DESIGNING FOR SAFETY: PERSPECTIVES FROM EUROPEAN UNION, UNITED KINGDOM, AUSTRALIA AND UNITED STATES PERTAINING TO SAFETY AND HEALTH IN CONSTRUCTION

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ABSTRACT
Occupational safety and health in construction is a global issue. Designing for safety in the features of a building or structure can facilitate the safety of people during construction and in the use of the facility as well. Almost all work on safety design to date has been undertaken in member countries of the European Union, Australia and the United States. This study sheds light on the history of 'design for safety' in these countries that can provide lessons learned and guidance for others to pursue and adopt. The study reviews relevant literature on 'design for safety' in general, with particular emphasis on construction. It is confirmed that designers should have responsibilities for addressing occupational health and safety for construction workers and building users and there is significant value for improved studies and practices on design for safety in the construction industry, although the concept and its application is still at its initial stage and there is a varying degree of successes in practice. Policy and practice implications to policy makers and project stakeholders are also identified respectively.

Keywords: Design, Safety, Construction safety, Designing for safety

INTRODUCTION
An increasingly popular approach to preventing and controlling injuries, illnesses, and fatalities in construction is to minimize hazards and risks early upstream in the design process. Designing for safety is recognized internationally as a feasible method to reduce construction workers' risk (HMSO 1994; WorkCover 2001). Generally, design errors are slipped through the check and review process. Kinnersley and Roelen (2007) reveal that for the accidents and incidents in the aircraft and nuclear industries, about 50% have a root cause in design. They found that the proportions for the aviation and nuclear industries are 51% and 46% respectively which are remarkably similar. Hale et al. (2007b) indicate that the influence of design on accidents and incidents vary across publications, but were typically in the range of 20-60% of accidents having at least one significant or root cause attributed to design. Hale et al. (2007b) conclude that 40% to 60% of accidents have at least some root causes in the design stage. This means that if such root causes would have been corrected in the design stage, the projects would have been completed more safely. Thus, the best route to operational safety is to 'get it right' from the start, during design. Lin (2008) states that designing for safety is a cross-cutting concept which can affect the practice of safety in all industries. Culvenor (2003) stated that safe design is about decisions which impact positively on safety downstream and has life-cycle effects. The authors postulate that designers need to be aware of how design affects workers, builders and users. However, what is known about the extent to which design issues contribute to work-related accidents, is limited. Manuele (2008) revealed that designing for safety was inadequately addressed in the popular safety literature. Further, design-safety know-how and knowledge were not accumulated in any organized manner, theories and principles that have been developed, are often not practiced. Almost all these limited efforts on 'design for safety' to date have been carried out in member

countries of the European Union, United States and Australia. The objective of this study is to review perspectives and evolutions of designing for safety in these countries that would provide lessons learned and guidance for others to follow and adopt.

In order to better understand design-safety concept, a number of past studies have been examined. Most of the papers that have been covered in this review are listed in Table 1, which provides a summary of the most relevant designing-for-safety research. It is believed that the seventeen (17) studies selected for this review constitute a general view of the subject matter. A discussion based on the studies together with a streamlining of the history of the topic is given in this paper to reflect on the important issues of designing for safety.

Reference	Summary of Research
Gambatese (1998)	Focuses on the liability of design consultants in the project delivery system and addresses the design community to incorporate design safety knowledge for construction worker safety into the scope of work for the purposes of fewer worker injuries and fatalities, and ultimately a safer construction jobsite.
Gambatese and Hinze (1999)	Build on the previous study of Gambatese et al. (1997) which recognizes an existing knowledge gap between constructors and designers and their commitment to jobsite safety. The work requires a major education effort in the design community and offers design suggestions or best practices for implementation in design. The study recommended that owners must provide the initial impetus requiring through contract terms that designers consider construction worker safety in their designs.
Coble and Blatter Jr. (1999)	Report that because of the separation of design and construction concepts, the construction process has become an haven for litigation, with owners routinely shopping for the cheapest designer. The paper suggests that there exists a need to foster synergy among participants in the construction process.
Rechnitzer (2001)	A discussion paper which describes generally the role of designers as regard responsibility and accountability for safety for the full product life cycle.
Bluff (2003)	A discussion paper that examines the regulation of safe design and planning of construction works. Taking account of existing Australian law and approaches drawn from European experience, the paper outlines some directions for Australian OHS law for the benefit of workers engaged in construction.
Culvenor (2003)	A discussion paper that emphasized safe design is a driver of innovation. Safe design can yield safety benefits as well as production benefits, quality improvement, new products, cost savings, and so on. Safe design is about thinking about downstream or life-cycle effects.
Gambatese et al. (2005)	Present a pilot study conducted to investigate the practice of addressing construction worker safety when designing a project. Through 19 interviews of architects and design engineers, the study found that design professionals are interested and willing to implement the concept of designing for safety. The study describes the key changes needed for implementing of the concept in practice which include: a change in designer mindset towards safety; establishment of a motivational force to promote designing for safety; increase designer knowledge of the concept; incorporate construction safety knowledge in the design phase; utilize designers knowledgeable about design-for-safety modifications; make design for safety tools and guidelines available for use and references; and mitigate designer liability exposure.
Weinstein et al. (2005)	Describe the impact of a safety-in-design initiative during the design and construction of a semiconductor manufacturing facility in the United States. The analysis of the initiative provided that injury prevention efforts in the construction industry can begin upstream by involving designers, engineers, and trade contractors in preconstruction processes.

