# Comparing Safety in Design Approaches and Tools in the US, UK, and Australia

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## Abstract

Excepting Europe and Australia that have enacted laws to increase the level of involvement of designers in the Prevention through Design process, contractors in many parts of the world are often found to be the sole implementers of construction hazard prevention. In depth analysis of literature related to occupational safety hazards indicates that addressing worker safety during design is a valuable contributor to the reduction of hazard rate of workers found in the construction industry (Gambatese et al. 2005). This research aims to determine tools and processes architects and designers are currently utilizing in conjunction with construction experts to address construction worker safety during design. The focus of this research is to determine the influence of tools and emerging technologies such as BIM and to harness collaboration between professionals in the field to aid designers in considering worker safety on construction sites. Based on the findings from the present stage of the research, it can be concluded that BIM can be a valuable tool for implementation of construction worker safety by designers. Along with other strengths of BIM, it also incorporates multiple facets of the construction industry. However, in countries such as the United States, where the laws have not yet been enacted for designers to practice construction worker safety, it is recommended that the concerns of professional and legal liability of designers and knowledge barriers should be addressed before considering utilization of BIM.

**Keywords: PtD, Design, Safety, BIM, Hazard**

## 1. Introduction

Funded by the National Institute of Occupational Safety and Health, as part of an industry wide Prevention through Design initiative, this research aims to determine tools and processes that can harness an earlier application of construction hazard, Prevention through Design. Occupational fatalities in the construction industry account for 23% of all work related fatalities, while they only employ 7% of the workforce (Behm 2008). Earlier studies on Prevention through Design (PtD) indicate that the design aspects of a project can significantly impact the rate and extent of construction site accidents. One such study aimed at analysing policies regarding accident prevention on construction sites, particularly the efficacy of one of the first directives that incorporated Prevention through Design. The study

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found that accident and incident rates had declined by at least 10 percent after the directive went into effect in ten countries in the European Union (Aires et al. 2009).

However, barriers in the industry are preventing widespread and thorough implementation of construction hazard prevention through design. These barriers include but are not limited to perceived legal and professional liability, lack of knowledge of the construction industry, lack of motivation for designers to take construction hazards into consideration, and lack of facilitation of collaboration between designers and constructors earlier in a project (Gangolells et al. 2010). In this article, we discuss findings from a study on how tools can overcome some of these barriers, and help designers in practicing construction hazard prevention in the design phase.

## 2. Research Objectives and Methods

The motivation for conducting research in this area lies in determining existing tools used by designers to address construction worker safety, and the effectiveness of these tools in harnessing collaborative insights of other professionals in the field for a comprehensive application of construction hazard prevention through design. The research also simultaneously attempts to analyse the existing barriers, if any that exist for designers in applying design for safety and, to explore if any tools and methodologies can mitigate the impact of these barriers.

The tools and methodologies that are under consideration in the research are Integrated Project Delivery (IPD), Hazard Identification Tools, Risk Assessment Tools, Procedural Guidelines, Visualization Tools, BIM, Semi-Automated Decision Support Systems. It must be brought to attention that the research found discrepancies in how literature defined these tools and methodologies, and how individuals practiced them. Thus, what can be summarized from the interviews is a more general overview of tools and methodologies that firms are utilizing for applications of Construction Hazard Prevention through Design. This research has been conducted in three phases to cover aspects of design for safety.

The first phase consists of expert panel interviews in order to gain general insight into the existing tools and methodologies, and their application in design for construction worker safety. Experts interviewed are determined through their academic publications, organization affiliations, and the innovative nature of the firm they work for. The first phase is not a comprehensive phase as its objective is to set the stage for the next two phases of in depth research.

The second phase incorporates a comprehensive industry wide survey to gain a greater sample size, and gather key metrics that indicate observable patterns in ways different professionals are utilizing Prevention through Design tools. Subsequently the survey aims to identify the most effective and accepted tools and the strength, weakness, and opportunity for further development of tools. The third phase focuses on assimilation and analysis of data collected in phase two; to identify tools being utilized and the method of implementation of tools in the applications of prevention through design in projects. Additionally, the third stage of the research is an in depth case study that aims at receiving more specific insights of what tools are being utilized and how they are implemented in the applications of Prevention through Design in practice. In this paper, the findings from the first phase expert panel interviews are discussed.

