrelated loops. There were around 350-400 design tasks, and more than 2,400 information dependencies.

Safety in design approaches often superimpose on design activity a standard H&S risk management process. The expectation is that, prior to specific 'hold points' in developing a design:

- protocols for hazard identification will be prepared
- risk assessment will be undertaken, and
- appropriate risk controls will be selected.

Standard H&S risk management assumes that all hazards will be clearly identified at the initiation of a linear risk management process. (A hazard is defined as conditions that have the potential to cause harm). The consequence of this approach is that if a hazard is not identified at the first step, it is excluded from any subsequent H&S risk analysis which assesses the likelihood that harm will eventuate, and the consequence of that harm. In effect, standard H&S risk management processes are blind to emergent hazards.

Standard risk management processes also assume that a project can be decomposed into its constituent parts and that controls can be implemented for risks inherent in each part.

Decomposition is found in commonly accepted methods for managing:

- project scope (work breakdown structures and milestone plans)
- project time performance (project networks, and project evaluation and review techniques), and
- project costs (cost breakdown structures and earned value analysis).

However, Cooke-Davies et al. (2007) put the view that decomposition models are ill suited to analysing complex, nonlinear, dynamic systems, such as construction projects. Pavard and Dugdale (2006) argue that decomposition models have limited practical application to complex systems. For construction design work, it is arduous (and perhaps not feasible) to decompose system elements into design functions, professional contributions, or logical 'steps'. The system elements are in continuous interaction with one another, and with the external environment. Continuous interaction generates emergent properties, which in turn trigger emergent risks. Even a good understanding of component parts cannot guarantee that emergent properties and risks can be identified or anticipated.

3. *The structure of governance*

The governance structure of a construction project has significant implications for design responsibilities. Commercial and contractual relationships that stipulate the allocation of risk and resources have an effect on decision making and the distribution of responsibilities among parties (client/promoter, designer, contractor, specialist contractors/consultants).

The role of each project participant varies according to the chosen project delivery strategy. A 'design and build' approach offers a natural opportunity to incorporate H&S in design. A 'construction management' approach allows the client/promoter to adopt a more aggressive role in project decision making. Between these two project delivery strategies lie many 'hybrid' project procurement strategies, each of which has varying implications for allocating risk and liability. In construction projects, the allocation of risk and responsibility is normally stipulated in contracts. The variety of procurement options and situations arising in the construction industry is reflected in a diverse array of contract types.

The diversity in project governance structures for construction projects means that there is considerable variation in allocating roles and responsibilities for H&S in design.

What is being designed?

The safety in design movement places an emphasis on designing H&S hazards out of the construction industry's products and processes altogether. Most definitions of safety in design imply that designers should address hazards associated with facilities, structures, processes, equipment, tools, and work systems. For example, the US National Institute for Occupational Safety and Health (2008, p.108) defines 'prevention through design' (the US terminology for safety in design) as:

... addressing occupational safety and health needs in the design process to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of *facilities, materials, and equipment* (italics added).

Schulte et al. (2008, p. 115) define safety in design as:

... the practice of anticipating and 'designing out' potential occupational safety and health hazards and risks associated with new *processes, structures, equipment, or tools, and organizing work*, such that it takes into consideration the construction, maintenance, decommissioning, and disposal/recycling of waste material, and recognizing the business and social benefits of doing so (italics added).

Some researchers challenge these definitions of safety in design because they lack sufficient clarity about what is actually being designed. Driscoll et al. (2008) reviewed the findings of coronial investigations in Australia to determine the extent to which design was a causal factor in construction industry deaths. They found that 44% of the deaths examined were design related. However, a close assessment of the accident circumstances described by Driscoll et al. reveals that the majority of the deaths were related to the design of work processes (including temporary works and equipment being used). The design of the permanent structure was clearly implicated in only one of the deaths examined and involved a maintenance worker, working on the roof of a building, falling through a fragile skylight.

It is also apparent that many of the commonly cited safety in design solutions in the construction industry actually involve redesign of the construction process, rather than design of the permanent building or structure to be constructed (see, for example, Wright et al., 2003). Design of healthy and safe work processes is a neglected area in the research on construction safety in design. Research has tended to focus exclusively on design modifications for the end product. Arguably, consideration of H&S in product design, without simultaneously considering the process design, will yield suboptimal risk reduction outcomes.

This lack of clarity is unhelpful in the construction industry because it creates confusion about who should be responsible for safety in design. Different project contributors will be involved in design decisions relating to buildings (or their component parts), equipment, work processes and so on. When implementing safety in design it is essential to have a clear understanding about what is being designed and who the relevant contributors to safety in design are. A principal architect will not, for example, be significantly involved in designing the construction process.

Good design can eliminate or minimise the major physical, biomechanical and psychosocial hazards and risks associated with work. Effective design of the overall system of work will take into account, for example, management practices, work processes, schedules, tasks and workstation design.

- Safe Work Australia, 2012b, p. 7

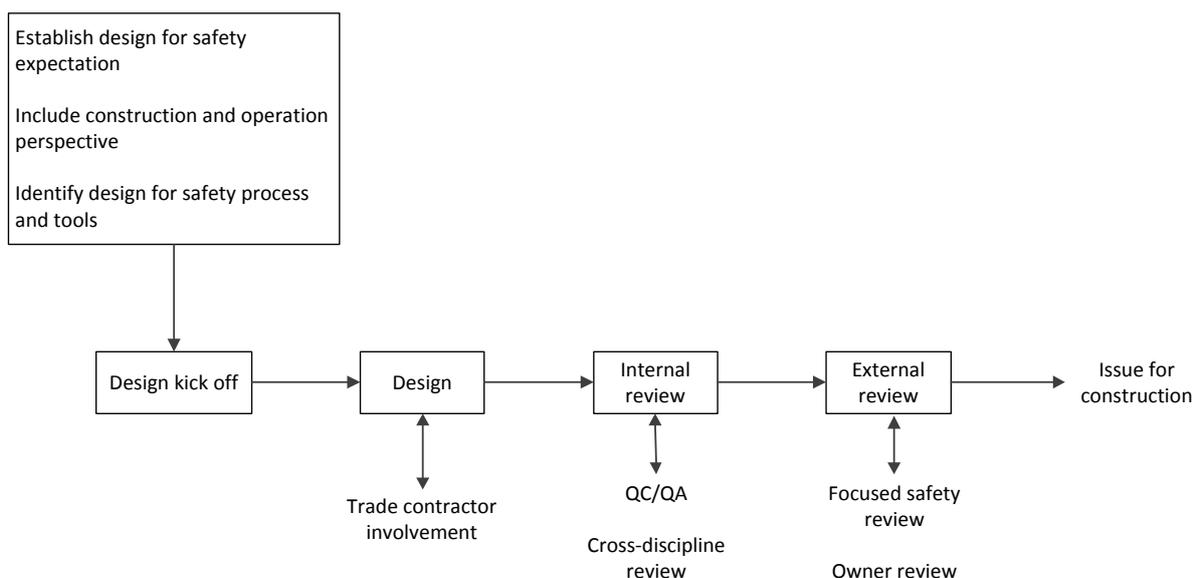
The dynamic nature of design

Designers make implicit and explicit choices which can significantly impact the health and safety of those who build, occupy, maintain, clean, renovate, refurbish, or eventually demolish a building/structure (Gambatese et al., 2008). With this in mind, integrating H&S risk management into design activities has been recommended. For example, Hinze et al. (1999) suggest that designers conduct a thorough risk assessment of each building element during a project's design stage. Mroszczyk (2006) recommends a process which includes the input of site safety knowledge into design decision making through a series of design safety reviews (see Figure 2.9 below).

However, Lingard et al. (2012) use detailed case studies to show the practical difficulties inherent in adopting a simple linear risk management method in the context of the construction industry's complex, dynamic and iterative design process. Traditional H&S risk management identifies H&S hazards when a linear process commences. The process follows a sequence of steps that include risk assessment and subsequent risk control and review. (See, for example, a description of this process in Lingard & Rowlinson, 2005). This approach assumes that all hazards are clearly identifiable when the linear process commences. In effect, if a hazard is not identified at this point it is excluded from subsequent analysis.

Tryggestad et al. (2010) conceptualise H&S risk management differently, suggesting that design decisions are the output of collective action. In their view, design goals are not static inputs established at project commencement. They argue that it is better to regard design as a flexible process in which 'trade-offs' are made so that emergent problems are met with workable solutions.

The weight of research leans towards this kind of analysis, suggesting that design is a dynamic, complex, and reflexive process of collective negotiations. Design decisions, and their H&S impacts, emerge from interactions between stakeholders, material artefacts and technologies (Lingard et al., 2011). This is a contingent perspective on the design process. It implies that the traditional, linear H&S risk management process does not have the flexibility to cope with adaptive decision making and emergent hazards. This perspective is an explicit challenge to most of the proposed implementation solutions for safety in design, given that they rely on the traditional, linear approach.



***Figure 2.9: The Design for Construction Safety Process – the process incorporates site safety knowledge into design decisions (Mroszczyk, 2006).**

2.5 Conclusions

This review of the published literature about safety in design leads to the following conclusions:

- Accident causation models have identified design as a causal factor in the occurrence of accidents in the construction industry.
- Retrospective research in the US, the UK and Australia has established a link between design and construction accidents. However, the objective strength of this link is still unclear.
- Safety in design has been demonstrated to be a viable activity in the construction industry.
- Recent Australian research shows that higher quality (that is, technological) risk controls are more likely to be realised when:
 - H&S is considered early in the project lifecycle (that is, in the design stage), and
 - when constructors are active participants in project decision making during the design stage.
- Many safety in design initiatives achieve suboptimal results – for example, specifying fall arrest systems rather than eliminating the need to work at height.
- There are some important impediments to achieving safety in design in the construction industry, including:
 - difficulty in applying a linear H&S risk management process in the dynamic design environment
 - confusion about what aspect of a project is the focus of safety in design activity
 - project complexity giving rise to problems in ascribing responsibility for safety in design
 - designers' knowledge and experience relating to construction in general and construction H&S specifically, and
 - the construction industry's fragmented supply chain and project delivery processes.

* Figure reprinted with permission. Originally published in 'Designing for Construction Worker Safety', by John W. Mroszczyk, Ph.D., P.E., CSP, from Vol. 5 No. 3 issue of Blueprints, the technical publication of ASSE's Construction Practice Specialty.

Part 3: Safety in Design – policy and practice

Part 3 presents and discusses current issues in policy and practice relating to safety in design in the construction industry. Part 3 is organised as follows:

- Section 3.1 examines recent and current Australian government policy about safety in design
- Section 3.2:
 - summarises the Australian H&S legislative framework and provisions for safety in design
 - briefly describes the content of codes of practice pertaining to safety in design in the construction industry
- Section 3.3 describes and critiques the UK Construction (Design and Management) Regulations
- Section 3.4 explores voluntary (industry based) guidelines for implementing safety in design, and
- Section 3.5 reviews various tools and technologies that support implementing safety in design in the construction industry.

3.1 Australian policy about designing for construction H&S

The National Occupational Health and Safety Strategy 2002-2012

In 2002, the National Occupational Health and Safety Strategy (the National Strategy) was released by the Workplace Relations Ministers' Council. The National Strategy records a commitment by all Australian governments, the Australian Chamber of Commerce and Industry, and the Australian Council of Trade Unions, to share responsibility for ensuring that Australia's performance in H&S is continuously improved. The National Strategy also established clear targets for reducing work related deaths, injuries and illnesses in Australia (National Occupational Health and Safety Commission, 2002).

The National Strategy identified five priorities for achieving H&S improvements, and for nurturing longer term cultural change, in Australian industry. The five priorities were:

Priority 1 To reduce the impact of risks at work

Priority 2 To improve the capacity of business operators and workers to manage H&S effectively

Priority 3 To prevent occupational disease more effectively

Priority 4 To eliminate hazards at the design stage

Priority 5 To strengthen the capacity of government to influence H&S outcomes

Australian Work Health and Safety Strategy 2012-2022

In 2012, the Australian Work Health and Safety Strategy 2012-2022 (the Australian Strategy) was released. The Australian Strategy builds on the National Strategy.

The Australian Strategy identifies the construction industry as an industry requiring priority action. It establishes ambitious targets for the ten year period to 2022. These targets include:

- a reduction of at least 20% in the number of worker fatalities due to injury
- a reduction of at least 30% in the incidence rate of claims resulting in one or more weeks off work, and
- a reduction of at least 30% in the incidence rate of claims for musculoskeletal disorders resulting in one or more weeks off work.

The Australian Strategy seeks to achieve these targets by addressing four key outcomes.

Outcome 1 A reduced incidence of work-related death, injury and illness *achieved by ...*

Outcome 2 reduced exposure to hazards and risks *using ...*

Outcome 3 improved hazard controls *supported by ...*

Outcome 4 an improved national work health and safety infrastructure

These outcomes, in turn, are supported through seven national action areas.

‘Healthy and safe by design’ is the first national action area mentioned in the Australian Strategy because:

- prevention activities should be directed to where there is the greatest potential for reducing harm
- hazards and risks are most effectively controlled at the source, and
- prevention effort should focus on eliminating or minimising exposure to serious hazards and risks, and progressively improving controls.

A number of strategic outcomes are expected to flow from the ‘Healthy and safe by design’ action area. These are:

- structures, plant and substances are designed to eliminate or minimise hazards and risks before they are introduced into the workplace, and
- work, work processes and systems of work are designed and managed to eliminate or minimise hazards and risks (Safe Work Australia 2012b).

3.2 Australian H&S Legislation Framework

Overview

Since the early 1980s in Australia, H&S legislation has moved away from a detailed prescriptive model in which technical solutions to H&S hazards/risks were prescribed in detailed specification standards. A more flexible approach is applied in which duty holders can decide, for themselves, how to comply with broadbased general duties. This shift followed recommendations made by the Robens Committee of Enquiry in the United Kingdom (Bluff & Gunningham, 2003; Workplace Relations, 2008). Robens argued that employees had difficulty in identifying their legal obligations due to the large volume of H&S legislation adopted on a piecemeal basis since the industrial revolution. Although the law was vast and complex, the piecemeal nature in which prescriptive H&S legislation was enacted meant that gaps in coverage existed. In addition, it was recognised that laws prescribing in detail the ways in which H&S risk were to be controlled:

- were cumbersome
- did not keep pace with technological change, and
- prevented duty holders from finding new and innovative ways to improve H&S.

The Robens-inspired legislative reform moved from a specification-standards approach to a more self-regulatory model, based upon employer-employee consultation and workplace decision making.

The Robens model includes two principal elements:

1. a single umbrella statute containing broad 'general duties' based on the common law duty of care, and
2. the empowerment of duty holders, in consultation with employees, to determine how they will comply with the general duties provisions.

Prescriptive requirements were replaced with a three tiered framework involving process based regulations, and hazard based codes of practice, designed to support the general duties in the *Employment and Workplace Relations Act 2008*.

Process based regulations go further than establishing duty holders' general duties. They focus attention on how H&S is being managed (Lingard & Rowlinson, 2005). They require duty holders to follow a certain process, or series of steps, when identifying, assessing, and controlling workplace hazards/risks.

Codes of practice (called Compliance Codes in Victoria) provide a greater level of detail to duty holders about ways in which they can comply with their general duties. Codes often adopt a prescriptive approach by specifying preventative measures to address an identified hazard. Though not mandatory, codes assist duty holders by suggesting how they can comply with the legislation regarding a particular hazard or issue (Bluff & Gunningham, 2003). In this sense, codes of practice possess quasi-legal status – measures described in a code are deemed to comply with the legislation.

National Standard for Construction Work

In 2003, Australia's national, state and territory governments agreed to address H&S inconsistencies within the construction industry. The result was the National Standard for Construction Work, introduced in 2005 by the forerunner to Safe Work Australia, the National Occupational Health and Safety Commission (NOHSC, 2005).

As a National Standard, this document was advisory only. Its purpose was to provide the basis for developing consistent H&S regulation across Australia. The Standard aimed to protect people from the hazards associated with construction work. It assigned certain responsibilities to those involved in the design and construction process, and provided for a nationally consistent approach to managing H&S in the building and construction industry. H&S responsibilities for construction designers were as follows:

1. Designers must ensure that hazards associated with the construction work required by the design are identified before the commencement of construction work.
2. Designers must ensure, to the extent that they have control over the design, that any risks to the health and safety of any person affected by the construction work, which includes the construction, repair, cleaning, maintenance or demolition of a structure, that are a result of the design, are eliminated, or where this is not reasonably practicable, minimised.
3. Designers must report to the client, in writing, on the health and safety aspects of the design identified in accordance with 1 & 2 above.
4. The level of detail to be provided in the report must be commensurate with the degree of risk identified by the designer.