Reference	Summary of Research
Kjellen (2007)	The paper analyzes two different perspectives of the principles used in different phases of design by the Norwegian oil and gas companies. Human centered approach focused on the design of work places while 'energy barrier' perspective provided technical safety functions on the platform. The paper shows that the barrier perspective has been implemented in design to prevent fires and explosions.
Gambatese et al. (2008)	Provide evidence of design's influence on construction site safety. To confirm the findings of a previous study (Behm 2005), an expert panel was established to review a sample of the 224 fatality cases. The previous research results and expert panel responses were in agreement for 71% of the cases reviewed that design influenced on site safety.
Schulte et al. (2008)	Offer 'prevention through design' initiative 2007-2014 in terms of four overarching areas where action can be directed: practice, policy, research, and education. A seven year strategy is envisioned to design out hazards rather than dealing with them.
Manuele (2008)	Discusses in short the 'prevention through design' initiative in historical and prospective perspectives.
Creaser (2008)	Presents safe design activity in Australia in the context of providing an overview of the regulatory environment.
Driscoll et al. (2008)	Present the analysis of fatal work-related injuries in Australia. The Australian National Coroners' Information System (NCIS) was the data source and deaths resulting from workplace injuries on or between 01 July 2000 and 30 June 2002 were analyzed. Results indicate that 37% of 210 workplace fatalities had design-related issues involved; another 14%, circumstances were suggestive that design issues were involved.
Kovalchik et al. (2008)	Present the quiet-by-design approach of a noise control that reduced noise exposures of continuous mining machine operators by 3dB(A) using the four functional area of 'prevention through design', namely research, practice, policy, and education.
Behm (2008)	Presents suggestions of the workshop participants describing that there was much enthusiasm for 'prevention through design', nonetheless, numerous challenges exist and among those, the liability issue must be resolved at a national level. The study asks that a clearer definition of 'prevention through design' must be agreed upon.
Toole & Gambatese (2008)	Suggest that the application of Construction Hazards Prevention through Design (CHPtD) concept can evolve along four trajectories: increased prefabrication, increased used of less hazardous materials and systems, increased application of construction engineering, and increased spatial investigation and consideration.

Table 1: List and summary of prior designing for safety research.

COUNTRY STUDY

The European Union and United Kingdom

In 1992, a rigorous effort was initiated to improve OHS in the European construction industry. The directive 92/57/EEC "on the implementation of minimum safety and health requirements at temporary or mobile construction sites", commonly referred to as the *Construction Site Directive* (European Commission 1992) was issued. In response to this Directive, the United Kingdom passed into law the Construction (Design and Management) Regulations (CDM), which became effective in 1995 (Her Majesty's Stationary Office 1994). France passed regulations which mandate a holistic view of construction safety including the design (OPPBTP 2002) and other European countries have since followed with similar regulations (Gibb, 2004). The EU directive is now adopted in the law of all member states of the European Union. It represents the most far-reaching regulatory initiative to improve OHS in the design and planning of construction works.

In the UK, particularly, the design and planning elements of the *Construction Site Directive* were adopted with enhanced amendments, in the *Construction (Design and Management) Regulations 1994* (CDM regulations). The CDM regulations require that designers are to give adequate consideration to the safety of construction and maintenance workers. The client must appoint one or more persons to coordinate OHS matters during the design and planning, and construction phases. The CDM regulations also address designers' involvement in selecting the bidders and in procurement. The CDM Regulations place duties on several parties who can contribute to the OHS management of construction works. These parties include *client, designers*, the *planning supervisor* and the *principal contractor*. The *client* must appoint persons, who are competent and have allocated resources to carry out their role under the CDM regulations. The *client* must:

- Appoint the planning supervisor and provide information to him/her that is relevant to OHS;
- Appoint the principal contractor;
- Ensure that a designer, if engaged, is competent;
- Ensure that the health and safety plan is prepared; and
- Ensure that s/he receives the health and safety file at the end of the project.