## 2.1 Expert Panel Participants

The expert panel interviews in the first phase consist of interviewing thirteen professionals in the design and construction industry in three countries: USA, UK, and Australia. The UK and Australia have been selected as comparison points with the United States, because of existing established regulations that allocate responsibility on designers for addressing worker safety. In the UK, CDM regulations have been allocating responsibilities onto the designer for addressing worker safety in the construction industry since as early as 1994 (Mackenzie et al 2000). Similarly, Australia has also put into effect a requirement for designers to address worker safety, for more than a decade (Bluff 2003). Due to the pre-established nature of these regulations, firms located in both countries have also had a considerable amount of time to refine their utilization and knowledge of designing for construction worker safety. However, in the United States regulatory requirements are still undeveloped and at a nascent stage. Therefore, a comparative study of regulatory environments for firms in Australia and UK to the United States served as a good indicator of the impact of applicability of tools in predicting barriers to implementation of design for safety.

Professionals interviewed have been selected from diversified backgrounds and belong to work in varying fields of specialization within the industry. The selection has been made to facilitate understanding of the correlation between professional backgrounds and the tools being utilized. Garnering multiple viewpoints on tool utilization aids in speculating as to how these tools can be used to harness collaboration of different backgrounds on design for safety. Table 1 categorizes the participants by company type and region. The firms being represented by the interviewees specialize in Architecture, Health and Safety Management, Construction Management, Design-Build, Façade Consulting, Structural Engineering, and Architectural Engineering. Of the thirteen professionals that have been interviewed, five of them were architects, one of whom with a background in health and safety working in a UK architecture firm, one an architect who is a US façade consultant, two US architecture firms, one who is directing the design division of a US design-build company, and one Australian architect.

***Table 1: Expert Interview Participants***

| Region / Company Type | USA | UK | Australia | Total |
|---|---|---|---|---|
| Architecture | 3 | 1 | 1 | 5 |
| Engineering/Consulting | 2 | 1 | | 3 |
| Construction | 2 | | | 2 |
| Safety Coordinator | | 1 | 2 | 3 |
| Total | 7 | 3 | 3 | 13 |

Safety coordinators were from the UK and Australia with backgrounds in health and safety and civil engineering. Additionally, Construction professionals from one US mechanical contractor and one US general contractor participated.

The information collected from the professionals interviewed has laid focus on their academic background and specialization, nature of their work, utilization of BIM and number of years of experience, strategies, and tools. The interviews also asked about knowledge of Prevention through Design(PtD), Design for Safety(DfS), buildability and/or constructability for worker safety, maintainability for worker safety, standards/regulations, company standards (laws, implementations), etc., and other tools and methodologies the firms may currently be using but not defined by literature yet.

## 3. Expert Interview Results

The primary objective of the expert interviews was to understand how designers incorporate construction workers' safety into the design process and what tools they use. Considering the different regulatory and industry context of US, UK and Australian practitioners, specific questions were asked.

1. How do practitioners consider worker safety in design in comparison to the design process identified in literature?

2. How do designers' approaches differ in the UK and Australia from the US?

3. What tools are mostly used by designers to prevent construction hazards?

### 3.1 Tools in Literature

Hazard analyses and risk assessments are central to safety in design approaches (Manuele, 2008a; 2008b). However, hazard recognition is quite difficult given the complexity and size of the building systems designed (Gambatese, 2008). Manuele (2005) indicates that construction planners typically rely on professional and personal experience and group assessments to determine risk levels. While PtD tools have the potential to support and improve designers' knowledge and skills of hazard recognition and facilitate communication between the designer and constructor, assisting designers to overcome their lack of expertise in construction safety and health issues, a limited number of tools are available (Ku and Mills, 2010). There are checklists such as the "Design for Construction Safety ToolBox (Gambatese et al., 1997), risk assessment forms in paper or software format (Duffy, 2004; Gambatese, 2004; Hecker et al., 2004) which are used by experienced professionals who qualitatively evaluate the risks of specific hazards and to rank the level of risk.