New regulations relating to the National Standard for Construction Work came into operation in 2008. Under the new regulations:

Designers must give a written occupational safety and health report to all clients commissioning design and/or construction work as part of a trade or business. The designer's report must set out:

- the hazards associated with the construction work required to build the design, (for example, hazardous structural features, hazardous construction materials or hazardous procedures or practices);
- the designer's assessment of the risk of injury or harm resulting from those hazards;
- the action the designer has taken to reduce those risks, (for example, changes to the design or changes to construction methods or construction materials); and
- any parts of the design where hazards have been identified but not resolved.

The level of detail given in the designer's report must be appropriate for the client, the nature of the hazard(s) and the degree of risk (WorkSafe WA, 2007).

State and territory H&S legislation

H&S legislation in Australia is the responsibility of each state and territory. All state and territory H&S laws are based on similar underlying principles, but inconsistencies remain in the detail and application of these laws. This has been particularly evident in inconsistencies in the statutory H&S responsibilities of designers of buildings and other structures, which varied according to the state or territory in which work was undertaken. Constitutional issues prevent the enactment of binding national H&S legislation and regulation that would cover all states and territories.

In March 2008, the Council of Australian Governments (COAG) agreed that nationwide harmonisation of H&S legislation was a top priority and that harmonisation could best be achieved by developing model legislation. A process of consultation and review was embarked on with the aim of developing model legislation that would provide a consistent basis for H&S laws in all Australian jurisdictions. It was envisaged that each state and territory would enact harmonised legislation by December 2011.

The Model Safe Work Act 2009 (Model Safe Work Provisions), with supporting regulations and guidance, was issued for public comment on the 28 September 2009. The Model Act was open for public comment until November 2009, after which time Safe Work Australia reviewed submissions. On 11 December 2009, the Workplace Relations Ministers' Council (WRMC) endorsed the revised Model Work Health and Safety Act. Safe Work Australia was authorised to make any further technical and drafting amendments to ensure its workability. On 29 April 2010, Safe Work Australia Members endorsed amendments to the Model H&S Act. A final version was made available on the Safe Work Australia website. The Model H&S Act was finalised in June 2011.

In its current version, Section 22 of the Model H&S Act establishes the following responsibilities for designers of a structure 'that is to be used as, or at, a workplace.'

Section 22: Duties of persons who design plant, substances or structures

1. This section applies to a person (the designer) who conducts a business or undertaking that designs:

- (a) plant that is to be used, or could reasonably be expected to be used, as, or at, a workplace; or
- (b) a substance that is to be used, or could reasonably be expected to be used, at a workplace; or
- (c) a structure that is to be used, or could reasonably be expected to be used, as, or at, a workplace.

2. The designer must ensure, so far as is reasonably practicable, that the plant, substance or structure is designed to be without risks to the health and safety of persons:

- (a) who, at a workplace, use the plant, substance or structure for a purpose for which it was designed; or
 - (b) who handle the substance at a workplace; or
 - (c) who store the plant or substance at a workplace; or
 - (d) who construct the structure at a workplace; or
 - (e) who carry out any reasonably foreseeable activity at a workplace in relation to:
 - (i) the manufacture, assembly or use of the plant for a purpose for which it was designed, or the proper storage, decommissioning, dismantling or disposal of the plant; or
 - (ii) the manufacture or use of the substance for a purpose for which it was designed or the proper handling, storage or disposal of the substance; or
 - (iii) the manufacture, assembly or use of the structure for a purpose for which it was designed or the proper demolition; or
- Example:** Inspection, operation, cleaning, maintenance or repair of plant.
- (f) who are at or in the vicinity of a workplace and who are exposed to the plant, substance or structure at the workplace or whose health or safety may be affected by a use or activity referred to in paragraph (a), (b), (c), (d) or (e).

3. The designer must carry out, or arrange the carrying out of, any calculations, analysis, testing or examination that may be necessary for the performance of the duty imposed by subsection (2).

4. The designer must give adequate information to each person who is provided with the design for the purpose of giving effect to it concerning:

- (a) each purpose for which the plant, substance or structure was designed; and
- (b) the results of any calculations, analysis, testing or examination referred to in subsection (3), including, in relation to a substance, any hazardous properties of the substance identified by testing; and
- (c) any conditions necessary to ensure that the plant, substance or structure is without risks to health and safety when used for a purpose for which it was designed or when carrying out any activity referred to in subsection (2)(a) to (e).

5. The designer, on request, must, so far as is reasonably practicable, give current relevant information on the matters referred to in subsection (4) to a person who carries out, or is to carry out, any of the activities referred to in subsection (2)(a) to (e).

The Model H&S Act is supported by the Model Work Health and Safety Regulations. Draft Model H&S Regulations were released in December 2010 for a four month period of public comment. The Model Regulations were finalised in November 2011 and form the basis of the H&S Regulations being enacted across Australian jurisdictions to harmonise work health and safety law.

The Model H&S Regulations 2011 specify duties for designers of structures in sections 61, 64, and 294-296. Of particular interest is section 295 which requires designers to provide a written report to a person commissioning their design about the health and safety aspects of the design.

Section 61: Duties of designers, manufacturers, importers and suppliers of plant or structures

1. A designer of a plant or a structure must ensure that the plant or structure is designed so as to eliminate the need for any hazardous manual task to be carried out in connection with the plant or structure.
2. If it is not reasonably practicable to comply with subregulation (1), the designer must ensure that the plant or structure is designed so that the need for any hazardous manual task to be carried out in connection with the plant or structure is minimised so far as is reasonably practicable.
3. The designer must give to each person who is provided with the design for the purpose of giving effect to it adequate information about the features of the plant or structure that eliminate or minimise the need for any hazardous manual task to be carried out in connection with the plant or structure.

Section 64: Duty to eliminate or minimise risk

1. This regulation applies in relation to plant or a structure that includes a space that is, or is intended to be, a confined space.
2. A designer, manufacturer, importer or supplier of the plant or structure, and a person who installs or constructs the plant or structure, must ensure that:
 - (a) the need for any person to enter the space and the risk of a person inadvertently entering the space are eliminated, so far as is reasonably practicable; or
 - (b) if it is not reasonably practicable to eliminate the need to enter the space or the risk of a person inadvertently entering the space:
 - (i) the need or risk is minimised so far as is reasonably practicable; and
 - (ii) the space is designed with a safe means of entry and exit; and
 - (iii) the risk to the health and safety of any person who enters the space is eliminated so far as is reasonably practicable or, if it is not reasonably practicable to eliminate the risk, the risk is minimised so far as is reasonably practicable.

Section 295: Designer must give safety report to person who commissions design

1. The designer of a structure or any part of a structure that is to be constructed must give the person conducting a business or undertaking who commissioned the design a written report that specifies the hazards relating to the design of the structure that, so far as the designer is reasonably aware:
 - (a) create a risk to the health or safety of persons who are to carry out any construction work on the structure or part; and
 - (b) are associated only with the particular design and not with other designs of the same type of structure.
2. If the person conducting a business or undertaking who commissions a construction project did not commission the design of the construction project, the person must take all reasonable steps to obtain a copy of the written report referred to in subregulation (1) in relation to that design.

The requirements of the Model Act and Regulations are not automatically adopted into state and territory H&S legislation. The impact of the Model Act and Regulations ultimately depends on states and territories revising their H&S legislation to reflect the content of the Model. Under the current COAG Inter-Governmental Agreement for Regulatory and Operational Reform in Occupational Health and Safety (IGA), all states and territories agreed to ‘take all necessary steps to enact or otherwise give effect to Model H&S legislation’. By the end of 2013, all states and territories except Victoria and Western Australia had revised their legislation to adopt the model work health and safety legislation. Table 3.1 lists the principal H&S Acts and regulations currently in force in Australian jurisdictions.

**Table 3.1: The principal H&S Acts and Regulations currently in force in Australia
(adapted from Safe Work Australia, 2013)**

Jurisdiction	Principal H&S Act/Regulations	Coverage of Act
Australian Capital Territory	<i>Work Health and Safety Act, 2011</i> <i>Work Health and Safety Regulations 2011</i>	Persons employed in ACT
Commonwealth of Australia	<i>Work Health and Safety Act 2011</i> <i>Work Health and Safety Regulations 2011</i>	Persons employed by the Commonwealth, Commonwealth authorities & certain licensed corporations
New South Wales	<i>Work Health and Safety Act 2011</i> <i>Work Health and Safety Regulations 2011</i>	Persons employed in NSW
Northern Territory	<i>Work Health and Safety(National Uniform Legislation) Act 2011</i> <i>Work Health and Safety(National Uniform Legislation) Regulations 2011</i>	Persons employed in NT
South Australia	<i>Work Health and Safety Act 2012</i> <i>Work Health and Safety Regulations 2012</i>	Persons employed in SA
Queensland	<i>Work Health and Safety Act, 2011</i> <i>Work Health and Safety Regulations 2011</i>	Persons employed in Qld
Tasmania	<i>Work Health and Safety Act, 2012</i> <i>Work Health and Safety Regulations 2012</i>	Persons employed in Tas
Victoria	<i>Occupational Health and Safety Act 2004</i> <i>Occupational Health and Safety Regulations 2007</i>	Persons employed in Vic
Western Australia	<i>Occupational Health and Safety Act 1984</i> <i>Occupational Safety and Health Regulations 1996</i>	Persons employed in WA

State and territory H&S Codes of Practice

Model Codes of Practice are practical guides that assist the parties to comply with the wide duties imposed by the Model H&S Act and the Model H&S Regulations. Codes of Practice provide detailed instructions on how to meet obligations for specific workplace health and safety issues.

To have legal effect in a jurisdiction, a Model Code of Practice needs to be approved as a code of practice in that jurisdiction. Under the Model H&S Act and Model H&S Regulations, transitional arrangements in each jurisdiction will allow duty holders a period of time to make necessary adjustments that comply with any new requirements.

As at November 2013, Safe Work Australia Members and the Ministerial Council have approved 23 Model Codes of Practice that apply in most, but not all, jurisdictions. The Model Codes of Practice are:

- How to Safely Remove Asbestos
- How to Manage and Control Asbestos in the Workplace
- Abrasive Blasting
- Confined Spaces
- Construction Work
- Work Health and Safety Consultation Cooperation and Coordination
- Demolition Work
- Managing Electrical Risks at the Workplace
- Excavation Work
- Managing the Risk of Falls at the Workplaces
- Preventing Falls in Housing Construction
- Managing the Work Environment and Facilities
- First Aid in the Workplace
- Labelling of Workplace Hazardous Chemicals
- Preparation of Safety Data Sheets for Hazardous Chemicals
- Managing Risks of Hazardous Chemicals in the Workplace
- Hazardous Manual Tasks
- Managing Noise and Preventing Hearing Loss at Work
- Managing Risks of Plant in the Workplace
- How to Manage Work Health and Safety Risks
- Safe Design of Structures
- Spray Painting and Powder Coating
- Welding Processes.

As at November 2013, Safe Work Australia Members have endorsed 12 Model Codes of Practice which are ready for endorsement by the Ministerial Council. They are:

- Working in the Vicinity of Overhead and Underground Electric Lines
- Safe Design, Manufacture, Import and Supply of Plant
- Traffic Management in Workplaces
- Managing Cash-in-transit Security Risks
- Tree Trimming and Removal Work – Crane Access Method

- Industrial Lift Trucks
- Formwork and Falsework
- Managing Risks of Plant in Rural Workplaces
- Cranes
- Managing Risks in Forestry Operation
- Scaffolds and Scaffolding Work
- Amusement Devices.

Once approved by the Ministerial Council, these draft Codes of Practice will become Model Codes of Practice under the IGA and will be published on Safe Work Australia’s website, replacing the draft Codes (Workplace Safety Australia, 2013).

In July 2012, Safe Work Australia published Safe Design of Structures – Code of Practice 2012, as part of the national harmonisation of H&S legislation. It provides practical guidance on design of structures that will be used, or could reasonably be expected to be used, as a workplace. South Australia and Tasmania have incorporated this Code into their legislative frameworks. Other jurisdictions still refer to their own Codes of Practice for safe design. The following table shows the Codes of Practice and guidelines related to Safety in Design process in different jurisdictions.

Table 3.2: Codes of Practice and guidelines on to Safety in Design process, in different jurisdictions

Jurisdiction	Code of Practice/Guideline on Safe Design of Structures/Buildings	Governing legislation
Australian Capital Territory	Safe Design: Safe Structures, Systems, Workplaces 2010	<i>Work Safety Act 2008</i>
Commonwealth of Australia	Safe Design of Structures – Code of Practice July 2012	<i>Work Health and Safety Act 2011</i>
New South Wales	Safe Design of Buildings and Structures August 2009	<i>Occupational Health and Safety Act 2000</i>
South Australia	Safe Design of Structures – Code of Practice July 2012	<i>Work Health and Safety Act 2012</i>
Tasmania	Safe Design of Structures – Code of Practice December 2012	<i>Work Health and Safety Act 2012</i>
Victoria	Designing Safer Buildings and Structures December 2005	<i>Occupational Health and Safety Act 2004</i>
Western Australia	Code of Practice – Safe Design of Buildings and Structures 2008	<i>Occupational Safety and Health Act 1984</i>

Safe Design of Structures – Code of Practice 2012

Based on *Work Health and Safety Act 2011* and *Work Health and Safety Regulations 2011*, this Code of Practice provides guidance to any person involved in, or making decisions that influence, the design of structures (including movable, temporary, or permanent) to be used as a workplace. The Code suggests using a systematic H&S risk management approach which involves:

- identifying reasonably foreseeable design related hazards
- assessing the risks arising from hazards
- eliminating or minimising the risks by designing control measures, and
- reviewing the control measures.

The Code requires designers to use the risk management process to address Safety in Design across the lifecycle of the structure. The Code states (Safe Work Australia, 2012c, p. 7):

... designers should consider how their design will affect the health and safety of those who will interact with the structure throughout its life....This means thinking about design solutions for reasonably foreseeable hazards that may occur as the structure is built, commissioned, used, maintained, repaired, refurbished or modified, decommissioned, demolished or dismantled and disposed or recycled.

To achieve this, the Code requires the designer to have, besides core design knowledge and capabilities:

- knowledge of risk management processes
- an appreciation of *construction methods* and their impact on the design, and
- the ability to source and apply relevant data on human dimensions, capabilities and behaviours.

At the same time, the Code acknowledges the fact that the design process involves different people who make decisions at different stages, and that their decisions might positively or negatively affect the health and safety of others. Thus, the Code emphasises consultation, communication and cooperation between different parties to identify and address H&S risks during the structure's lifecycle.

As part of the risk management process, the code requires that (p. 9):

Key information about identified hazards and action taken or required to control risks should be recorded [by designers] and transferred from the design phase to those involved in later stages of the lifecycle.

The Code suggests two methods for transferring safety related information.

Safety Report	Based on regulation 295 of Work Health and Safety Regulations 2011. The Safety Report is required if the structure has unusual or atypical features which present hazards and risks unique to the design during the construction phase. The Safety Report should include information about identified hazards and the designer's assessment of the risk consequences for construction workers. It should also include the action that the designer has taken to control the risks.
Work Health and Safety File	Although not compulsory, the Code suggests that designers develop a H&S File for the structure to meet their duty to provide information to others. The H&S File could include relevant health and safety information prepared and used in design process including the Safety Report, risk register, safety data sheets, and manuals and procedures useful in later phases.

The Code recommends a three phase process for integrating risk management and design process.