Under the CDM regulation, the *designer* must ensure that the client is aware of his/her duties and that OHS matters are addressed in the design of the project. Designers have responsibilities for OHS in all designs that they prepare directly, as well as designs prepared by their employees or other persons under their control. The *planning supervisor* must ensure for the project that: OHS matters are addressed in the design; ensure cooperation between designers; give advices to the client and contractors to enable them to comply with the regulations; ensure that a health and safety plan is prepared. The *principal contractor* must coordinate OHS matters in the construction phase of the project, including the development of the construction phase health and safety plan. The CDM Regulations require the *planning supervisor* to ensure that notice of the project is given "as soon as practicable" after his/her appointment. The regulation warns that with late notification, there is little opportunity for the regulatory authorities to intervene or address weaknesses in the design and planning phase, except after the event.

The Health and Safety Executive (HSE 2002) suggests that designers take the following specific steps: "Identify the significant health and safety hazards likely to be associated with the design and how it may be constructed and maintained; consider the risk from the hazards which arise as a result of the design being incorporated into the project; if possible, alter the design to avoid the risk, or where this is not reasonably practical, reduce it." HSE (2002) further states that designers must ensure construction documents properly communicate the designer's suggestions for dealing with specific risks, such as ensuring "the design details of items to be lifted include attachment points for lifting."

Efforts on designing for safety in the academic and professional areas progressed side by side. For example, there is a special issue in January-February 2007 of the journal *Safety Science*, which is concerned with getting safety into design. Fourteen of its sixteen articles were the presentations made at a workshop on "Safety by Design" held by the NEW Technology and Work Network, a European entity. The purpose was to assist the designers to stand back from their work and see the processes that are operating and how safety fits into them, and then to reengage in that work with the help of the knowledge, tools, and approaches offered through the workshop to embrace the designing for safety concept (Hale et al. 2007a).

Australia

Safe design work in Australia commenced at a national level under the National Occupational Health and Safety Commission (NOHSC) in the late 1980s. In 1994, the National Standard for Plant (NOHSC 1994) was published, which described duties for designers, manufacturers, importers, and suppliers, to ensure that risk and hazards associated with the plant that they were designing, manufacturing, and supplying, were eliminated, or where this was not practicable, minimized. In 1998/1999, the Safe Design Project was initiated by the NOHSC and in 2000, two reports were prepared. The first was a review of safe design literature and of initiatives of OHS authorities, and other key players, relating to safe design (Cowley et al. 2000). This report

identified areas of deficiency in the understanding of legal requirements and knowledge related to safe design, and was helpful in setting the direction of future work in this area. The second report was an analysis of 225 fatality studies, involving machinery and fixed plant in Australia, between 1989 and 1992 (NOHSC 2000; Driscoll et al. 2008). Of these fatalities, 117 were found to have at least one design factor contributing to the incident. Several other research papers (Caple and Associates 2000; Gunningham et al. 2000; National Research Centre for Occupational Health and Safety Regulation 2002) were produced under the Safe Design Project. These papers collectively elevated the issue of safe design as a key OHS policy and highlighted that improving design would reduce injury and fatality rates.

To "eliminate hazard at the design stage" is one of the priorities set out by the National Occupational Health and Safety Commission (2002). The National Occupational Health and Safety Strategy states that the 'responsibility to eliminate hazards or control risk rests at its source. This principle applies to all sources of hazards. Responsibility falls on a wide range of parties, including those outside of the workplace such as designers, manufacturers, constructions or suppliers (NOHSC 2002: p. 9).

Another report (NOHSC 2004) disclosed that 37% of 210 workplace fatalities studied had design-related issues involved; another 14%, circumstances suggested design issues were involved and design issues appeared to contribute to at least 30% of injuries. A work-related serious injuries report by Driscoll et al. (2005) found that design problems were involved in many fatal incidents and design is an important contributor to fatal injury in many industries.

In May 2006, The Australian Government issued *Guidance on the Principles of Safe Design for Work*. The Australian Safety and Compensation Council (ASCC 2006a) published *Guidance on the Principles of Safe Design for Work* and launched an educational resource package *Safe Design for Engineering Students* (ASCC 2006b). The package was designed to enable educators to incorporate examples of safe design into the existing engineering curriculum. This safe design effort got strong support from Engineers Australia, the professional and registration body for engineers in Australia.