In order to facilitate hazard identification and risk assessment, a number of researchers have developed prototypes that automate hazard analyses and risk assessment. ToolSHeD (Cooke et al., 2008) captures expert reasoning through argument trees to assess the risk of falling from height during roof maintenance work. The prototype provides interactive risk assessment via an online interface that generates the risk level of specific activities or materials. Nussbaum et al. (2009) developed a decision support system of residential panelised walls to identify high levels of musculoskeletal disorders risk. The tool is based on breakdown tasks and laboratory based simulations and modelling to mathematically and computationally calculate ergonomic risks, and supports design optimization of panels. Sacks et al. (2009) developed algorithms to estimate the likelihood of exposure of construction workers to loss-of-control events. Their prototype software was used to assess risk levels of spatial and temporal exposure events of falling objects onto workers below. Zhang et al. (2012) proposed to incorporate automated safety rule checking into BIM for falls hazards. Table 2 classifies research areas by their application algorithms and interfaces. The majority of tools focus on construction planning while a few extend their approach to design for safety. With the continuing adoption of Building Information Models (BIM) in construction, there is an increasing interest in utilizing 3D models and visualization for hazard analysis.

***Table 2: Automated Hazard Analysis Tools***

| Algorithm / Interface | Construction Planning | | PtD – Safety Design Optimization |
|---|---|---|---|
| | Hazard identification | Hazard Identification/Risk | |
| Text based interface | | | Cooke et al. (2008) |
| 3D model interface | Zhang et al. (2012) | Sacks et al. (2009) | Nussbaum et al. (2009) |

In addition to the above mentioned tools, others recommend a structured review process (Gambatese, 2004) such as the Australian CHAIR tool which provides detailed and systematic examination of the construction, maintenance, repair, and demolition safety issues. Under the UK CDM regulations, the Safety-in-Design knowledge benchmark (SiD) plan is promoting a standard for Safety in Design for designers.

While literature shows various approaches and tools to address construction safety, there is a lack of understanding of what tools design and construction professionals use in practice. The following sections describe the findings from the expert panel interviews.

## 3.2 Design for Safety (DfS)

Designers who were interviewed from the UK and Australia seemed more receptive and comfortable with the applications of construction worker safety. This was due to the fact that they were already working within the norms of established regulations that required designers to be involved in designing for construction worker safety. When the designers from the US were interviewed, we observed a pattern was found that indicated a lack of comfort on applications of designing for construction worker safety. In some cases, designers explicitly did not find any reason to practice construction worker safety, as they felt it was the contractor's responsibility. However, designers practicing in the US were knowledgeable on primarily operational and maintenance aspects of worker safety related to OSHA requirements. Due to the established regulatory requirements and the generally rigid nature of role designations in the industry, designers in the United States felt obligated to address maintenance/operation worker safety. Other barriers to the applications of construction worker safety were legal liability, lack of comfort/knowledge of the construction trade, and lack of interaction with the constructor under specific project delivery methods.

### 3.2.1 Liability

Considering the liability concerns of design professionals, the expert panel was asked about how they addressed worker's safety. A UK architect of a full service high profile international firm mentioned that they develop method statements for cleaning, maintenance, and replacement operations which may involve hazardous conditions such as window cleaning at heights. This architect's firm designs a large number of non-standard buildings that involve complex geometries. Regarding construction worker safety and health concerns, the firm has a set of design guides addressing constructability and buildability that incorporate general safety concerns such as masonry unit sizes to reduce musculoskeletal injuries or use of prefabricated systems to reduce falls hazards. Similarly, an Australian architect of a small size firm who identified his focus on design for safety, explained his primary concentration on maintenance and operation phases rather than construction. But he also mentioned that prefabrication was a main consideration for buildability.

Interestingly, while the UK architect and Australian architects were receptive to practicing design-for-safety, their main area that they felt responsible for was on maintenance and operation phases similar to US architects.

The majority of the expert panellists mentioned that they would involve facility management personnel of the client, consultants, and constructors to address maintenance and operation safety issues. One architect of a US design-build company where the design team has direct internal relations with the construction team in addressing construction worker, mentioned familiarity with safety guidelines and risk assessment tools.

The research also indicates that incentives for designers to consider construction worker safety are very few; some of these incentives include contractual requirements on behalf of the client in highly specialized facilities.