Phase 1 Pre-design phase	<p>This phase mostly involves planning and information collection.</p> <p>During this phase, design and risk management contexts are established and different roles and disciplines involved in design or subsequent phases are identified and consulted to assist in risk identification, assessment and control.</p> <p>Some hazards are identified by considering the intended use of structure, industry accident profile and statistics, and guidance material.</p> <p>Workshops can be conducted with experienced personnel who will construct, use and maintain the new structure, as well as with specialist consultants.</p> <p>The client is also required to give all the relevant and available information about the structure and its intended use.</p>
Phase 2 Conceptual and schematic design phase	<p>Hazard identification and preliminary hazard analysis are undertaken for different hazard categories in this phase.</p> <p>It should be decided which hazards are design related and consideration should be given to possible ways of eliminating or minimising these hazards.</p>
Phase 3 Design development phase	<p>Control measures decided for hazards with consideration of hierarchy of control.</p> <p>For common hazards, control measures are chosen from known solutions.</p> <p>For others, a risk assessment can be conducted.</p> <p>Solutions are chosen with consideration of costs and benefits.</p> <p>After finalising the design, a Safety Report is prepared and other risk control information (including information about residual risks) should be documented.</p> <p>During the construction phase, the construction team needs to consult with the designer and client to ensure any design changes would not increase H&S risks.</p> <p>Design safety reviews are conducted at various points in the process, and where possible, should involve people with construction knowledge, including those who will construct the structure.</p>

Figure 3.1 is a graphic representation of this three phrase process.

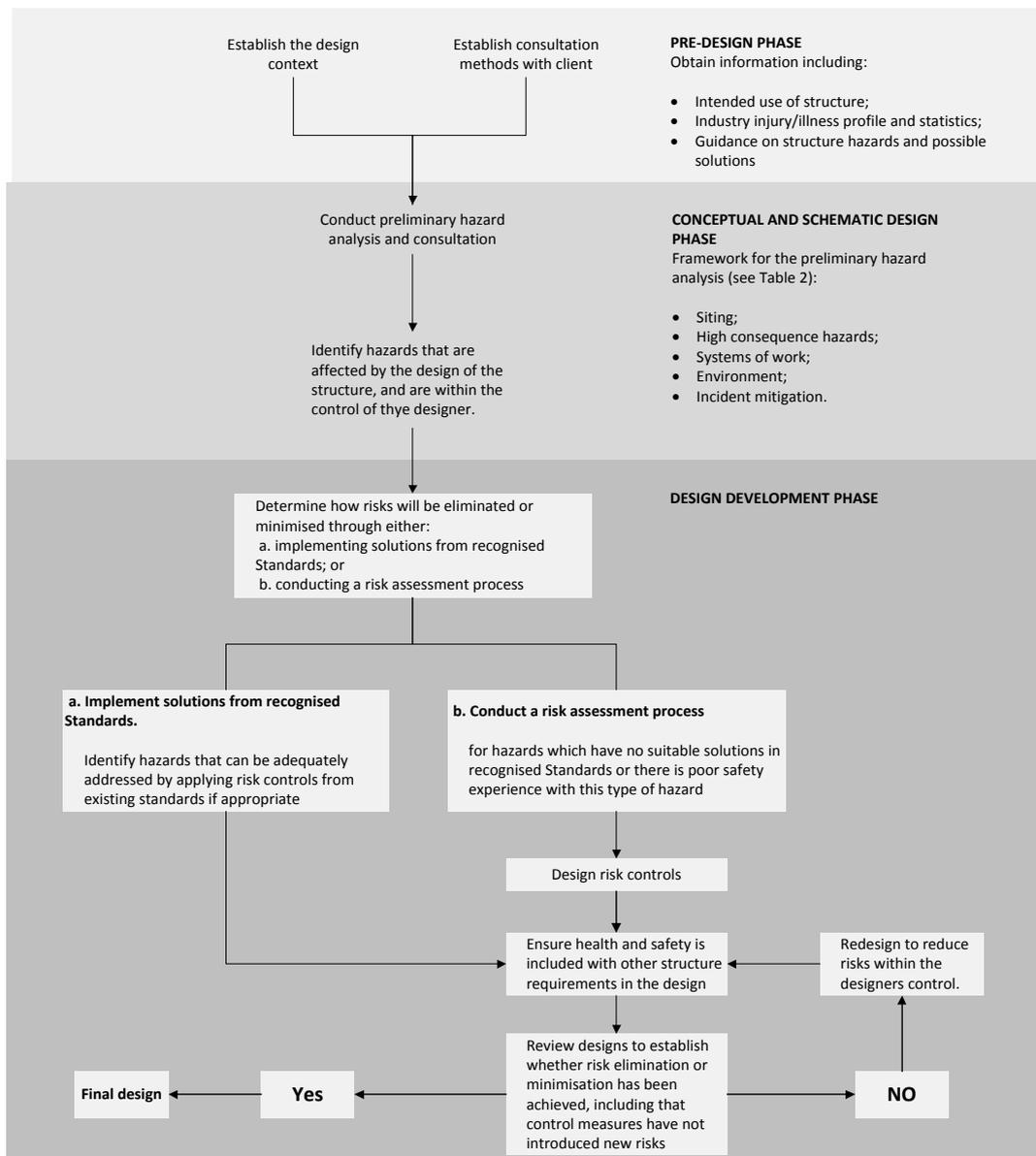


Figure 3.1: A systematic approach to integrate design and management (Safe Design of Structures – Code of Practice 2012)

The Code emphasises communication between various parties involved and provides different communication models for a number of procurement methods. The main idea implicit in the provided models is that consultation and collaboration duties are separated from contracted responsibilities. It is suggested that unless contractual responsibilities conflict, designer and constructor should cooperate and communicate, especially in case of residual risks and new hazards.

Codes of practice in other jurisdictions

Two Australian states (South Australia and Tasmania) have incorporated in their legislative frameworks the Safe Design of Structures – Code of Practice 2012. Other states and territories continue to use their own codes of practice/guidelines as the reference point for the safety in design process. However, all these codes/guidelines are based on the same five principles for safe design identified by Safe Work Australia (2006). These principles are set out below.

Principle 1	Safe design is everyone’s responsibility – ensuring safe design rests with all parties influencing the design of a building or structure.
Principle 2	Safe design employs lifecycle concepts – applying to every phase in the lifecycle of a building or structure, from conception through to redevelopment and demolition.
Principle 3	Safe design implements risk management – through systematically identifying, assessing and controlling hazards.
Principle 4	Safe design requires knowledge and capability – which should be either demonstrated or accessed by any person influencing design.
Principle 5	Safe design relies on information transfer – requiring effective documentation and communication between everyone involved in the lifecycle of a building or structure.

Based on these principles, the codes of practice/guidelines require that risk management procedures are integrated into the design process. The recommended processes for design risk management, although explained differently, are similar in that they all include the basic steps in the generic, linear risk management process: that is, risk identification, risk assessment, risk control. The codes of practice/guidelines recognise various parties are involved in the design process and emphasise communication and collaboration between stakeholders. Most require a Safety Report prepared by designers at the end of the design process and submitted to the client. In addition, Safe design of Structures – Code of Practice 2012, and Code of Practice – Safe Design of Buildings and Structures 2008 (WorkSafe Western Australia), recommend designers develop a H&S file to assist in transferring information to other parties at subsequent phases of the structure/building lifecycle.

Most of the codes/guidelines, except Designing Safer Buildings and Structures December 2005 (WorkSafe Victoria), address H&S issues across the lifecycle of a structure/building, including construction workers health and safety. Designing Safer Buildings and Structures December 2005 (WorkSafe Victoria) focuses only on end user health and safety and does not apply to the design of the construction process. The following table summarises the scope and recommended risk management processes by different codes of practice/guidelines in Australian jurisdictions.

Table 3.3: Summary of scope and recommended risk management process for Safe Design in different codes of practice/guidelines

State/ territory	Code of practice/ guideline	Scope	Recommended process
Victoria	Designing Safer Buildings and Structures December 2005	<ul style="list-style-type: none"> • Safe Design of buildings/ structures (or parts of structures) to be used as a workplace • Focus on end-user’s safety and end-product design • Does not apply to the design of the construction and demolition phases • Does not apply to residential dwellings, roads and footpaths 	<p>A systematic risk management process to identify and address H&S risks to end-users. The process consists of two main steps:</p> <ul style="list-style-type: none"> • Preliminary Hazard Analysis: <ul style="list-style-type: none"> ○ Establish a strong collaborative relationship between designer and client ensuring effective information exchange ○ During the pre-design phase, identify broad groupings of potential hazards using information about intended use of the structure, industry accident profile, and available guidelines ○ During the conceptual design phase, identify design related hazards using the broad groupings and information in hand. Consider possible ways to eliminate or control hazards. • Systematic Risk Management. Along with the iterative design process: <ul style="list-style-type: none"> ○ Identify applicable solutions from recognised standards ○ Conduct full risk management for hazards with no standard solution, apply detailed hazard identification techniques, identify design solutions to eliminate/control hazards, review and evaluate options against H&S requirements, redesign until desired outcomes are achieved, and document the information ○ Ensure that design changes in subsequent phases do not increase workplace hazards.

State/ territory	Code of practice/ guideline	Scope	Recommended process
Australian Capital Territory	Safe Design: Safe Structures, Systems, Workplaces 2010	<ul style="list-style-type: none"> • Safe design of structures, systems of work, and workplaces • Safety is considered throughout the lifecycle of the structure or system 	<p>A generic risk management process is suggested:</p> <ul style="list-style-type: none"> • Take reasonably practicable steps, in an ongoing manner, to: <ul style="list-style-type: none"> ○ Identify and assess any design related risk. Suggested processes include using hazard checklists, using established risk assessment tools such as HazOp or CHAIR. Review records of past incidents, standards and codes, and consult experienced stakeholders. Assessment is based on the likelihood and consequence of risks ○ Eliminate/minimise each risk (based on HOC). • Inform anyone else who has the duty about the possible risks: <ul style="list-style-type: none"> ○ Designers need to identify and consult with other parties involved in other phases ○ Feedback from users should be fed into the process to improve safety outcomes overtime.

State/ territory	Code of practice/ guideline	Scope	Recommended process
New South Wales	Safe Design of Buildings and Structures August 2009	<ul style="list-style-type: none"> • Safe design of buildings and structures including residential housing and other buildings and structures not normally considered workplaces • Safety is considered throughout the lifecycle of the building or structure (including safety of those who construct, work in, maintain, clean, repair and demolish the structure) • The Code specifies responsibilities and requirements for the 'Design Manager' to lead the safety in design process. • Design Manager is defined as: <i>the person(s) responsible for the design (or a design element) of a building or structure. Different parties may act as a design manager in a project, depending on its size and complexity.</i> 	<p>A systematic risk management process which starts from the concept development phase is suggested. The process consists of eight basic steps:</p> <ul style="list-style-type: none"> • Discuss the project and its intended use. This includes establishing a collaborative relationship between those involved in the design process to ensure effective information exchange • Identify other stakeholders. Include them in consultation process to draw on their expertise • Determine the consultation process. This includes conducting workshops for large and complex projects • Prepare a 'risks and solutions' register. This involves identifying and documenting a broad range of hazards at each phase of the project before the detailed design begins. The risks are assessed and ranked based on their likelihood and consequences. Solutions are identified using standards, guidelines, previous hazard analysis documents, or in consultation with technical experts • Provide an initial report to the client. The report includes any known hazards, design solutions or alternative construction methods to eliminate or minimise the hazards in each phase • Amend and finalise the design • Provide a final report to the client and constructor. The report should include information about the residual risks • Review the design in case any new information relevant to design is brought to attention.

State/ territory	Code of practice/ guideline	Scope	Recommended process
Western Australia	Code of Practice – Safe Design of Buildings and Structures 2008	<ul style="list-style-type: none"> • Safe design of buildings and structures • Safety is considered throughout the lifecycle of the building or structure 	<p>The code emphasises consultation between all relevant stakeholders (including end users of a building or structure) during the risk management process to draw out the knowledge and expertise of those either performing tasks or overseeing the construction process.</p> <p>A systematic risk management process is suggested with three generic steps:</p> <ul style="list-style-type: none"> • Identify hazards throughout the lifecycle of the building or structure. This may include using hazard checklists, using established risk assessment tools, reviewing records of past incidents, referring to standards and codes, and conducting constructability reviews and consulting experts • Assessing risk of injuries or harms. This involves considering the likelihood and consequences of risks • Controlling risks. This involves implementing control measure (referring to the HOC) to eliminate or reduce hazards. Interaction between a combination of hazards, and the effect on the level of risk, should be considered. Information about the residual risks should be documented and communicated to relevant stakeholders. <p>Designers are required (under OSH Regulations 1996) to report to the client in writing on safety and health aspects of the design. The report includes information about identified hazards, actions taken to control risks and residual risks.</p> <p>The code recommends that designers develop a H&S file to provide information to others.</p>

3.3 The Construction Design and Management (CDM) Regulations

In 1992, the Council of European Communities implemented the Directive 92/57/EEC – Temporary or Mobile Construction Sites. The Directive established minimum H&S requirements for temporary or mobile construction sites. The Directive required consideration of H&S during the design and organisation of construction projects. A key feature of the Directive was the requirement to develop Health and Safety Plans in the pre-construction stages of construction projects. In 1994, the UK responded to the Directive with the Construction (Design and Management) Regulations (CDM 1994) which:

- established specific statutory H&S duties for clients and designers, and
- required the creation of a project-specific health and safety file to ensure H&S information was documented and communicated through all stages of the project lifecycle.

In 1997, the UK's Health and Safety Commission (HSC) evaluated the impact of CDM 1994. It was concluded that although the philosophy of the regulations was widely understood and accepted in the UK construction industry, there was a need to clarify the CDM requirements for duty holders. This finding led to a revised Approved Code of Practice (ACoP) and Guidance which accompanied CDM 1994. In 2002, HSC published a discussion document called *Revitalising Health and Safety in Construction* (HSE, 2002) which sought the construction industry's view on improving health and safety performance. The responses from the UK construction industry showed that (HSE, 2011):

- there was a need for:
 - improved competence at all levels
 - recognition of the influence that clients wield
 - re-evaluation of the Planning Supervisor role
 - more specific legislation and clear responsibilities
 - improved consultation with the workforce.
- poor project management and fragmentation in the industry were considered as major obstacles to progress in health and safety.
- fragmentation and the associated adversarial attitudes encouraged people to pass risk down the supply chain, often to those least able to actually reduce and manage the risk.
- integrated teams were strongly supported by the respondents; however, the majority believed that there was no need for health and safety law to require integrated teams.
- there was a clear desire for better Regulations. However, industry culture (particularly its inertia and complacency) was seen as the biggest hindrance to progress. There was recognition that law itself cannot change the industry's culture directly, but the actual process of changing the law does provide opportunities to positively influence the culture.

In 2003, HSC agreed to revise the CDM regulations to simplify regulations, improve clarity and flexibility, minimise bureaucracy, improve coordination and cooperation (particularly between designers and contractors), and simplify the assessment of competence.

On 6 April 2007, the revised CDM 2007 Regulations came into force. The changes:

- made explicit what was already implicit – examples include encouraging coordination and communication
- altered duties – examples include telling duty holders how much time they have before work starts on site, and
- affected duty holders – Coordinators replaced Planning Supervisors.

CDM 2007 included two changes to designers' duties:

- designers must demonstrate their competence and the adequacy of their resources as part of the prequalification and bidding process – an amended duty, and
- designers must ensure that any workplace which they design complies with relevant sections of the Workplace (Health, Safety and Welfare) Regulations 1992 (that is, designing for the safe use of premises that are to be used as workplaces) – a new duty.

To assist clients in discharging their duties, in CDM 2007 HSE replaced the Planning Supervisor (a role introduced in CDM 94 which many industry respondents saw as largely ineffective) with the role of Coordinator. The duties for the Coordinator are to:

- advise and assist the client with their duties
- ensure that HSE is notified of the project (unless a domestic client)
- coordinate H&S aspects of design work
- facilitate good communication between client, designers and contractors
- identify, collect and pass on pre-construction information
- prepare and update the health and safety file
- liaise with the principal contractor regarding ongoing design
- check own competence
- cooperate with others and coordinate work so as to ensure the H&S of construction workers and others who may be affected by the work
- report obvious risks
- ensure compliance with Part 4 Duties Relating to Health and Safety on Construction Sites
- apply the principles of prevention in Appendix 7 of the ACoP.

The CDM Regulations 2007 are currently undergoing further review and revision, but the focus remains on addressing H&S before construction commences.