In a separate effort, the ASCC is currently revising the National Standard for Plant and is developing Essential Safety Outcomes (ESOs) as the minimum standards for plant design. In relation to Australia, Driscoll et al. (2008) found design problems associated with fatal incidents. The most common scenarios involved problems with rollover protective structures or associated seat belts; inadequate guarding; lack of residual current devices; inadequate fall protection; failed hydraulic lifting systems in vehicles and mobile equipment; and inadequate protection mechanisms on mobile plant and vehicles. According to Driscoll et al. (ibid), there is a considerable scope for preventing serious work-related injuries through improving design of plant, equipment, and vehicles used for work-related purposes.

Regarding construction design, several state regulations are in place in Australia that require designer to consider how the structures they design are going to be safely constructed (Bluff 2003). For example, New South Wales requires that a management strategy to be in place in the design process which includes consideration, evaluation, and control of occupational safety and health during construction (New South Wales Construction Policy Steering Committee 2000). Additionally, the Construction Hazard Assessment Implication Review (CHAIR), a design for construction safety implementation tool, was developed (WorkCover 2001). However, the effectiveness of these developments for *safety through design* is still to be determined.

The United States

In the early 1990s, several safety professionals recognized that designing for safety was inadequately addressed in the safety literature in United States. For example, Gambatese et al. (1997) stated that the designers were not directly involved in the safety efforts. In 1995, the National Safety Council of USA established "the *Institute for Safety through Design*" (Manuele 2008). An *advisory committee* for the *Institute* was formed with the mission: "to reduce the risk of injury, illness, and environmental damage by integrating decisions affecting safety, health, and the

environment in all stages of the design process." The term '*safety through design'* was used which defines the integration of hazard analysis and risk assessment methods early in the design and engineering stages (Manuele ibid). This was done to take actions necessary to achieve that risks of injury or damage are kept to an acceptable level. The strategies adopted by the *Institute* included: (1) expand the knowledge and concept of *safety through design*; (2) develop engineering curricula course materials; and (3) establish liaisons with school, socities, industry, and labor to increase awareness. Much work has been done by the *Institute* in forms of seminars, workshops, and symposia.

In March 2007, the Occupational Safety and Health Administration Construction Alliance Roundtable Design for Construction Safety Group issued a 3 hour course entitled "Design for Construction Safety". In July 2007, the first Prevention through Design (PtD) Workshop was held in Washington DC to launch a National Initiative at the National Institute for Occupational Safety and Health (NIOSH) aimed at eliminating occupational hazards and controlling risks to workers "at source" or as early as possible in the life cycle of projects. As part of the initiative, NIOSH was entrusted to send letters to the chief executive officers of the 5,000 largest companies in the United States describing what the initiative intend to accomplish (Manuele 2008). CEOs of the companies were asked to write to the Deans of engineering schools, and science degree programs, highlighting the need of graduates to be knowledgeable about hazards, risks, and risk assessment techniques. The objective is 'to achieve a cultural change whereby management insists that engineers and safety science graduates have knowledge of designing for safety concept (Manuele 2008).' Additionally, a three-hour course in PtD was made available by NIOSH to schools and research grants were established to support safety educators and professionals to consolidate their best practices.

IMPLEMENTATION: STANDARDS/CODES, PROCESSES/TOOLS, AND REGULATIONS

Hale et al. (2007b) state that design standards provide designers with instructions and guidance on how and for what situations to design. Fadier and De la Garza (2007) revealed that designers place a great reliance on these standards and if something is not in the standards, then they claim not to consider it. Also, there is a danger of standards which are not complete or not updated with recent experiences. ISO (2000) aim to resolve these issues by adopting work processes to be used by the design organization. The Building Code of Australia 2008 (BCA) is concerned with safeguarding people from injury, illness or loss of amenity in the use of a building including authorized emergency activities such as rescue operations and fire fighting (ABCB 2008). When the BCA is comprehensive in its approach to regulating various aspects of design, choice of materials and methods of construction, its scope is considerably narrower than the OHS regulations. The BCA is concerned with minimizing risks arising in buildings once they are constructed – it is not concerned with OHS in the construction phase. In the USA, some standardized tools are available including the Design for Construction Safety Toolbox (CII 1996) which is utilized in practice. Nevertheless, designers also need to learn from accidents, incidents and errors.