## 3.3 Codes, Checklists, Company Manuals

To find out about the design for safety tools mostly used by designers, questions were asked about hazard identification, risk assessment, company manuals. The majority of interviewees, regardless of profession or country of origin agreed that written assessments and checklists were tools that were limiting and often ineffective. Designers believed that written assessments were not conducive to their design methodology, and suggested usage of more qualitative tools for risk assessment and hazard identification. The success of utilization of risk assessments and hazard identification by designers relied heavily on applying open ended and less prescriptive tools to prevent any constraint on the designer's objectives.

### 3.3.1 Hazard identification

Interviewees in construction and engineering firms identified themselves more with checklists and risk assessment matrices. A founder of a UK structural engineering known for their innovative projects mentioned the applicability of checklists for younger and inexperienced engineers to ensure that all integral aspects to a project had been addressed. Additionally, interviewees suggested a strong reliance on the expertise and knowledge base of key stakeholders in the project, or expert guidance from consultants outside of the project, instead of following set procedures or guidelines.

### 3.3.2 Risk assessment

In response to the use of risk assessment tools, an Australian safety professional detailed that their firm was utilizing process mapping rather than risk assessment matrices to identify health and safety drivers. Another designer mentioned that their UK based firm utilized a less prescriptive methodology in addressing risk assessments. The interviewee described the risks being segregated into low, medium, and high risk categories, and diagrams and drawings were attached to each category to make it user friendly for designers.

### 3.3.3 Company manuals

The expert panellists also described internal company databases that were compiled and updated based on changing (1) regulatory requirements and (2) lessons learned from projects. The majority of the US designers did not have formal databases but referred to OSHA standards. A US general contractor explained their use of a searchable database for lessons learned and OSHA requirements. The UK architect and UK CDM coordinator described the use of internal knowledge management platforms and company standards that integrated lessons learned and best practices. An innovative design firm in the UK also mentioned their internal program that was responsive to designer specifications.

## 3.4 Quality Control

The panellists were asked about utilization of structured design reviews during various phases of the project. The design review process is a quality control measure and serves as a method of lessening the perceived liability by designers. Incorporating the insights of experts and key stakeholders not only aids in ensuring quality control, but also helps the designer to feel more confident about applying design for safety principles.

### 3.4.1 Design review

All US, UK, and Australian designers described the use of a review process that incorporated constructability reviews and/or code reviews. One US architect who works for a general contractor mentioned the use of constructability reviews (30%, 60%, 90% completion) through work groups who would have experience with incident reviews. The three US architects explained that internal senior technical reviewers or consultants would review design documents. One of them required facility personnel to be a part of the design and construction review process, to ensure that aspects of the building process were consistently addressed. However, construction workers' safety was not part of such reviews. The UK architect explained the participation of specialized groups and peer reviews that would involve people with construction backgrounds and design backgrounds to ensure the adequacy of the deliverables. The Australian architect mentioned engaging all related stakeholders through assessment workshops. Another prominent structural engineering firm utilized a designated formal review team to inspect adequacy of project deliverables.

An Australian Safety Professional mentioned the utilization of CHAIR, Construction Hazard Assessment Implication Review, which facilitate collaboration between various stakeholders in order to address construction, maintenance, and demolition safety risks. He explained this as a three stage process of (1) identifying issues and concerns, (2) risk assessment, and (3) identifying residual risks, which would be facilitated through workshops with stakeholders including the designers. As a CDM coordinator of a UK firm explained, they would coordinate safety in the same manner whether they would work with internal engineers or external team members.

The majority of architecture and engineering firms in the US were unfamiliar with a similar formalized process that addresses worker safety as there no such regulation in the US. One variation of a procedural guideline was a project delivery manual in a US Architecture firm that was utilized as a quality control method to incorporate the expertise of senior level technical professionals that participate in determining if construction documents complied with regulatory codes.

## 3.5 Building Information Modeling (BIM), Visualization, and Automation

Building Information Modeling Systems that interviewees most commonly mentioned were Revit, Navisworks, Tekla, and AutoCAD. Synchro LTD for 4D simulation and Solibri for code checking were also acknowledged. In spite of observed differences in the motivations for reasons why firms practiced design for safety, the majority of the interviewees provided similar insights into the strengths of utilizing Building Information Modeling (BIM) in the field. Interviewees stated that the strengths of BIM lied in physical clash detection, managing larger and more complex projects, and aid in collaborating with other professionals and stakeholders on the project. The ability of BIM to manage a large amount of information in a project, ranging from the project schedule to analysing the constructability of a building made it a powerful tool in fostering the collaboration of a wide variety of expertise in the industry.

