Research needs for Building Information Modeling for Construction Safety

Dr. Kihong Ku and
Thomas Mills, RA
Virginia Tech
Blacksburg, Virginia

Literature indicates that there is a lack of responsive tools and resources to assist designers with addressing construction safety. Current tools are primarily text-based standalone check-sheet type tools which are either accessed via paper or software interface. Simultaneously, the current and growing movement of BIM in the construction industry is offering new means and approaches to improve the inefficiencies of paper-based processes. In an attempt to take advantage of the potential of BIM for safety in design and to facilitate its integration, this paper outlines the primary characteristics of existing design-for-safety (DfS) tools and elaborates on the potential of BIM for safety. The paper classifies BIM by functionalities and maps applicable DfS concepts to describe the constraints. The paper identifies future research needs for key parameters of BIM tools to better address safety considerations and suggests that a BIM for Safety approach which incorporates understanding of hazard recognition and design optimization could lead to creating a built environment that successfully integrates safer construction processes.

Key Words: BIM, safety, design-for-safety, hazard recognition, risk assessment

Research Goal and Methodology

The focus of the paper is the promise of Building Information Modeling enabled Design-for-Safety tools and its needs assessment for support of earlier collaboration between the designer and constructor. Traditional design-for-safety tools are presented and the promises of commercial BIM tools are reviewed and mapped to identify the shortcomings of currently available tools. The primary research sources for this paper are from structured literature reviews and on-going research on BIM tools by the authors. The paper also includes observations and expertise of the authors.

Design for Safety Approaches

In 2004, the National Bureau of Labor Statistics published the disproportionately high number of occupational fatalities in construction which accounted for 23% of all work-related fatalities while only employing 7% of the workforce (Behm, 2008). The National Construction Agenda (2008) notes that design aspects are the missing pieces in a holistic approach to enhance construction worker safety. Various studies found that design considerations could prevent or reduce a significant percentage of incidents (Gibb et al., 2004; Gambatese et al., 2005). Addressing this concern, European countries and Australia have employed and implemented Prevention through Design (PtD). Specifically, in 1994, the UK CDM regulations (HMSO, 1994) allocated responsibility for addressing project safety on all of the parties involved in the project (Gambatese et al., 2008). Similarly, Australia mandated since 1998, a design requirement for consideration, evaluation, and control of occupational safety and health during construction on all State projects having a value of AU$3 million or greater (Behm, 2005). Under this initiative, the Construction Hazard Assessment Implication Review (CHAIR) process (Hecker et al., 2005) requires a structured review process that incorporates focused reviews at different stages of design.

While construction safety is typically not included in the responsibilities of architects, there is a growing interest among owners to improve safety. A recent practice report published by the AIA (Piven & Silverman, 2006) states that federal clients put emphasis on sustainable design and safety concerns in their selection criteria of architects. Safety concerns in this report particularly relate to the safety of the end users and the general public but there is also an increasing interest in environmental issues that have drawn interest in design for deconstruction (Drogemuller, 2008). The Business of Architecture – 2003 AIA Firm Survey reports that 44 percent of the work done by architecture firms nationwide in 2002 were concerned with building rehabilitation, indicating the enhanced role of architects in planning, documenting, and specifying demolition work (Diven &Taylor, 2006). This involves not only the protection of the general public and adjacent property but also the worker.

While the U.S. lacks regulatory requirements for PtD (Hecker et al., 2005), precedence from the UK (Istephan, 2004;WorkCover, 2001) including leading architectural and engineering firms (e.g., Foster and Partners, Arup, etc.), changing U.S. client demands such as the Intel Corporation (Hecker et al., 2004) or Harvard University (2010), and a few large construction firms such as Jacobs Engineering, Bechtel, Washington group, BE&K, Southern Company, Haskell, Parsons (Behm, 2008) illustrate the growing awareness of PtD. Behm (2008) discusses the lack of systematic research design for case studies of the various PtD systems, practices, and methods, of these larger firms. Maloney and Cameron (2004) reported that even in the UK, designers were lacking an understanding of their responsibilities and furthermore missing the capabilities to implement safety in design. Literature identifies a number of barriers to PtD practice (Hecker et al, 2005):

- OSHA places safety and health responsibility on the employer, most often the general or trade contractor in construction.
- Architects and engineers fear added liability for involvement in construction safety (Gambatese et al., 2008; Behm, 2005).
- Construction and design practice tends to be narrowly specialized (Gambatese, 1998).
- Preconstruction collaboration between the designer and constructor is commonly minimal due to the traditional contracting structure of the construction industry (Toole, 2005).
- Safety-in-design tools, guidelines and procedures are not widely available (Toole, 2005; Gambatese, 2000).
- Architects and engineers receive little or no formal education on issues of construction worker safety (Behm, 2008; Weinstein et al., 2005; Toole, 2005).