Duty holders and projects under CDM regulations 2007

CDM regulations apply to all construction projects from inception, through design, tender, construction, and subsequent cleaning stages. Under the regulations, construction (definitions regulation 2) means the carrying out of any building, civil engineering or engineering construction work. Construction includes the following (CDM 2007):

- (a) the construction, alteration, conversion, fitting out, commissioning, renovation, repair, upkeep, redecoration or other maintenance (including cleaning which involves the use of water or an abrasive at high pressure or the use of corrosive or toxic substances), decommissioning, demolition or dismantling of a structure;
- (b) the preparation for an intended structure, including site clearance, exploration, investigation (but not site survey) and excavation, and the clearance or preparation of the site or structure for use or occupation at its conclusion;
- (c) the assembly on site of prefabricated elements to form a structure or the disassembly on site of prefabricated elements which, immediately before such disassembly, formed a structure;
- (d) the removal of a structure or of any product or waste resulting from demolition or dismantling of a structure or from disassembly of prefabricated elements which immediately before such disassembly formed such a structure; and
- (e) the installation, commissioning, maintenance, repair or removal of mechanical, electrical, gas, compressed air, hydraulic, telecommunications, computer or similar services which are normally fixed within or to a structure.

Under CDM 2007, there are five parties or individuals identified as having specific duties:

1. The Client
2. The CDM Coordinator
3. The Designer(s)
4. The Principal Contractor
5. The Contractor(s).

Except for the Client, all the duty holders are required to be competent to undertake their duties. The regulations also explicitly place additional responsibility on the individual duty holders (excluding the Client) to be satisfied that they themselves are competent.

Under CDM 2007 regulations, a project is notifiable to HSE if:

- the construction work is expected to last more than 30 working days, or
- the construction works involve more than 500 person days (except where the project is for a domestic client).

For notifiable works, Clients are required to:

- appoint a CDM Coordinator and a Principal Contractor, and
- provide all relevant information about a project to the CDM Coordinator.

The Coordinators will then ensure that details are correct and information is sufficient, and held in a Health and Safety Information Plan to assist all parties (especially the Principal Contractor and Designer) to comply with the Regulations.

The CDM Coordinator is:

- required to give notice to HSE about the project
- responsible for ensuring that sufficient health and safety information is prepared for use by the project team, and
- responsible for ensuring that a Health and Safety File is prepared.

The Health and Safety File is intended to support the whole project team, including Designers, with health and safety advice. The scope, structure and format for the File are agreed between the Client and CDM Coordinator at the start of a project. It should contain the information needed for safely carrying out future construction work (including cleaning, maintenance, alterations, refurbishment and demolition). During the project, any party providing information ensures the File is accurate, and provided promptly. On project completion, the Health and Safety File will be handed to the Client and should be kept up to date after any relevant work or surveys are undertaken (HSE, 2007).

Designers' duties under CDM 2007

The CDM Regulations 2007 establish responsibilities across the lifecycle of projects, requiring designers to avoid foreseeable risks to any person:

- carrying out construction work
- liable to be affected by such construction work
- cleaning any window or any transparent or translucent wall, ceiling or roof in or on a structure
- maintaining the permanent fixtures and fittings of a structure, or
- using a structure designed as a workplace.

CDM Regulations define the Designer's duties for reducing H&S risks during construction to avoid hazards, combat risks, and provide information. In line with the HOC concept, CDM Regulations state

that the best form of protection against a hazard is to eliminate the hazard at source. Where elimination of the hazard is not possible, the next strategy is to reduce the likelihood, or the potential impact, of the hazard. Where elimination and/or reduction of the hazard is not possible, information about the hazard should be provided so that it can be dealt with as safely as possible.

Part 2

Duties of designers

11.

- (1) No designer shall commence work in relation to a project unless any client for the project is aware of his duties under these Regulations.
- (2) The duties in paragraphs (3) and (4) shall be performed so far as is reasonably practicable, taking due account of other relevant design considerations.
- (3) Every designer shall in preparing or modifying a design which may be used in construction work in Great Britain avoid foreseeable risks to the health and safety of any person—
 - (a) carrying out construction work;
 - (b) liable to be affected by such construction work;
 - (c) cleaning any window or any transparent or translucent wall, ceiling or roof in or on a structure;
 - (d) maintaining the permanent fixtures and fittings of a structure; or
 - (e) using a structure designed as a workplace
- (4) In discharging the duty in paragraph (3), the designer shall—
 - (a) eliminate hazards which may give rise to risks; and
 - (b) reduce risks from any remaining hazards,and in so doing shall give collective measures priority over individual measures.
- (5) In designing any structure for use as a workplace the designer shall take account of the provisions of the Workplace (Health, Safety and Welfare) Regulations 1992 which relate to the design of, and materials used in, the structure.
- (6) The designer shall take all reasonable steps to provide with his design sufficient information about aspects of the design of the structure or its construction or maintenance as will adequately assist—
 - (a) clients;
 - (b) other designers; and
 - (c) contractors,to comply with their duties under these Regulations.

Part 3

Additional duties of designers

18.

- (1) Where a project is notifiable, no designer shall commence work (other than initial design work) in relation to the project unless a CDM co-ordinator has been appointed for the project.
- (2) The designer shall take all reasonable steps to provide with his design sufficient information about aspects of the design of the structure or its construction or maintenance as will adequately assist the CDM co-ordinator to comply with his duties under these Regulations, including his duties in relation to the health and safety file.

Apart from designers, CDM Regulations specify duties for other parties involved in construction projects. Although some of the duty holders might not be involved directly in the design process, under the Regulations they have duties to provide information to designers and support them in carrying out their duties in the best manner. Table 3.4 summarises the duties of different main parties under CDM 2007 and highlights the design related duties of those parties.

Table 3.4: Summary of duties under CDM 2007 (HSC, 2007)

	All construction projects (Part 2 of the Regulations)	Additional duties for notifiable projects (Part 3 of the Regulations)
Clients (excluding domestic clients)	<ul style="list-style-type: none"> • Check competence and resources of all appointees • Ensure there are suitable management arrangements for the project including welfare facilities • Allow sufficient time and resources for all stages • Provide pre-construction information to designers and contractors 	<ul style="list-style-type: none"> • Appoint CDM Coordinator* • Appoint Principal Contractor* • Make sure that the construction phase does not start unless there are suitable: <ul style="list-style-type: none"> ○ welfare facilities, and ○ construction phase plan in place • Provide information relating to the Health and Safety File to the CDM Coordinator • Retain and provide access to the Health and Safety File <p>(*There must be a CDM Coordinator and Principal Contractor until the end of the construction phase.)</p>
CDM Coordinators		<ul style="list-style-type: none"> • Advise and assist the client with their duties • Notify HSE • Coordinate health and safety aspects of design work and cooperate with others involved with the project • Facilitate good communication between Client, Designers and Contractors • Liaise with Principal Contractor regarding ongoing design • Identify, collect and pass on pre-construction information • Prepare/update Health and Safety File
Designers	<ul style="list-style-type: none"> • Check Client is aware of their duties • Eliminate hazards and reduce risks during design • Provide information about remaining risks 	<ul style="list-style-type: none"> • Check CDM Coordinator has been appointed • Provide any information needed for the Health and Safety File

	All construction projects (Part 2 of the Regulations)	Additional duties for notifiable projects (Part 3 of the Regulations)
Principal Contractors		<ul style="list-style-type: none"> • Plan, manage and monitor construction phase in liaison with Contractor • Prepare, develop and implement a written health and safety plan and site rules, with initial plan completed before the construction phase begins • Give Contractors relevant parts of the health and safety plan • Make sure suitable welfare facilities are provided from the start of construction and maintained throughout the construction phase • Check competence of all appointees • Ensure all workers have site inductions and any further information and training needed for the work • Consult with the workers • Liaise with CDM Coordinator regarding ongoing design • Secure the site
Contractors	<ul style="list-style-type: none"> • Check client is aware of their duties • Plan, manage and monitor own work and that of workers • Check competence of all their appointees and workers • Train own employees • Provide information to their workers • Comply with the specific requirements in Part 4 of the Regulations – Duties Relating to Health and Safety on Construction Sites • Ensure there are adequate welfare facilities for their workers 	<ul style="list-style-type: none"> • Check a CDM Coordinator and a Principal Contractor have been appointed and HSE notified before starting work • Cooperate with Principal Contractor in planning and managing work, including reasonable directions and site rules • Provide details to the Principal Contractor of any Contractor engaged in connection with carrying out the work • Provide any information needed for the Health and Safety File • Inform Principal Contractor of problems with the health and safety plan • Inform Principal Contractor of reportable accidents, diseases and dangerous occurrences

Implementing the CDM Regulations

CDM Regulations have been in force for some 20 years, since 1994. Yet research within the UK construction industry (HSE, 2007a; HSE, 2007b; HSE, 2011; HSE, 2012a; Larsen & Whyte, 2013) has indicated that problems still exist. In 2006, before CDM Regulations were revised, a study (HSE, 2007b) was conducted to evaluate the views of construction stakeholders on the effectiveness of the Construction (Design and Management) Regulations 1994. The lack of clarity about the roles and responsibilities of different duty holders, including designers, was one of the main issues identified

which was believed to hinder the effectiveness of the legislation. This lack of clarity led to the Regulations being interpreted differently by different duty holders. At the same time, key duty holders were unclear about the scope and extent of their responsibilities. Industry stakeholders interviewed in the study also commented that the CDM Regulations encouraged risk transfer and self-protection, rather than focusing on problem solving and cooperation. Lack of proper knowledge about who should be responsible for safety in design in complex project delivery structures was found to be a contributing factor to this problem. In the highly fragmented, technologically specialised and dynamic construction design environment, cooperation requires each contributor to the design of a building or structure to be mindful of the effect of their decisions on other interdependent design activities.

Problems inherent in the operation of the legislation were highlighted particularly in relation to cooperation between designers and contractors. The industry stakeholders thought that education programs undertaken by designers (in both formal academic education, and continued professional development) were inadequate in their treatment of H&S issues and CDM obligations (HSE, 2007b). Interviewees believed that designers needed to improve their ability to communicate H&S, particularly when residual risks could impact people 'downstream' of design (for example, constructors). Designers' abilities to address H&S across the entire lifecycle of the building or structure were also questioned. CDM Regulations were also criticised by industry stakeholders for creating excessive paperwork and bureaucracy. Participants believed that the need to create a large volume of documentation threatened the cost-effectiveness of implementing the Regulations. The costs associated with implementing the CDM Regulations have been raised in other critical reviews of the effectiveness of CDM (HSE, 2007a).

In 2007, the CDM Regulations were revised with the aims of improving clarity and flexibility, minimising bureaucracy, improving coordination and cooperation (particularly between designers and contractors), and simplifying the assessment of competence (HSE, 2012a). In 2010, an evaluation of CDM 2007 was undertaken. The results suggested general improvements in stakeholders' opinions about construction design (HSE, 2012a). However, respondents still highlighted concerns about interpretation and implementation of the Regulations in the industry. It was stated that some organisations overstepped their roles and provided 'design' input without assuming design responsibilities. Stakeholders' perceptions were that designers still did not address H&S issues pertaining to the entire lifecycle of a building or structure, believing that regulations make them mainly responsible for construction risks. Even when designers acted on this responsibility, they were still unclear about the interpretation of 'so far as is reasonably practicable' (HSE, 2012a).

Nevertheless, the study suggested that interviewees perceived improvements in designers' work on addressing construction hazards like falls, manual handling, and health hazards from substances, noise and vibration (HSE, 2012a).

Interpretation of the Regulations was highlighted in a more recent study by Larsen and Whyte (2013) in which interviewees suggested that different stakeholders held varied interpretations. They claimed that the CDM Regulations were not being enacted in the manner intended. The authors concluded that the CDM Regulations have too much room for interpretation, making it easy for the designers to focus too much on design aspects other than safety (for example, aesthetic aspects). This issue was identified in relation to CDM 1994 in a previous study (HSE, 2007a) in which construction industry interviewees pointed out that substantial differences existed in implementing and interpreting CDM 1994. Despite revisions intended to improve their efficiency, the understanding and enactment of the roles outlined in the CDM Regulations remain inadequate (Larsen & Whyte, 2013). This could indicate incompatibility between the regulations and the structure of the UK construction industry.

An aim in revising the Regulations was to simplify the process for assessing competence. However, interviewees suggested that using commercial competence assessment schemes was time consuming and costly. Respondents agreed with the concept of competence assessment, yet felt that completing multiple competence assessments imposed a considerable burden. As these requirements were imposed by those procuring work, organisations had little choice but to register if they wanted to bid for that work (HSE, 2012a). In addition, these schemes may not be effective in assessing an individual's competence. An Institution of Civil Engineers (ICE) (2011) report highlighted this specifically in the case of CDM Coordinators. The ICE report suggests that the current regulations and industry guidelines fail to clearly define Coordinator competencies. It seems that assessment is limited in these documents to touch screen tests, certificates and professional memberships. However, qualifications, certificates, and membership of learned bodies do not necessarily reflect an individual's competence: knowledge of the design and construction process, knowledge of risk management, and the ability to communicate and influence are also important (ICE, 2011).

The new CDM Coordinator role has been questioned by some industry participants (HSE, 2012a) who stated that often Coordinators are not appointed early enough in projects, and are usually informed about the design decisions after the work has been undertaken. Under CDM 2007, Designers and Contractors are responsible for checking that the CDM Coordinator has been appointed before the start of their work. However, interviewees observed that in the poor economic climate at the time of the study, Designers and Contractors were not always willing to challenge a Client's demand to start the work even without the appointment of a Coordinator. Interviewees in the HSE study (2012a) considered it would be more effective if the Coordinator's role was undertaken by:

- a lead designer. Given that there is a lead designer on many projects, it was suggested that they could fulfil the design coordination role.
- a Project Supervisor through the life of a project. The Project Supervisor would be the team leader to whom Clients have already given extensive powers regarding design, budget and timing.
- a team which could provide more effective coordination for larger projects, particularly where the competences required may be beyond the capacity of any one person to perform.

Industry stakeholders often cite additional costs as an issue associated with CDM regulations. A study conducted in 2010 on behalf of HSE (2011) evaluated the costs associated with CDM 2007. Participants from the UK construction industry were asked to report the costs they incurred in 2009 for introducing and maintaining CDM 2007 in their organisations. In total, 46 responses were received from the UK construction industry. HSE (2011) reports the following results for the survey.

Costs of introducing CDM 2007 in organisations for the first time	
<i>Employing health and safety staff/advisors</i>	A third of respondents (15) reported negligible costs. However, nine respondents reported spending £10,000 or more, and of these four were Principal Contractors.
<i>Preparing health and safety management systems</i>	More than half of the respondents (26) spent less than £5,000. However, five respondents reported spending £10,000 or more, and of these three were Principal Contractors and two were Contractors.
<i>Health and safety training</i>	More than half of the respondents (27) spent less than £5,000. However, eight respondents reported spending £10,000 or more, and of these two were Coordinators, two were Designers, two were Principal Contractors and two were Contractors.

Costs of maintaining CDM 2007

<i>Employing health and safety staff/advisors</i>	A third of the respondents (14) reported negligible costs. However, ten respondents reported spending £10,000 or more, and of these four were Principal Contractors.
<i>Health and safety management systems</i>	More than half of the respondents (27) spent less than £5,000. However, five respondents reported spending £10,000 or more, and of these three were Principal Contractors and two were Contractors.
<i>Health and safety training</i>	More than half of the respondents (25) spent less than £5,000. However, five respondents reported spending £10,000 or more, and of these two were Principal Contractors.

In general, respondents' views about CDM 2007 were positive. The H&S benefits were seen as moderate, and the costs were viewed as moderate or low (HSE, 2011)

In 2012, a study was funded by HSE and the Institution of Civil Engineers (ICE) to review CDM 2007 implementation during the construction of venues for the London 2012 Olympic Games and Paralympic Games (HSE, 2012b). Generally, the results suggested successful CDM 2007 implementation, which in turn contributed to benefits to H&S, and to business. However, establishing direct links was not possible since many of the benefits could be also gained from using best practices.

As the report comments:

CDM 2007 has been implemented with additions on London 2012 and although the approach was driven by regulatory requirements, it would have probably been undertaken in a similar way as part of good construction practice ... CDM 2007 did give a common framework and a backup if necessary (HSE, 2012b, p. 8).

In fact, from the early stages of the construction program, the client (the Olympic Delivery Authority) stated that H&S was the first priority and reinforced the message during construction. The client was also influential in developing a CDM 2007 strategy which went beyond the basic requirements of CDM 2007 (HSE, 2012b).