Overall, BIM was seen as a beneficial tool in communicating various aspects of a project, and design firms emphasized its a value as a visualization tool in communicating all aspects of a design, and communicating effectively to the constructor, and receive feedback about their project during design reviews.

The collaboration through BIM tools seemed beneficial to the designer as it lessened the extent of legal liability through enhanced collaboration. As a result, the designer may be better placed to practice design for worker safety. Interviewees mentioned utilizing BIM to analyse the constructability of a building, as well as operation and maintenance. A US architect of a design-build firm asserted on more than one occasion, that designer’s would prefer utilizing BIM to consider worker safety over checklists and other prescriptive tools that were traditionally used by contractors. One of the main reasons was the belief that checklists and risk assessments stifled innovation and creativity of designers due to their prescriptive nature.

The US architect of the design-builder mentioned utilizing BIM to check code requirements in their respective country.  The other US construction company mentioned using BIM to check if the structure complied with all operational and maintainability requirements by OSHA.

Perceived drawbacks of BIM included difficulty of managing and navigating larger projects, and the time and resources that tended to be invested into managing a BIM document. Therefore, in order for the BIM model to be completely successful in utilization for design for safety, further development of BIM is necessary.

When asked about (semi) automated Decision Support Systems, none of the panellists suggested using such tools, due to the nascent stage of this tool in research and practice. The majority of interviewees were not familiar with it. However, interviewees did show an interest in integrating current company processes into a tool that incorporates other tools they are utilizing. Additionally, existing usage of internal company databases and manuals indicated an opportunity to apply databases to automated tools.

## 4. Conclusions

As part of a three stage research, the expert panel interview conducted with thirteen US, UK, and Australian professionals on the implementation of construction hazard tools led to preliminary insights of the different and similar attitudes of designers in the US, UK, and Australia. Coinciding with the common belief, US designers have a resistance towards the consideration of construction hazards during design stages because of the lack of in depth knowledge of construction processes and safety hazards. The US panellists were also not clear as to how the construction hazards could be incorporated into the design phase of the project.  Fear of legal and professional liability was a major deterrent for them to consider implementation of these worker hazards. However, while the UK and Australian architects demonstrated more confidence and familiarity with the notion of construction hazard prevention, their primary focus of hazard identification and risk assessment related to the maintenance and operation of buildings rather than construction hazards. This corresponds to the responsibility of US architects who similarly consider maintenance and operation worker safety. Hazards during maintenance and operation phases of a building such as window cleaning, safe access to equipment on roofs, etc., required design considerations by architects in all three countries.

The extent of identification activities of maintenance and operation hazards by designers was somewhat different between US, UK, and Australian designers. The UK and Australian architects explained internal procedures of design guides, assessment workshops, and structured reviews that address not only code requirements but also lessons learned throughout their projects. The US designers were concerned more with satisfying code requirements (OSHA) and had not developed or used internal design guides or assessment workshops but some involved stakeholders beyond the design team if requested by the client.

Regarding hazard prevention tools for design, all architects indicated that prescriptive checklists were ineffective and preferred visualisation tools in general. The UK and Australian architects emphasised that hazard identification also depended mostly on the experience and knowledge of personnel and was oftentimes assured through design reviews of senior technical personnel. In contrast, the UK structural engineer found checklists effective for entry level engineers.

US designers were mostly unaware of hazard identification checklists and risk assessment forms. UK and Australian architects utilized risk assessment forms to qualitatively rank low/medium/high risks but mentioned that those forms were rather used for reporting purposes and the panellists warned that the forms are prone to get challenging and time consuming on larger projects.

The expert interviews also revealed that the panellists consider BIM an effective communication and visualization tool. But it is currently not well integrated into processes and should incorporate more functions that can facilitate and motivate designers in practicing construction worker safety. Structured review processes do harness collaboration and ensure quality control of company processes, but are depend on who they can incorporate into their reviews. By establishing a standard set of procedures for firms to practice and address some of the shortfalls of BIM, developing a motivational force for designers to practice construction hazard prevention may be possible.

The expert panel interview results have offered valuable insights of design for safety practices in US, UK, and Australia. The results are used to guide the second phase of this research which will gather broader perspectives of US, UK, and Australian practitioners through an online survey.

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