The shift in legislation is altering that view and asking designers to consider systematically the case for increased attention to safety during design. In the EU, the standards of 'good design practice' for example the EN standard 292 (CEN 1991) provides a powerful incentive to make design explicit. They can be used in court cases as a benchmark for assessing design that whether each party had fulfilled its responsibility. Nevertheless, creating statutory occupational health and safety duties for designers do not automatically deliver reductions in construction safety risks. When statutory responsibilities for occupational health and safety in the construction stage of a project were imposed upon construction designers under the *CDM Regulation,* they created a new professional role by requiring the appointment of a *Planning Supervisor*, with the responsibility to co-ordinate the occupational health and safety activities on construction sites. The *CDM regulations* place a duty on the designers to ensure that any design prepared avoids foreseeable risk to construction workers. Nonetheless, the success of the CDM regulations in reducing construction fatalities was not established (Gibb 2004). Designer's lack of knowledge (Gibb 2004) and their disregard for the legislation (Cosman 2004) was always been a barrier to a successful legislative process.

IMPLEMENTATION: PERFORMANCE

Since the advent of the *Temporary and Mobile Construction Site Directive* of 1992 in Europe, legislative duties have been placed on designers (Anderson 2000). In the UK as mentioned before, the design and planning elements of the *Construction Site Directive* are adopted with enhanced amendments in the form of *Construction (Design and Management) Regulations 1994*. Nonetheless, a survey by HSE (2004) revealed that only 33% of designers had sufficient knowledge of their legal responsibilities to "design out" risk and only 8% had received any training on the subject. Thirty-seven percent (37%) of designers had little or no knowledge of the *CDM regulations* affecting contractors. Sixteen percent (16%) of designers abdicated their responsibilities in the design risk assessment process, resulting in principal contractors having to deal with risk that could have been addressed during the design process. Fifteen percent (15%) of designers included specified solutions to work-at-height by relying on safety harness systems, without necessarily having considered alternative design solutions. On the subject of work-at-height hazards, one third of designers had not considered "constructability" and "buildability" with regard to risk from working at height, nor had they considered risk from work at height associated with future maintenance. Of course, there were examples of good practices in this regard, but the actual practices exposed in this survey definitely fell below expectations (HSE 2004). Despite CDM regulations, UK designers frequently expressed the opinion that it was not their responsibility to know how the building was to be built, as that was a problem for the *principal contractor* (Gibb 2004). It appears that there are areas of weakness in the UK approach to regulating designing for safety in construction works.

Nevertheless, Gibb (2004) revealed that significant work had been done in the UK to provide practical design tools to improve construction site safety and health. For example, a renowned designer Ove Arup has produced "Work sector guidance for designers" for the Construction Industry Research and Information Association (CIRIA). The revised report provides advice for designers of various elements of building and civil engineering projects (CIRIA 1997/2003). Additionally, revised *CDM 2007 regulations* came into force on April 6, 2007 with the focus on effective planning and management of risk – 'manage the risk not the paper work' (HSE 2007a). The regulations of 2007 can ensure that construction projects are safe to build, safe to use, and safe to maintain and deliver good value (HSE 2007b). Nonetheless, CDM 2007 regulations require choosing a competent team and helping them to work safely and efficiently together.

SUMMARY AND CONCLUSION

Designers including architects, engineers and related technical experts, should give 'designing for safety' a high priority. Safety will improve if a design process is well managed in terms of construction safety mitigation. By addressing safety during the design process, hazards can be eliminated or reduced during construction, thus improving the safety performance of the constructor. Also, there is a need to create design documents that address worker safety throughout the design process. The success of design for safety depends upon the joint efforts among stakeholders including owners, designers, researchers, educators, practitioners, manufacturers, and policy-makers. By sharing and collaborating opportunities and challenges, progress on injury prevention can be made by adopting the safe design. Additionally, designers are urged to understand that their job is to design use of the facility, not just to design the facility.

Despite the implementation approaches that need to be improved and a mixed performance, the authors do not want to end the discussion with a negative note. The designers are urged to take a reasonable share of ownership of safety in their designed product and service. Designers are urged to agree to a safety policy for designers so that safe design practices would flow. It is stressed that designers should develop their own 'safety culture' for contributing towards a safer construction. Also, the authors would like to make a strong appeal for studies to be undertaken on designing for safety. The authors believe that there is an utmost need to develop modern design standards. Implementation and use of modern design standards and tools can foster change in the construction industry of respective countries. Use of safe design standards and tools can generate additional safety suggestions, which are to be incorporated into future versions of design software. Continuous use of safe design standards and tools can lead to further development of functions in the safe design programs to better meet the needs of designers.

It is believed that this study will help in developing awareness and understanding of designing for safety concept when there have been little progress in producing designs that are safer to construct. This study may be helpful to provide background information to regulatory agencies in policy making, and architects, design engineers, developers, project owners, and safety professionals in project level decision making about utilizing the design for construction safety concept and applying it in practice.

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