The HSE study also suggests that through early appointment of CDM Coordinators and Contractors, it was possible to identify risks early and to learn from the experiences of Contractors and Designers to improve buildability, address technical issues, reduce cost and time, and improve H&S using an integrated risk management approach (HSE, 2012b). While the early appointment of Contractors and CDM Coordinators was important, the study shows that coordination and cooperation was achieved through collocation, the Designers' willingness to work with the best Contractors to get the most out of their designs, and the NEC 3 contract (New Engineering Contract) which facilitated the sharing of financial risks. This type of contract is developed for procuring a diverse range of works, services and supply. The out-turn financial risks are shared between the client and the contractor in an agreed portion (HSE, 2012b). At the same time, given the size and complexity of the London 2012 construction work, several CDM Coordinators were appointed from a number of organisations, and a CDM Integrator was appointed to manage the CDM Coordinators. The CDM Integrator's role provided a common approach that produced a uniformly high standard of CDM coordination (HSE, 2012b).

So far as minimising bureaucracy – a stated aim of revising the CDM Regulations – the study suggests the London Olympics projects reduced the paperwork burden in some areas, using generic risk assessments. The streamlined pre-qualification process also resulted in less competency-related paperwork (HSE, 2012b).

The London 2012 case highlights that, at project level, if CDM 2007 is implemented correctly, it should not be a burden on, or an impediment to, efficient management of construction. However, CDM 2007 needs to be:

- implemented in such a way as to focus on achieving genuine H&S improvements rather than focusing primarily on the creation of an overly bureaucratic paper-based system
- embedded in projects from the start, and
- associated with quality management to ensure that it is aligned with business practices (HSE, 2012b).

Nevertheless, at industry level, UK construction industry views on the effectiveness of CDM suggest that almost 20 years after their introduction, challenges remain in securing acceptance of the CDM Regulations from the relevant stakeholders. Larsen and Whyte's (2013) analysis of recent interviews with stakeholders in the UK construction industry suggested that CDM Regulations are not enacted completely in practice and mostly exist on paper. Larsen and Whyte (2013, p.687) comment that:

... the CDM Regulations were designed, in part, to ensure safety provision becomes a more integral part of the design and construction process by bringing stakeholders closer together. However, based on the research findings, safety is still very much seen as an afterthought or bolt-on to the design, rather than an integral part of the process. The relevance and power of the CDM Regulations as a change agent are seriously limited. Until there is a paradigm shift regarding safety during the design process, accidents influenced by poor design will continue within the UK construction sector.

The challenges experienced in implementing CDM Regulations in the UK highlight the need to change the mindset of industry participants about their health and safety responsibilities. A whole-of-industry effort is needed to make safety in design legislation work. Project teams that embrace safety in design seek to integrate and align the efforts of different parties to achieve collective positive outcomes in relation to reduced H&S risks through the lifecycle of a building or structure. However, the success or otherwise of legislative approaches is likely to depend on the industry's readiness to adopt more cooperative and integrated ways of working. Cooke et al. (2009) state that:

The UK experience has demonstrated that the inclusion of design safety requirements in OH&S legislation does not automatically deliver reductions in H&S risk in the building and construction industry. Given the lessons from the UK, the achievement of 'safer' design in the Australian construction industry is likely to depend upon the readiness of construction design professionals to accept responsibility for H&S and proactively work to integrate OH&S risk management into the construction design process (Cooke et al., 2009, p.103).

3.4 Voluntary Approaches

The Guide to Best Practice for Safer Construction

The relatively poor safety performance of the Australian construction industry concerned industry participants, prompting senior representatives of each of the key stakeholders groups – clients, designers and constructors – to embark on a collaborative project to improve the industry's safety performance. Engineers Australia commissioned the 'Safer Construction' project, which was funded by the Cooperative Research Centre for Construction Innovation.

The *Guide to Best Practice for Safer Construction* emerged from the project. The *Guide* is an industry-endorsed set of voluntary guidelines for Australia. The *Guide* was developed in consultation with Engineers Australia, the Association of Consulting Engineers Australia, and the Australian Institute of Architects (Godfrey & Lingard, 2007). Promoting construction H&S in design is a key principle underpinning the *Guide*, which defines H&S best practices for construction industry stakeholders, including designers, throughout the lifecycle of a construction project (Fleming et al., 2007a, 2007b).

A high level industry taskforce was established to oversee the development of the *Guide to Best Practice for Safer Construction*. The taskforce comprised senior representatives of major industry stakeholder groups, industry peak bodies and professional institutions. It was representative of construction clients, the design professions, constructors, and government and policy makers. Represented were:

- Engineers Australia
- Property Council of Australia
- Australian Procurement and Construction Council
- Association of Consulting Architects Australia
- Association of Consulting Engineers Australia
- Australian Institute of Architects
- Australian Constructors Association, and
- Master Builders Association.

A representative of the Office of the Federal Safety Commissioner also contributed to the Safer Construction taskforce.

The Safer Construction project brought together the perspectives of each of these parties through their respective professional/industry associations. The project provided the basis for moving away from a reactive industry culture of blaming other parties for H&S problems. It provided a platform on which to move to a proactive culture of establishing (on a project-by-project basis) an appropriate allocation of responsibility for H&S during the planning, design, construction and commissioning stages of project delivery. The objective was to identify additional measures clients and designers could take prior to commencing construction work that would contribute to H&S during the construction stage. The purpose was not to reduce the responsibility of the Constructor for the H&S of the workers and contractors they employ.

The Safer Construction Framework

The *Guide* comprises a number of documents, tools and checklists. At the heart of the *Guide* is an 'Implementation Table', specifying safety practices to be undertaken at four lifecycle stages of a construction project – Planning, Design, Construction, and Post-construction.

The *Guide* also establishes six broad principles for managing H&S within the construction industry. The 'Safer Construction' principles are as follows.

Principle 1	Demonstrate Safety Leadership
Principle 2	Promote Design for Safety
Principle 3	Communicate Safety Information
Principle 4	Manage Safety Risk
Principle 5	Continuously Improve Safety Performance
Principle 6	Entrench Safety Practices

Principle 2 particularly focuses on Safety in Design. Under Principle 2, the *Guide* states:

Effective safety management at the design stage can minimise risks to the health and safety of people who subsequently construct, occupy and maintain a facility/structure. Consequently, the client should ensure that a designer is engaged who has a demonstrated understanding and awareness of safety risk management or other suitable credentials of safety in design, appropriate to the risks of the project. Often during the design stage, a number of organisations or individuals contribute to the final design, with their contributions being coordinated by a prime design manager — usually a principal designer acting for the client (the designer), or the client itself. In such cases, all organisations and individuals should participate in appropriate risk assessments and safety management decisions appropriate to their sphere of control. Comprehensive and systematic design safety reviews should be conducted at appropriate intervals during the design process. These reviews should be based on appropriate risk management methods. Design safety reviews should be collaborative in nature where possible. Safety risks arising as a result of the design should be eliminated wherever possible or practicable. Where elimination is not possible, efforts to reduce safety risk through design modification should be made. Residual risk, i.e. the identified risks remaining following the design safety risk management process, should be documented and clearly communicated to relevant stakeholders — including the client, the constructor, and the owner/occupier — where they would not, or may not, be readily apparent to ‘downstream’ stakeholders in their own risk assessment (Fleming et al., 2007a, p. 4).

The *Guide* establishes 62 ‘Best Practice’ tasks which should be carried out during four key stages in the life of a construction project. Each task is documented using a standard layout that is intended to provide the user with a concise tool for implementation, monitoring and review. The layout features are set down below.

Best practice	The identifying name of the best practice
Description	A short description of the best practice
Key benefits	The key benefits to be achieved by implementing the best practice
Desirable outcome	The behavioural and procedural changes effected by the implementation of the best practice
Performance measure	Any output measures that can be recorded for the best practice
Leadership	Which party would typically take responsibility for this best practice and who needs to be consulted/involved

Design stage tasks

In the Design Stage, the *Guide* suggests 14 tasks be performed. Two of these tasks are particularly important to designers.

Task 2.7	Conduct design reviews to eliminate/reduce risks at concept/detail design stages
Task 2.8	Consider constructability in design safety reviews

The *Guide* suggests that the designer should take a leadership role on both of these tasks. Below is an explanation of what the *Guide* suggests these tasks entail.

Safer construction task 2.7 – Conduct design safety reviews

During the Design Stage, planning concepts and the preferred technical solution for a facility/structure are converted into the drawings and technical specifications necessary for construction.

The *Guide* suggests that designs should be reviewed collaboratively at both concept and detailed design phases, to enable identification of hazards associated with the design, and to allow an assessment to be made of the risk posed by design related hazards. The *Guide* states:

Design safety reviews should consider [occupational health and] safety in the construction and commissioning (along with the operation and maintenance) of the project facility/structure. Wherever it is possible, design safety reviews should allow contribution from the people who will actually construct the facility/structure. If constructor input is not possible, then efforts should be made, by the client and designer, to include people with relevant knowledge and experience in the construction and commissioning processes in the design reviews. The experience and expertise of these persons will help to identify any safety issues which may have been overlooked in the design (Fleming et al., 2007b, p.20).

Design safety reviews should follow a systematic approach to safety risk management. This can be achieved by:

1. identifying potential and known hazards
2. assessing the level of risk associated with those hazards
3. evaluating the level of risk against pre-established levels of tolerance, and
4. where practicable, selecting measures to eliminate or reduce risks through design modifications.

It is essential that any residual risk remaining after the above process is recorded (in a project risk register) and communicated to the relevant downstream parties, including constructors, users, occupants and maintenance personnel.

There are four key benefits associated with the conduct of design H&S reviews. These are:

1. H&S risks inherent in a design are systematically assessed
2. where practicable, H&S risks are eliminated through design modification
3. design decision making is based on a robust assessment of H&S risks, and
4. any residual risk, that could not be eliminated or further reduced through design can be recorded and communicated to downstream parties.

The stated outcome is that H&S risks arising from the design of a facility/structure are minimised.

Safer construction task 2.8 – Constructability in design reviews

H&S considerations are linked closely with the concept of constructability – the process of design and detailing that takes account of the problems likely to be encountered in construction to achieve the desired result, safely and at least cost to the client. The *Guide* suggests that the client and the designer should, as far as reasonable, take account of the proposed construction and maintenance methods and practices to ensure that they do not present inherent risks.

The *Guide* suggests that factors to consider in constructability reviews include (but are not limited to):

1. Using prefabricated elements which can be made under safer factory conditions and which reduce construction times and therefore limit exposure to risk
2. Selecting durable and non-hazardous materials as built-in features in the design to assist in operating maintenance equipment
3. Specifying sufficient tolerances and features to aid safe alignment and initial connection of structural elements
4. Standardising details as much as possible
5. Providing adequate ventilation in confined spaces
6. Designing ready access for maintenance of services
7. Safety during the demolition of the facility/structure
8. Clear identification in the design of staged construction when the permanent facility/structure becomes self-supporting — and the criteria to be met to achieve this state
9. Proximity to traffic
10. Site access and storage areas
11. Clearances for construction and maintenance equipment, and
12. Emergency evacuation arrangements (Fleming et al., 2007b, p.21).

The benefits of considering safety in design in constructability reviews include:

1. Planned sequence of work
2. Coordination between key disciplines
3. Simplicity
4. Reduced defects and errors
5. Increased speed of construction
6. Improved management techniques
7. Improved 'maintainability'
8. Strong and open communication channels
9. Awareness of the construction environment with regard to safety and industrial relations, and
10. A better understanding of the design by the client, designer, builder and end user.

Good design for constructability and safety should consider:

1. Thoroughness of design and investigation
2. Practical sequences of operation
3. Planning for simplicity of assembly and sequence
4. Maximising repetition and standardisation
5. Detailing for practically achievable tolerances
6. Specifying robust and appropriate materials, and
7. Reviewing past practices and incorporating lessons learned into future design.

Industry efforts to implement Safety in Design

There are examples of the construction industry's attempts to develop and implement safety in design processes. In Florida, US, a design-build firm has developed a safety in design program with an entire lifecycle approach. The program involves three major elements:

1. Requires designers to participate in an 'intense but modified' 10-hour US Occupational Safety and Health Administration safety course which is typically required for construction workers.
2. Includes eight different warning symbols for project plans to alert the constructors of potential hazards that could result in accidents such as electrocution, asphyxiation, falls
3. Uses safety-oriented design checklists for each project to help identify potential hazards and propose design modifications (Angelo, 2004).

In London, an international design firm has involved safety in all its planning and design activities (Istephan, 2004). The firm has tried to put into practice the Construction (Design and Management) Regulations alongside the company's own design philosophy. The company has developed a program which involves several elements: training, design reviews, integrating health and safety with quality assurance and other processes, producing and transferring information, and feedback on lessons learned. Conducting planned design reviews, which start early in projects, is a critical aspect of the firm's program (Gambatese et al., 2005a).

In the US, a large high-tech firm has developed a 'Lifecycle Safety' (LCS) process for designing and constructing a new semiconductor manufacturing facility in the Pacific Northwest (Hecker et al., 2005). Underlying the program was an emphasis on safety in design as one goal for the new facility, along with traditional goals such as cost, energy consumption, emissions, and schedule (Hecker & Gambatese, 2003). The LCS process included some important features:

1. Before the start of the project, the design firm involved in designing other facilities for the owner was appointed to undertake the basic and detailed design of the facility. The firm developed a 101-item safety in design checklist. The checklist was based on lessons learned from earlier projects. These items consisted of design issues identified as potential problem areas for constructing and/or operating the facility. The checklist was developed as an interactive and open-ended tool for designers (Weinstein et al., 2005).
2. A Safety in Design taskforce was formed early in the programming phase. It was responsible for planning and developing a process that increased the focus in the design stage on safety issues in construction and subsequent phases. It was also responsible for balancing cost, quality, schedule, and safety (Hecker et al., 2005). Taskforce members included senior representatives of the three main parties involved in the design process: the owner (representatives from different departments of the company), the design firm, and the contractor serving as construction manager (CM), along with an outside safety consultant who facilitated the process. Involving the CM was important for bringing the knowledge and experience of the construction community into the process early in the project (Hecker & Gambatese, 2003).
3. The taskforce developed a plan of record (POR), or baseline design (based on the last fab built on the campus), and the process and tools required for evaluating design options during the programming phase.

4. During the programming phase, focus groups were organised involving trade contractors and vendor tool technicians (who had worked on previous projects at the campus), the designer, and the owner. The purpose of the focus groups was to identify modifications to the POR that would improve the safety of those who construct, operate and maintain the facility. The focus groups prepared a database of 196 items, with issues and suggested design solutions identified. These data were sent to the workgroups who participated in the programming phase of the new fab design (Hecker & Gambatese, 2003).
5. Focused safety reviews of each design package were conducted by the owner, CM, trade contractor, and environmental safety and health personnel, at approximately the 30%, 60%, and 90% completion points in the design (Hecker et al., 2005).
6. Comments collected during the design reviews were passed on to the design team for adjudication, after review and filtering by appropriate discipline based owner representatives. The comments could be:
 - accepted 'as is' or in modified form
 - rejected for a variety of reasons, or
 - referred for mitigation during the construction phase if they raised legitimate safety concerns but were more appropriately addressed in construction than through design (Hecker & Gambatese, 2003).

Studies of the LCS process implementation and outcomes (Hecker & Gambatese, 2003; Hecker et al., 2005; Weinstein et al., 2005) indicated that:

- The process was successful in eliminating or mitigating significant safety hazards during construction (Weinstein et al., 2005).
- During the process, trade contractors were involved during the programming and detailed design phases. This was particularly effective due to their unique insights into construction safety hazards. Weinstein et al. (2005) found that the programming stage was critical for implementing trade contractors' suggestions for safety-enhancing design changes. 85% of the design changes suggested by trade contractors during project programming activities were eventually implemented – only 39% of the suggestions made at a later stage by trade contractors were implemented. Based on the results, the researchers concluded that there is a higher likelihood for design changes to be implemented if noted early by trade contractors. This highlights the value of considering construction knowledge in the safety in design process (Weinstein et al., 2005).
- The process increased the extent of cross-disciplinary discussion. The cross-disciplinary design review process generated ideas and concerns that might not have emerged otherwise. The detailed design reviews were a distinctive and integral part of the LCS process and provided a mechanism for various groups involved in the construction phase to address safety over the lifecycle of the facility (Hecker & Gambatese, 2003).
- The early consideration of suggested design modifications greatly impacted their implementation. Weinstein et al. (2005) found that 71% of the design changes noted in programming stage were implemented, while only 44% of the changes raised later in the project were implemented. The researchers identified reasons for this, including:
 - high capital costs associated with implementing the change later in the design
 - a lack of information regarding the impact on worker safety and health, and
 - schedule constraints, specifically the particular market forces associated with rapid obsolescence in the semiconductor industry driving the completion of the project as early as possible without any delays.

3.5 Tools to support the implementation of safety in design

A number of tools have been developed to assist in identifying and addressing safety issues during project planning and design phases. The most relevant tools include:

- knowledge based decision support tools to provide designers with 'expert' H&S knowledge when reviewing their designs (Gambatese et al., 1997; Davison, 2003; Cooke et al., 2008)
- visualisation tools to identify H&S hazards associated with the design of building components and the process of construction (Hadikusumo & Rowlinson, 2004)
- multidimensional Building Information Modelling (BIM) tools to incorporate H&S considerations into construction design and planning (Toole & Gambatese, 2008; Sulankivi et al., 2013; Kamardeen, 2010), and
- frameworks/processes for systematic evaluation of safety issues at different phases of a project (Workcover NSW, 2001).

Knowledge Based Tools

Design for Construction Safety Toolbox

Some knowledge based tools have been further incorporated into software applications. For example, the Design for Construction Safety Toolbox developed by the Construction Industry Institute, Austin, Texas (1995) uses a database of more than 400 design for safety suggestions to assist designers to recognise project specific hazards and to implement the design suggestions into project designs (Gambatese et al., 1997; Gambatese & Hinze, 1999). The application requires selecting a design package. The software then helps reduce/remove safety hazards by providing suggestions on common hazards associated with the selected design package.

To develop the database, the researchers searched for existing design suggestions from two sources: construction industry literature, and personnel. In addition to the search for existing best practices, the study included developing additional design suggestions from three sources: worker safety manuals, safety design manuals and checklists, and the research team's personal knowledge and experience. The researchers concluded that the design tool is useful for improving safety in the construction, start up, maintenance and decommissioning phases (Gambatese & Hinze, 1999).

The software assists designers to learn about construction site hazards (something they are often not exposed to, nor have knowledge of), and provides alternative approaches that improve their design for safety knowledge. However, Clark (2010) contends that the tool does not provide genuine practical insights into how to reduce H&S risk in the complex and dynamic construction design environment. He argues that the tool is static. The generic 'checklist' approach encouraged by the tool reinforces designers' reluctance to think creatively about better ways to reduce H&S risk. Requirements imposed by clients to use tools of this nature would, Clark suggests, eventually burden designers and stifle innovation.

In the UK, similar criticisms have been levelled at safe design 'solutions' checklists (HSE 2007b). Further, these generic checklists are unlikely to apply to the majority of specialist designers whose focus is on a very small (and often very technical) component of a complex building or structure.

At the same time, the static and generic nature of suggestion lists restricts the applicability of these tools. As design progresses and more detailed information is generated, this information becomes more project specific. Thus, generic solutions may be difficult to apply. Bespoke and more creative approaches to risk reduction are needed.

Knowledge based decision support tools

Knowledge based systems (KBSs) seek to replicate, by computer, the problem solving expertise of human specialists in a specific area of application. KBSs are ideally suited to providing H&S decision support because designers may not have specialist H&S knowledge, yet make decisions that impact on H&S. Deploying through software H&S expertise that would otherwise be unavailable to decision makers can be of considerable benefit in managing H&S (Roberston & Fox, 2000). Given concerns about the level of H&S experience and expertise among construction design professionals (architects and engineers), providing H&S decision support via a knowledge based system has the potential to improve designers' ability to integrate H&S into design decisions, and to assist them to comply with legislative requirements for H&S in construction design.

In Singapore, knowledge based systems have been used to deploy artificial intelligence techniques for the automated assessment of building plans against building regulations. Building elements are represented using the International Alliance for Interoperability's (IAI) industry foundation classes (IFC). The knowledge base represents Singapore's building regulations, including rules applicable to each building entity and its properties. During an automated plan checking session, rules associated with each building entity are examined to identify breaches of the building regulations. In the UK, Davison (2003) reported on a prototype KBS that used similar technology to provide knowledge based advice on H&S in building design. Elements were encoded as IFC's, but rather than apply building regulation rules, H&S rules were applied to identify risks inherent in the design of each building entity.

However, the effectiveness of rule based KBSs for determining compliance with H&S legislation is likely to be limited. H&S legislation is not prescriptive. It requires duty holders to make professional judgments about what H&S controls are reasonably practicable to implement in a given situation. Safety in design requires professionals with responsibility for design of buildings and structures to conduct a thorough risk assessment of the components of the facilities they design, and to attempt so far as is practicable to modify the design to reduce H&S risk. Consequently, a knowledge based system that steps designers through the analysis of H&S risk is likely to be much more helpful than a prescriptive rule based system (Cooke et al., 2008).

ToolSheDTM

An alternative approach to capturing and representing H&S information for the purposes of facilitating safety in design was developed in Australia by a consortium comprising RMIT University's School of Property, Construction and Project Management, and two private companies. The consortium developed a prototype web tool to help architects and engineers make design decisions that take account of H&S.

The resulting knowledge based system incorporated the expert safety in design knowledge of construction H&S professionals, facilities managers, maintenance workers, and construction personnel. This knowledge was captured, structured, and made available to design professionals to inform their H&S risk assessment and risk reduction decisions.

The one year project was funded jointly by the Information Technology Online (ITOL) Program (through the former Department of Communications, Information Technology and the Arts). The prototype, known as ToolSheD (Tool for Safety and Health in Design), is briefly described below.

ToolSHeD is a knowledge based tool that assists construction designers to integrate H&S risk management into their design decision making by stepping them through an online risk assessment consultation. As a knowledge based system, ToolSHeD reproduces the reasoning used by a panel of experts to assess the H&S risk associated with relevant features of a building design.

At present, a web based prototype of ToolSHeD has been developed with its scope restricted to the risk of falling from the roof of a building during maintenance. The reason for this scope focus is that fall hazards are the Australian building industry's most frequent cause of accidental death and the second largest cause of non-fatal injuries. Recent research in Hong Kong revealed that nearly one third of accidents in the construction industry occurred during maintenance and repair works (Yam, 2006). An analysis of construction fatalities over five years in the UK showed that 34-50% of construction fatalities occurred during maintenance, and of these the largest proportion involved falling through or from a roof (HSE, 1988).

To capture expert reasoning regarding design impacts on H&S risk, an expert panel (including designers, facilities managers, engineers, building surveyors, and H&S specialists) ascertained the design factors that contributed to the risk of falling from height during maintenance work. A number of secondary data sources were also consulted, including H&S guidance material, industry standards, and codes. This knowledge was then structured in the form of 'argument trees', and refined by panel members in an iterative process until consensus was reached.

Argument trees represent a template for reasoning in complex situations. They provide a practical way of representing knowledge when the outcome being considered is subjective and interrelated with other issues that need to be considered simultaneously, such as design H&S. ToolSHeD's argument trees represent the hierarchy of factors relevant to assessing design related H&S risks. Consistent with risk management principles, the risk rating is inferred with knowledge of three factors:

- the likelihood that an injury or illness will occur
- the likely severity of the consequence of that injury or illness should it occur, and
- the degree of exposure to the risk.

The risk assessment prompts designers to enter information about relevant design features that experts agree could impact upon the risk of falling from height. The data entered are then used to infer a risk rating based on a reasoning model agreed by a panel of experts. A risk report is generated as a system output, advising the designer about the level of risk of falling from height (extreme, high, medium, or low) and explaining the design factors contributing to this inferred level of risk.

When a full risk assessment is not required, but the designer would like to assess certain aspects of a design, ToolSHeD allows the user to select single design elements for review by using 'a quick hazard assessment'. For example, if a designer would like to review only the safety issues relating to the type of roof access, then the tool can review that single element while cautioning the user that this quick assessment should be understood in the context of the whole design. Unlike a safety risk assessment, following which the user can determine whether the design presents itself as an acceptable risk or not, a quick hazard assessment only provides the user with an indication of the influence that a selected hazard will have in determining the outcome of a full risk assessment.

ToolSHeD recognises that not all risks can be eliminated at the design stage, given that some decisions impacting upon H&S risk may be made beyond the scope of the designer's influence. For example, local statutory authorities may require a minimum 18 degree pitch roof. This would have an impact on the safety of persons needing to access the roof for maintenance and would require a

designer to consider alternative ways in which the risk of falling could be reduced (for example, by specifying safe access to the roof and suitable walkways). ToolSHeD recognises that some design decisions are beyond the designer's control. It provides free text boxes for all design decision points, permitting designers to enter notes, recording the rationale for the decisions they make at each decision point, and providing a 'decision history' of the design. This information can be printed as required as a report, retained for records, and/or provided to a client or other stakeholders.

The tool also recognises that not all building designs will present the same hazards. To overcome this, the user is required to confirm certain design inclusions prior to undertaking a full risk assessment. For example, if the proposed design does not incorporate fall arrest equipment, then the user could indicate this at the outset, excluding the evaluation of design issues relevant to fall arrest equipment from the risk assessment. However, hazards applicable to all designs (such as roof access, or slips and trips), are hard-coded and the relevant prompts must be answered to complete a full risk assessment for the design. This ensures that the designer is prompted to consider all the relevant factors during each risk assessment.

After completing a full risk assessment, ToolSHeD provides the user with a printable report which includes an overall risk rating, and maps the decisions and comments made throughout the assessment. The report provides the user with enough information to make an informed decision about whether H&S risk has been reduced 'so far as reasonably practicable'. If an overall risk rating is above the designer's pre-determined tolerance level, the designer can identify 'high risk' design features that gave rise to that risk rating. These features can then be reviewed and modified to reduce the level of risk, and/or more robust protection systems can be included (for example, suitable safe walkways). Changes made can be recorded in the ToolSHeD prototype, permitting a designer to:

- keep full records of their risk mitigation decisions
- document the design decision making process, and
- communicate relevant information to clients, maintenance contractors and other relevant stakeholders as appropriate.

The majority of design professionals are unsure about how to incorporate H&S considerations into their design decision making, and they are concerned that doing so may expose them to greater legal risk. The ToolSHeD decision support tool addresses the need to consider H&S in construction design. Its development is timely as it offers easy-to-access, expert H&S information and decision support in an area in which learning from one's mistakes is undesirable. The method deployed in ToolSHeD for modelling design H&S knowledge also overcomes problems inherent in rule based alternatives. Argument trees make the system more adaptable and efficient because they can accommodate situations of complexity uncertainty, and discretionary decision making. They are an improved method for modelling H&S, risk management, and regulatory compliance knowledge. ToolSHeD is likely to be more viable than cumbersome rule based systems. However, ToolSHeD is limited at present as it deals only with the design related risks of falls from heights during maintenance work on building roofs.

Knowledge Based Energy Damage Model

Building on ToolSHeD and expanding its application, researchers at RMIT University are developing a knowledge based model for evaluating H&S risks designed into the construction process (Abas et al., 2011, 2013). The model combines 'argumentation theory' and an 'energy damage model'. Like ToolSHeD, the new knowledge based model uses argument trees to represent expert reasoning in the process of H&S risk assessment. The argument trees deployed are supported by Viner's (1991) knowledge based energy damage model which assesses H&S risks in the design construction process (Abas et al., 2011).

The energy damage model suggests that ‘when an unwanted and harmful energy source is transferred unexpectedly (in type, time, speed or force) to an unwilling or unwitting person, the problem may arise even though the energy itself is not dangerous’ (Viner, 1991). Therefore, identifying and controlling potentially harmful energy is necessary to eliminate or reduce the latent conditions (for example, an unsafe action in an unsafe workplace). The types of damaging energies (hazards) relevant to construction activities include: gravity; noise and vibration; chemical, electrical, mechanical, and thermal pressure; radiation; microbiological, biomechanical/body muscle, and psychosocial energies (Safetyline Institute, 2005). Identifying damaging energies early in the design process enables designers to consider proactive controls that eliminate or reduce the energies and their potentially harmful consequences (Abas et al., 2013).

The research has focused on H&S risks in Industrialised Building Systems and traditional projects for residential building construction. Case studies in Malaysia have involved interviews with project team members and document analysis. The case studies covered a wide range of construction processes and were used to collect data about the building envelope and volumetric units (Abas et al., 2013). Different construction processes were identified and analysed to identify associated risks. The information was then transferred into argument trees.

It is anticipated that the model could contribute to further developing ToolSHed by enabling it to assess H&S risks at construction stage. It is also expected that by integrating construction process knowledge into the design process, the model could improve designers’ capability to proactively eliminate or reduce construction hazards.

The current research is also exploring the potential benefits of argumentation based safety in design tools in two areas:

1. Improving designers’ safety in design capability and competence

KBS use is reported to increase users’ domain knowledge and to accelerate the development of expertise (Federowicz et al., 1992). Antony and Santhanam (2007) found that using a KBS results in ‘implicit’ learning (that is, learning that occurs unintentionally) (Berry & Dienes, 1993). Safety in design KBS could potentially improve safety in construction design, directly through its impact on the quality of design decision making, and indirectly through developing in users design H&S knowledge, skills and abilities.

2. Enhancing project team collaboration and communication

Stefik et al. (1987) suggest that making the structure of arguments explicit supports the development of consensus in a collaborative design environment by reducing uncommunicated differences between stakeholders. This is likely to be particularly important in the context of construction projects in which distinct professional and functional groups differ in their cognitive and emotional orientation towards H&S (Gherardi et al., 1998).

Visualisation tools

Design-for-Safety-Process Tool for Capturing Construction Safety Knowledge

A Design-for-Safety-Process tool was developed (Hadikusumo & Rowlinson, 2004) to reduce problems with capturing knowledge about construction site safety, and to help engineers identify construction hazards early in the project. The tool was designed for three purposes: knowledge capture, safety planning, and training. The tool creates 3D virtual real construction components. It simulates construction site inspections through enabling the user to move around the virtual site and observe different construction components. The tool is equipped with a safety database based on ‘construction components-possible safety hazards-accident precautions’ relationships. The tool contains different construction processes for each component. Each component is related to several safety hazards, and for each safety hazard several accident precautions can be identified

(Hadikusumo & Rowlinson, 2004). The tool incorporates a theory of accident causation and investigates safety hazards by applying the theory to a database of pre-identified unsafe acts and conditions (Zhou et al., 2012).

As a safety planning tool, the user moves the computer mouse to select any construction component. The tool then retrieves from the safety database, and lists, all the possible safety hazards relevant to the component. The user can choose any of the safety hazards and the tool will provide a list of possible accident precautions. The user can select preferred accident precautions and the information (including component name, component type, safety hazards identified, accident precaution, and time of installing the precaution) is used to create a safety plan.

As a knowledge capture tool, after selecting the construction components, users can add new hazards, based on their experience, to the list of pre-identified safety issues. Similarly, if other accident precautions are possible, users can add them to the list and they will be included in the final safety plan. This new knowledge can be stored permanently by adding it to the tool's safety database.

For training purposes, the tool can be used as a walk through in construction projects, supporting the study of possible safety hazards related to different construction components. The advantages of this tool include:

- overcoming problems inherent in capturing tacit knowledge
- providing a means of maintaining valuable safety knowledge in organisations, in an environment where learning from accidents is undesirable, and
- enhancing knowledge transfer from experts to others by combining knowledge based functions and Building Information Modelling (BIM) tools.

Multidimensional Building Information Modelling (BIM) tools

Several researchers (Augebroe & Hensen, 2004; Kamardeen, 2010; Sulankivi et al., 2013) have advocated applying multidimensional Building Information Modelling (BIM) in construction design and planning.

BIM has helped to integrate information from different construction project perspectives (for example, schedule, cost, sustainability), and to combine them with widely used 3D models of structures/buildings to facilitate easy retrieval and communication of information. Project planners and designers have used multidimensional models to analyse projects from different aspects, including clash control, cost analysis, sequencing construction activities, timing and resource analysis.

BIM-based multidimensional models have been used in construction site safety planning (Zhou et al., 2012). For example, research by Sulankivi et al. (2013) at VTT Technical Research Centre in Finland, applied a safety rule checking algorithm to 4D BIM models of permanent and temporary structures created with Tekla Structures. The prototype safety rule checking BIM tool checks structure models for falling hazards, and includes the application of engineering controls (such as guardrail installation) in the construction schedule and in the visual model. The research showed the possibilities for improving construction safety planning using commercially available BIM tools. The research indicated that BIM models created in the design process can be developed to serve site and safety planning by adding the planned temporary site and safety arrangements to the model. However, safety related custom components for the selected modelling software had to be developed in the project in cooperation with the contractor (Zhou et al., 2012)

Kamardeen (2010) proposed a framework for BIM based tools consisting of three components: a BIM model of the building/structure, a safety knowledge base encompassing hazard profiles of

building elements for different construction methods, and an analysis engine that automatically performs hazard checking on BIM models.

Similarly, Benjaoran et al. (2010) developed a rule based system for safety using 4D CAD models of buildings/structures. The system aimed to automate identification of working-at-height hazards. The input data consisted of factors related to building component details and activities (for example, component type, dimension, placement, working space, activity type, sequence, and materials and equipment). The system assessed the input data to identify working-at-height hazards, then used rule-based algorithms embedded and visualised in the 4D CAD model to suggest safety measures. Advantages of the system, according to Zhou et al. (2012), include:

- identifying working-at-height hazards based on progress of the construction work
- identifying different building components with the hazards that present a particular H&S hazard
- proposing safety measure advice
- integrating safety measures into the construction schedule
- assisting people to identify problems in the original design and schedule, and
- supporting control of safety measures.

However, using hard-coded, closed algorithms limits the ability of the system to make complex design decisions that need human creativity or knowledge (Zhou et al., 2012).

In their review of digital tools for construction safety, Zhou et al. (2012) concluded that while various digital BIM based tools have been developed for addressing safety issues in construction planning, BIM application for addressing construction safety issues at the design stage is much less mature. In fact, BIM has been used mainly at the design stage to identify construction clashes and buildability issues. One of the main reasons for this is probably the inability of BIM based approaches to cope with the design process, which is dynamic, complex, and reflexive, and in which design goals are subject to rapid change (Lingard et al., 2011). The process involves many iterations and refinements based on continuous information updates over time. At the same time, the client and other stakeholders continuously try to fine tune precisely what they want from the project (Larsen & Whyte, 2013). The result is continuous change and modifications in the design of both final product and the construction process. However, BIM based tools require static models of structures/buildings as an input for analysis. The notion of freezing the design is appealing. However, it is difficult, if not impossible, to achieve in reality (Larsen & Whyte, 2013). For BIM based tools to address design related safety issues effectively, the input models need to be updated continuously. This does not happen in reality. Even in construction safety planning, Zhou et al. (2012) identified a significant shortcoming of model based approaches in their dependence on computerised models of the construction process (schedules). As they state:

Construction operations are dynamic and subject to frequent changes that do not comply with originally scheduled work. Hence, digital schedules are rarely updated sufficiently frequently to accurately reflect all operations underway at any given point in time (Zhou et al., 2012, p.108).

Safety evaluation frameworks

Construction Hazard Assessment Implication Review (CHAIR)

The CHAIR (Construction Hazard Assessment Implication Review) safety in design tool facilitates a structured review of health and safety implications at different points in the design process. Using a coordinated approach by all stakeholders, the tool aims to identify and reduce design related safety risks that potentially exist at construction, maintenance, repair, and demolition stages, to improve constructability, and to reduce project lifecycle costs (WorkCover NSW, 2001).

The CHAIR process consists of three phases of review. After completing the concept design, the first review phase commences as CHAIR 1 proceeds to probe the design using guidewords. The concept design is divided into logic blocks and the implications of guidewords for each element are considered to identify sources of risks and assess the appropriateness of risk controls. The guidewords prompt discussion of design issues. During the review, all the findings, attendees, methodology, and guidewords, are documented in a central chart.

The second review, CHAIR 2, is structured to analyse the construction work sequence which is divided into defined logical steps. For each step, the sources of risks or other factors related to safety hazards are identified and assessment is carried out of the appropriateness of the risk controls. The aim is to improve the design, and to clarify a preferred construction method and sequence. Like CHAIR 1, at the end of the CHAIR 2 review, the findings, attendees, methodology, and guidewords, are documented. The CHAIR 3 review is conducted (at the same time as the CHAIR 2 review) to address maintenance concerns with the finalised design (WorkCover NSW, 2001).

This approach is proactive in that it brings together the project stakeholders at an early stage of a project, and it prompts safety discussions right after the concept design is completed. Yet the quality of the outcomes largely depends on the knowledge and experience of attendees involved in each review stage. The quality of the outcomes also relies on the facilitator's ability to manage a constructive discussion during each workshop and to stop attendees from getting caught up in endless discussions or unnecessary arguments. Additionally, it can be argued that CHAIR 2 and CHAIR 3 reviews occur too late in the design program to allow any major design alterations (Clark, 2010).

It is unclear whether the CHAIR process allows for further reviews in the construction process, such as after any client changes or major redesign. These changes can often lead to new H&S hazards. Designing for safety applies both to the original design and to design changes. Processes like CHAIR need to allow for further review of particular elements affected by the design changes.

3.6 Conclusions

This review of current policy and practice about safety in design leads to the following conclusions:

1. Safety in design is an integral component of Australian H&S policy and legislation.
2. State and territory H&S legislation requires a systematic approach is taken to managing H&S risk associated with the design of structures (as well as plant and materials).
3. Codes of practice establish risk management processes to assist duty holders to comply with statutory requirements for safety in design in the construction industry.
4. The UK Construction (Design and Management) Regulations (2007) establish detailed requirements for managing safety in design. These differ from Australian statutory approaches – they are more explicit about the mechanisms for integrating safety in design into project team decision making. The CDM Regulations, for example, require the appointment of a person to the professional role of Project Health and Safety Coordinator.
5. Evidence suggests the CDM Regulations have changed the culture of the UK construction industry about safety in design, but in some UK projects the Regulations are still treated as a ‘paper-based’ exercise.
6. Voluntary initiatives (for example, the *Guide to Best Practice for Safer Construction*) reveal widespread acceptance of, and willingness to implement, safety in design in the Australian construction industry.
7. Numerous toolkits and technologies support implementing safety in design in the construction industry.
8. Several promising knowledge intensive tools are being used to help design teams to understand the H&S implications of their decisions before finalising decisions.
9. Virtual prototyping, visualisation, and building information modelling, are promising new tools for integrating H&S into design. However, further research is needed to better understand how these tools can cope with the dynamic, iterative nature of design work in construction.

Part 4: Current practice in the Australian construction industry

4.1 Introduction

Part 4 provides the results of a telephone survey that explored current safety in design practice among eleven ACA member organisations. Part 4 is structured as follows:

- Section 4.2 summarises the safety in design management processes adopted by survey participants
- Section 4.3 summarises the stakeholder engagement processes adopted in implementing safety in design
- Section 4.4 summarises tools and resources used in the current implementation of safety in design, and
- Section 4.5 suggests opportunities to share good practice, and to integrate the lessons drawn from the safety in design literature review into safety in design practice improvements.

4.2 Safety in design management processes

Risk management

All survey participants reported that they adopt a systematic approach to risk management that underpins their safety in design processes. Generally, this involves a series of staged reviews (or facilitated workshops) at which both risks and opportunities for safety in design improvements are identified. Issues considered during these workshops include logistics, constructability, and construction sequences. Typically, workshops are held at:

- concept design, detailed design, and pre-construction stages, or
- 15% and 40% design completion points.

All participants also emphasised the importance of considering H&S early in project decision making. One commented: 'If you think about safety and design early, it usually gives you a good productive outcome.' A key part of early consideration is to identify the correct mix of knowledge and skills required of people who participate in safety in design reviews. The importance was emphasised of ensuring that people with direct and specific construction knowledge are involved in safety in design reviews.

Case study: Early involvement of construction knowledge

We've found that each project brings up a unique set of issues around safety and design. In response to this, we have undertaken what we call the *operational excellence study*. We chose over 250 of our former projects and reviewed them to understand the factors that make some projects more successful than others. The results of this study showed a clear correlation between upfront planning and the success of a project.

So, we now allocate a lot more experienced resources at the front end of a project (even during the tender phase). We bring in construction, engineering, and buildability knowledge and expertise into a project at a very early stage, and this often includes the proposed construction team. So now, safety and design is at the start of the process and it continues on through to delivery and final completion.

Design change management

Several participants indicated that they paid particular attention to assessing and managing new H&S risks introduced when changes are made to a design. The literature highlights the dynamic nature of design in construction work as a challenge for implementing safety in design (Larsen & Whyte, 2013). In some instances, design changes introduce new (and unexpected) H&S risks.

Lingard et al. (2013) used case studies to show how H&S risk management tools can be ineffective in the context of a dynamic and uncertain design process. Risk management processes tend to be simple and linear. They assume that design is stable, and that all foreseeable hazards can be identified and subject to risk assessment and risk control at a particular point in time. Design changes can create problems because emergent hazards, that might not be evident when a design review workshop is held, may not be controlled.

Survey participants emphasised the importance of ensuring that the process for managing design changes is integrated with safety in design management processes. Thus, all modifications to a design are subject to rigorous review of their H&S implications. Any new hazards/risks are assessed and appropriately managed. Interviewees described how the system for managing design changes also needs to link to the project risk register. This step ensures that information about new H&S risks arising from a design change is communicated to all participants in a construction project.

Collaborative decision making

The interviewees described a highly collaborative approach to implementing safety in design within their organisations. Multidisciplinary meetings and workshops are a universal feature of the eleven organisations' safety in design activities. This is important because design process relies on exchanging information, and frequent and detailed interaction between specialists, to ensure that the components of a building/structure, which must fit together, are compatible. Activities and interfaces between specialists form a complex network of design activity (Gray, Hughes & Bennett 1994).

One analysis of four typical building designs revealed that the building design process comprised between seven and ten iterative loops, each comprising between five and 30 interrelated loops. The number of design tasks was around 350-400, and the number of information dependencies was more than 2400 (Austin et al., 2000). In this context, involving different design disciplines and technical specialists in collaborative safety in design workshops is likely to produce the best safety in design outcomes.

Case study: Safety in design workshops

We believe workshops are an invaluable process in getting designers and people from the construction, operations and maintenance teams together to discuss the design. And although this nearly always results in modifications, it is a better design than what we started with.

In one example the contract required all pipes to be located underground, which meant excavating a large trench in sandstone. The design workshop highlighted the fact that the pipes would have methane in them, which could make the trench a confined space, and that maintenance would be much more difficult and more prone to unintended injuries. So we decided to put the pipes above ground, which resulted in a reduction in cost, the elimination of a confined space, and easier maintenance. A win all round.

Clear lines of responsibility

Most participants described the way in which clear lines of responsibility are established for safety in design in project teams. When hazards/risks are identified during the design stage, risk control strategies are selected and a specific, named person is:

- given 'ownership' of ensuring these controls are put in place, and
- responsible for reporting on the progress of implementing the risk controls.

Construction design teams are 'temporary, multidisciplinary and network-based organisations' (den Otter & Emmitt, 2008, p122). Design involves a network of tasks, requiring contributions from many specialists and involving a complicated 'web' of interorganisational relationships (Pietroforte, 1995, 1997; Nicolini et al., 2001). In this context, clearly allocating responsibility for specific safety in design activities is critical, and this is reflected in the practices of survey participants.

Recording risk information

All participants indicated they use a project risk register to capture and share important information about H&S risk. H&S hazards/risks that cannot be eliminated through design modifications are recorded in a risk register so that information about 'residual' risks can be transferred to the project management team.

A recent review of H&S in the UK construction industry identified separation and poor communication between the design and construction functions as a causal factor in construction fatalities (Donaghy, 2009). The recording of risk information in a project-specific repository is extremely important so that critical H&S information is effectively transmitted to all project participants. This is particularly important for:

- communicating information about identified H&S hazards/risks, and
- communicating risk control decisions made during the design stage to project participants who may be exposed to these hazards/risks 'downstream', such as construction and maintenance workers.

Capturing safety in design lessons

Several participants described specific activities their organisations undertake to capture safety in design lessons at the end of the project, and to transfer these lessons to future projects.

Participants' described 'Lessons Learned' workshops as an essential element in safety in design activities. One participant described the starting point for any safety in design project management process within his organisation as preparing a safety in design action plan. The first step in this plan requires the project team to examine design documents from previous projects to identify H&S risks, and to use existing knowledge and past experience.

The ability to learn and continuously improve processes and performance is a feature of a mature and positive H&S culture (Reason, 1997). Rollenhagen (2010) identified the need to improve the safety culture inherent in design organisations and practices, arguing that design cultures should focus on developing innovative ways to improve safety in design outcomes.

Learning will help to enable innovation in safety in design. Learning can be facilitated through using information and communications technology platforms, such as that described in the following case study.

Case study: Capturing lessons learnt and knowledge during the risk management process

We use an Enterprise Risk Management System, called *Active Risk Manager (ARM)*, to integrate a centralised risk management process into the organisation. We use ARM to record the findings and to capture knowledge and lessons learnt from across the whole life cycle of all our projects. It can be used to record unforeseen risks or additional risk controls so that we begin to develop a knowledge bank that can be referred to in the future.

Using ARM means we don't have to start from scratch every time we start a new project, and the company builds a significant risk management tool.

Managing safety in design in the supply chain

Several participants commented that the safety in design management process in their organisations required them to assess whether safety in design reviews are required of their suppliers. It is noteworthy that the design of specific building components and building systems (especially in non-residential construction) is characterised by high levels of interpretation, innovation and discretionary decision making by manufacturers and suppliers of building components and systems (Gray & Flanagan 1989; Slaughter 1993). Organisations with overall responsibility for project H&S (that is, the principal contractor) should establish clear safety in design requirements for the specialised contractors who manufacture and supply building elements and components.

4.3 Stakeholder engagement processes

Adopting a stakeholder perspective was another common feature of the respondent organisations' approach to safety in design. Stakeholders commonly involved in safety in design activities included:

- client representatives
- the project manager
- the design manager
- lead and specialist design consultants
- component manufacturers and suppliers
- health and safety managers
- environment managers
- representatives of the construction team, including the construction manager and site supervisors
- representatives of the end user's asset management team
- subcontractors
- community representatives
- maintenance personnel
- independent safety assessors/auditors
- temporary works consultants, and
- other relevant stakeholders and subject matter experts.

Design work in construction projects involves multiple stakeholders who interact with one another to produce design outcomes (Ewenstein & Whyte, 2007). Research also shows that stakeholders' concerns and priorities can change over the life of a construction project (Olander, 2007). Thomson (2011) presents an industry case study revealing that stakeholders' understanding of what they want from a construction project develops through their reflection on emerging design solutions. Thus,

rather than viewing design as a linear process characterised by stability and predictability, Thomson argues design should be regarded as an iterative and reflective process in which stakeholders engage in continuous negotiation and learning.

Lingard et al. (2012, 2013) documented case studies in the Australian construction industry that showed the extent to which stakeholders external to project teams (that is, people from groups who have no contractual links to a project), can exert a significant influence on design decisions. Potentially, these external stakeholders can exert substantial influence on a project's safety in design outcomes. The inclusive, stakeholder based approach to safety in design adopted within the surveyed organisations will help to ensure that these impacts are managed.

The benefits flowing from this multi-stakeholder approach are likely to be substantial. One interviewee commented that, in his opinion, the benefits associated with effective safety in design practices clearly outweigh the costs, saying:

I have found design modifications generally have little cost implications, but considerable safety implications. For example, installing an extra pressure transmitter to provide duplicate measurement of a critical process variable can prevent serious accidents like the Longford disaster.

4.4 Tools and resources used to support safety in design

The interviews revealed that various tools and resources used by respondent organisations support them in implementing safety in design.

Commonly used tools include safety in design management processes and protocols, such as the Construction Hazard Assessment Implication Review (CHAIR) process. (CHAIR is described in Part 3 of this report.)

To support safety in design activities, many ACA member organisations have developed their own templates, documents, pro formas and checklists. These include:

- safety in design checklists
- safety in design prompts or guidewords for use in risk analysis
- risk registers
- workshop protocols, and
- standard reports.

Several organisations indicated that they are developing in-house databases to capture and share safety in design solutions.

Other tools in use reflect the adoption of advanced technologies, such as modelling tools to enable the early identification, assessment and mitigation of H&S risks.

Case study: 3D and 4D modelling

We've found many contracts can now benefit from the use of 3D and 4D modelling. This modelling allows everyone on the team to visualise the project in a much more engaging and meaningful way than what can be achieved just by looking at 2D plans. So with an infrastructure project, for example, we can take the client through the design of the plant so they can discuss and raise issues or make suggestions about different aspects of the design: for example, services locations, access for maintenance. This modelling allows really important points to be raised before construction starts. It has the opportunity to capture and distil the client's preferences into something cost effective, while also leading to a better design outcome.

These tools were particularly effective in ensuring that clients' requirements were met while also delivering improved safety in design (see, for example, the case study below). Adopting these technology based approaches to delivering best practice in safety in design reflects a growing acknowledgement of the potential to use technologies associated with building information modelling as a means to improve H&S in the construction industry (Sulankivi et al., 2013).

Case study: Structural Design Modelling – Melbourne Park Redevelopment, Eastern Plaza

For the design to meet international standards for vibration/acceleration, planarity, evenness and slope, we were required to design the tennis courts to strict dimensional tolerance and vibration criteria. This would have been challenging enough, but the courts were constructed on suspended concrete slabs above two levels of car parks. We used full structural and vibration modelling to enable our consultants to collaborate with the acoustic and vibration consultants to ensure the design, construction, and subsequent maintenance and use of courts were safe, while meeting the hard-to-achieve parameters set out by the client.

4.5 Conclusions

The survey conducted with eleven ACA member organisations reveals that currently much is being done to manage safety in design effectively.

Critical success factors are likely to be:

- developing a safety focused design culture that is reflective, and adept at learning from past experience
- considering H&S as early as possible in the project lifecycle
- involving people with relevant H&S knowledge in safety in design reviews
- adopting a broad, stakeholder based approach in which all parties whose interests and actions could impact on safety in design are engaged in an appropriate and timely way
- effectively capturing, communicating, and managing information arising from safety in design activities, and
- using advanced technologies to improve the effectiveness of risk identification and analysis activities, and to evaluate the potential H&S improvements associated with design modifications.

Part 5: Conclusions and recommendations

5.1 Introduction

Part 5 sets out the conclusions and recommendations that flow from the foregoing review of the safety in design literature, government policy documents, and industry practices. Part 5 is structured as follows:

- Section 5.2 summarises the key findings from the survey of ACA members and the literature review, and offers eight recommendations for improving the effectiveness of safety in design processes in the Australian construction industry.
- Section 5.3 briefly recaps the review outcomes.

5.2 Key findings

The survey of eleven ACA members' safety in design activities reveals that a systematic approach is adopted for managing safety in design in the Australian construction industry.

Safety in design reviews

Safety in design is managed through a process of staged design and constructability reviews that become increasingly more fine-grained. For example, H&S risks are analysed in more detail as the design work progresses. Typically:

- a risk assessment protocol is established at the proposal development stage
- a preliminary risk review is undertaken, and a risk register established, at the concept design stage
- further, and progressively more detailed, safety in design reviews occur at the concept and detailed design stages, and
- a final review of design H&S risks takes place at the construction document development stage (when detailed design is 'frozen').

This systematic approach to managing safety in design is enabled by the use of paper or web based tools, templates, checklists, and guidewords. These undoubtedly increase the consistency and reliability of safety in design activities when they are applied across projects.

There is widespread recognition among surveyed ACA members that safety in design reviews must include people with knowledge and experience in the construction and maintenance of the facilities being designed. The quality of safety in design reviews is likely to hinge on the knowledge and experience of reviews participants.

The research literature suggests that the potential benefits arising from systematic safety in design activities may not be realised if knowledge does not flow freely between project participants.

Construction work is characterised by vertical segregation between participants engaged in initiating, designing, producing, using, and maintaining facilities (Atkinson & Westall, 2010). This can:

- impede the development of shared project goals (Baiden & Price, 2011), and
- negatively impact on project outcomes (Love et al., 1998).

In the UK, functional separation and poor communication between the design and construction functions was identified as a causal factor in construction fatalities (Donaghy, 2009).

In this context, integrating mechanisms are needed to ensure that communication flows are free and open, and that people with the correct mix of knowledge and experience are engaged in safety in design reviews.

It is also recognised that in non-residential construction, the technical complexity of design and high levels of specialisation have created a situation in which manufacturers and suppliers of building systems/components may be responsible for their design. Even when they are not directly responsible for designing these elements, it is recognised that specialist subcontractors often exercise considerable discretion and influence in the design of components they supply and install. This is acknowledged by Wright et al. (2003) who note that many technology based safety in design solutions are driven by building systems manufacturers, and not by principal design consultants.

The subcontractors who supply and install specific building elements may not be contractually engaged in a project when safety in design reviews take place. However, their specialised knowledge and experience of H&S risks (and the best ways to control them) can be critical.

To ensure the effectiveness of safety in design processes, it is recommended that:

Recommendation 1

People with relevant knowledge and experience should be engaged in safety in design workshops and design reviews.

Ideally, people with the correct mix of knowledge, skills and experience should always be engaged in safety in design reviews. However, if this is not possible, then some alternatives might ensure the correct 'knowledge' is fed into decision processes.

In Part 2 of this report, the ToolSHeD decision support tool was described. ToolSHeD is a knowledge based tool that captured the collective H&S knowledge of a diverse group of project participants. The tool was a prototype only and attempted to capture and represent the reasoning that an 'expert' group would use to determine the level of H&S risk inherent in designing a building component (a roofing system). The 'expert' group participated in a workshop at which members exhaustively discussed the H&S implications of detailed aspects of a roof design, including:

- location and environmental factors (such as wind loadings, noise, building orientation)
- height
- slope/pitch
- access requirements/options
- plant requirements and location (if applicable), and
- choice of materials.

The reasoning was reproduced in an online risk assessment tool, which underwent testing and validation. Although only a prototype, the ToolSHeD method was proven effective for capturing and representing the reasoning of a group of 'experts'. These types of knowledge based tools can:

- provide an effective mechanism for capturing the specialised knowledge and experience of technical experts, and end users (including construction and maintenance workers), and
- make this information available to decision makers in the design stage of a facility.

Some work is required to develop the initial knowledge models. However, once captured, this knowledge base can be refined and re-used in designing facilities of a similar type.

H&S risk communication

Surveyed ACA member organisations all use a structured approach in projects for capturing and communicating H&S information. The most commonly used means to achieve this is through establishing a project risk register. The purpose of the risk register is to:

- capture and communicate H&S risks identified in safety in design reviews
- record choices made about how these risks will be controlled
- establish clear responsibilities for implementing risk controls, and
- monitor the progress made in managing H&S risks.

Free flowing communication of information has been identified as a critical component in the effectiveness of safety in design processes (Atkinson & Westall, 2010).

Recent Australian research developed a quantitative technique to analyse and understand the way that the flow of communication between construction project team members shapes safety in design outcomes.

This technique was based on social network analysis (SNA), which has been used previously to:

- analyse knowledge flows (Pryke, 2004; Ruan et al., 2012; Zhang et al., 2013)
- explain failures in team based design tasks (Chinowsky et al., 2008)
- identify barriers to collaboration (Chinowsky et al., 2010), and
- understand formal and informal patterns of safety related communication (Alsamadani et al., 2013).

The Australian research showed that the construction contractors' position in a project communication network during the design stage is a key factor in achieving effective safety in design outcomes. The more involved the constructor is in project communication during the design stage, the greater the likelihood that safety in design will produce high quality risk control outcomes (that is, elimination or engineering controls).

The analysis of communication networks can be used to identify critical 'gaps' or information 'bottlenecks' that prevent the flow of critical H&S related knowledge during design activities (El-Sheikh & Pryke, 2010). Used in this way, the technique can identify opportunities for increasing information exchange to support H&S improvement.

To better understand and improve safety in design outcomes, it is recommended that:

Recommendation 2

Project communication networks should be analysed and understood to remove blocks and 'bottlenecks' that might impede the free flow of information.

Recommendation 3

Involving key project participants in communication networks be used as a 'leading indicator' for assessing the quality and effectiveness of safety in design activities.

Stakeholder engagement

Surveyed organisations' safety in design practices show that a consultative and collaborative approach is taken to:

- analysing H&S risks arising from a design, and
- decision making about how to control identified hazards/risks.

Within this collaborative approach there is extensive engagement of internal project stakeholders, including:

- the client
- the client’s customers
- design consultants
- trade contractors, and
- suppliers.

Internal stakeholders are entities which have entered into a contract (either formal or informal) with the client for the supply of design, construction, or other services. Internal stakeholders can either:

- be demand side internal stakeholders who focus on the end use of the project – it is common for the needs and expectations of demand side internal stakeholders to drive project design decisions, or
- be supply side stakeholders who supply a service to the client.

However, Australian research shows the considerable impact that external project stakeholders can have on the design of a facility (Lingard et al., 2012).

External stakeholders also have a direct interest in the project, but are not bound to the client through any contractual arrangement. These groups are much more diverse than the internal stakeholders and are more likely to serve the interests of an individual, or the stakeholder group they represent, rather than the client’s planned project.

External stakeholders can be identified as either private or public. External private stakeholders might include concerned individuals, environmental and conservationist associations, and neighbourhood associations. External public stakeholders might include local governments, state governments, federal regulatory agencies, the federal government, unions, or international agencies.

The positions and types of internal and external stakeholders are shown in Figure 5.1.

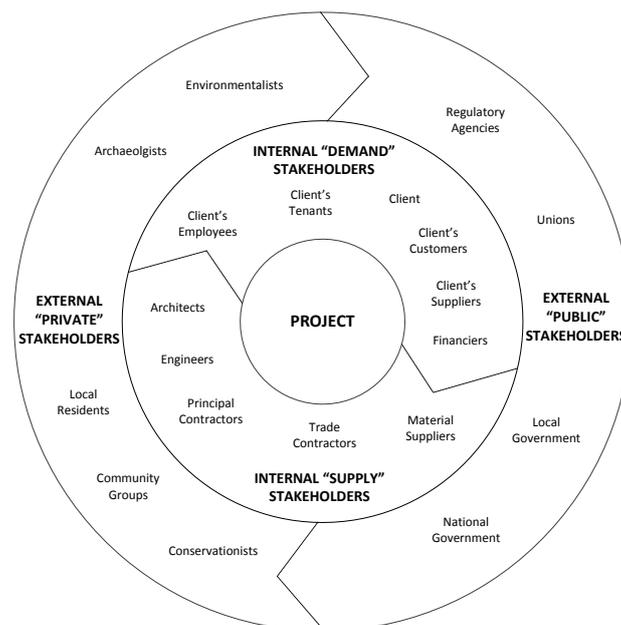


Figure 5.1: Project stakeholder model (adapted from Winch, 2010)

H&S can be significantly impacted by decisions made in response to key stakeholders' interests. For example, Priemus and Ale (2010) describe how frequent changes to the functional requirements of a major development in the Netherlands undermined the logic of the design and ultimately resulted in a serious structural failure. A series of design changes were required to respond to the aspirations of key stakeholders, in particular the developer.

Recent Australian research reveals the influence of these external stakeholders can lead to design decisions that increase H&S risks experienced by construction workers (Lingard et al., 2012). For example:

- a food retail chain changed the requirements for food packaging during the construction of a food processing plant. This led to extensive redesign of plant and services in the facility and exposed construction workers to substantial risk during rework
- after the detailed safety in design review at an industrial facility, regulatory authorities imposed requirements for fire protection, waste water and sewerage disposal systems that presented new and unexpected hazards for the construction contractor
- in the design and construction of a suburban train station the 'Design and Construct' contractor undertook a comprehensive safety in design review at the proposal stage, suggesting some changes to improve constructability. However, a post-award risk assessment, which focused primarily on the safety of end users, resulted in further changes that introduced new, significant, and unforeseen hazards at the construction stage.

External stakeholders may also positively influence project safety in design outcomes; for example, by engaging trade unions and H&S regulatory agencies in decision making.

To optimise the effectiveness of safety in design processes, it is recommended that:

Recommendation 4

All stakeholders (both internal and external) whose influence could have a positive or negative H&S impact on safety in design be identified.

Recommendation 5

The interests of these stakeholders and their potential to influence H&S be assessed.

Recommendation 6

Those stakeholders with the potential to influence H&S be engaged in safety in design activities in an appropriate manner.

Design complexity, iteration and change management

The surveyed ACA members revealed the importance of ensuring that safety in design processes are linked to managing design changes. Uncertainty and change are key features of design work in the construction industry. Tryggstad et al. (2010) argue that design is a process of collective negotiation. The emergent nature of design related H&S hazards can be a problem, especially when safety in design reviews assume a certain level of stability and are based on a series of 'hold points'.

Surveyed ACA members recognise this challenge and address it in a number of ways:

- the staged safety in design review process is one way of ensuring that new H&S risks are identified and managed as the design develops and greater levels of detail become available, and
- linking the design change management process to the project risk register, and reviewing design changes to ensure risks and opportunities are identified and acted upon.

There are substantial challenges inherent in applying a linear risk management approach (which implies stability) to a highly dynamic design process.

The survey revealed the benefits associated with integrating H&S into design change management processes. For example, it was proposed that, when a design is to be changed, the change should be reviewed by people with appropriate levels of H&S or technical construction process knowledge. If this review suggests the change has significant potential to impact on H&S, a safety in design review is triggered automatically.

To ensure the risks associated with design changes are managed, it is recommended that:

Recommendation 7

Safety in design be directly linked with design change management processes to ensure ongoing assessment and management of 'emergent' H&S risks.

Using advanced technology to support safety in design

The surveyed ACA members revealed the significant benefits associated with using 3D and 4D modelling technologies in anticipating H&S hazards, and supporting the elimination/reduction of these hazards at the design stage. This is supported by the literature, and by research that is developing and testing the way that H&S risks can be analysed using:

- building information modelling (BIM), and
- advanced tools for analysing H&S risk.

Such tools are frequently used for visualisation, clash detection, and construction planning and scheduling. More recently, BIM tools have been combined with H&S knowledge bases to enable checking for basic levels of H&S compliance. These tools assume a degree of precision in the way that H&S requirements are specified. Standards (expressed as rules) are used to evaluate the extent to which a design satisfies a minimum H&S performance standard. However, the objective in H&S should always be to reduce risk to a level that is 'as low as reasonably practicable'. Rule based approaches to checking H&S compliance potentially reduce the level of innovation that is applied to reducing H&S risks through design.

There is considerable potential to integrate H&S knowledge bases into BIM tools to support safety in design more comprehensively. If an integrated knowledge base can capture the H&S implications of design options as they are experienced by different groups (for example, construction workers, maintenance workers, end users, and others), then applied optimisation algorithms can be developed to ensure safety in design processes produce the best possible levels of H&S risk reduction.

To enhance the application of advanced technology to safety in design it is recommended that:

Recommendation 8

Further research be carried out to develop and evaluate the use of knowledge intensive, integrated safety in design systems, using advanced technology such as BIM tools.

5.3 Conclusions

Designers' responsibility to reduce the H&S risk to people who will come into contact with a building or structure (or its component parts) is now a key component of Australia's H&S legislation.

This reflects the growing body of evidence that the physical design of a building or structure is sometimes a 'latent' cause of workplace deaths, injuries or illnesses. Safety in design is most frequently addressed by implementing risk management processes that underpin progressive, collaborative, project level safety in design reviews.

The review of safety in design literature and practices has identified much evidence of good practice. However, some practical implementation challenges remain. It is likely that the effectiveness of safety in design processes will vary according to the knowledge and experience of people involved in reviews and decision making.

Eight recommendations are made that could assist in improving the quality of safety in design outcomes across the industry.

The recommendations capture opportunities identified in the research literature for supporting the effective implementation of safety in design in construction projects. They do not require substantial structural or procedural change to the way safety in design is currently implemented.

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About RMIT Centre for Construction Work Health and Safety

The RMIT Centre for Construction Work Health and Safety provides leading-edge, applied research to the construction and property industries. Our members are able to work with organisations to analyse health and safety (H&S) performance and identify opportunities for improvement. We can develop and evaluate innovative solutions, provide specialised H&S programs or undertake other research-based consulting activities. Our work addresses real-world H&S challenges and our strong international linkages provide a global perspective to our research.

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