Given the division of labor between design and construction, the authors argue that the focus design-for-safety practice and emerging supporting tools should focus on facilitating earlier collaboration between the designer and constructor, rather than designating architects and engineers as the primary entity for construction safety.

The Need for Development of Tools for Construction Safety

Maloney and Cameron (2004) categorize these barriers into capability, opportunity, and motivation of designer's qualifications. *Capability refers to the possession of the knowledge, skills, and abilities pertinent to identifying potential hazards, conducting risk assessment, and revising the design or providing control measures to avoid or minimize the risk. Opportunity is related to project delivery systems that allow collaboration between the designer and constructor so that the designer's safety plan incorporates actual construction methods and allows buy-in from the contractor. Motivation is necessary to promote collaboration beyond the practice conventions and constraints of fee structures. Currently, the primary motivation in the UK comes from CDM regulations while the U.S. is rather limited to contractually imposed client requirements.* However, even in the UK many designers lack the motivation to fulfill their regulatory requirements. The authors suggest that BIM may be adopted to develop new tools that better assist the design for safety process and accordingly increase participation of designers with safety. While Gambatese (2008) discusses the need for PtD tools, devices, processes for designers who lack expertise in hazard recognition and risk assessment, there is little research that has examined the effectiveness of current PtD tools.

Overview of Design-for-Safety Tools

At the core of the safety in design concept are hazard analyses and risk assessments (Manuele, 2008a; 2008b). Hazard recognition is quite difficult given the complexity and size of the building systems designed (Gambatese, 2008). PtD tools have the potential to support and improve designers' knowledge and skills of hazard recognition. Simultaneously, it can facilitate the communication between the designer and constructor, and thus assist designers to overcome liability concerns associated with means and methods and compensate for their lack of expertise in construction safety and health issues. However, currently, only a limited number of tools are available. One type of tools is checklists either in paper format or software format such as the "Design for Construction Safety ToolBox (Gambatese et al., 1997). These tools incorporate a list of safety items to be addressed during design reviews and are integrated into a database system. The Design for Construction Safety ToolBox allows user to access hazard information related to specific activities, design features or project systems. Another category of tools are risk assessment forms in paper or software format (Duffy, 2004; Gambatese, 2004; Hecker et al., 2004). An example is the ToolSHeD (Cooke et al., 2008). This tool provides interactive risk assessment via an online survey interface that generates the risk level of specific activities or materials. A few case studies illustrate that standard simple forms offer a systematic way to evaluate and compare between different design alternatives (Duffy, 2004; Hecker et al., 2004). A third category of tools focuses on documentation of a structured review process (Gambatese, 2004). An example is the Australian CHAIR tool which provides detailed and systematic examination of the construction, maintenance, repair, and demolition safety issues associated with design (CHAIR). Also under the CDM system in the UK, the Safety-in-Design knowledge benchmark (SiD) plan is promoting a standard for Safety in Design for designers. The last category of tools are 3D, and four-dimensional (4D) computer-aided-design (CAD) models which assist in visualizing 3D components to detect interferences between building systems and spatial-temporal workspace conflicts during construction. While a few case studies (Duffy, 2004; Hecker et al., 2004; Design Best Practice, 2010) highlight the effectiveness of such tools, the evidence is anecdotal and hence there is a need to better understand the impact of these tools on PtD processes. Table 1 outlines the current application of existing tools and indicates the limitations of these tools. Therefore, research should focus on the limitations of current tools and investigate new approaches that can utilize BIM technologies.

Table 1

Summary of current Design-for-Safety Tools (modified from Gambatese (2004))

Type	**Tool examples**	**Application**	**Research Needs**
Hazard recognition	Checklists Computer software (ToolBox)	Safety analysis and design review	Integration with drawings and context awareness of specific building types, size, environment, etc.
Risk assessment	Risk mitigation forms Computer software (ToolSHeD)	Evaluate hazards associated with specific design options and propose mitigation strategies to support decision-making	Development of metrics to measure impact of design strategies and integration of dependencies between strategies
Procedure	Review tools (CHAIR)	Structured review process to incorporate reviews utilizing prompts	Integration of safety needs with other project goals
Visualization	3D/4D CAD Virtual construction	Visualize spatial-temporal conflicts	Development of simulation tools to support design optimization

Characteristics of the Design Process

Standard practice defines design as a linear process that proceeds from schematic design through design development to construction documents. The American Institute of Architects (AIA) B141 – Standard Form of Agreement between Owner and Architect – or Royal Institute of British Architects (RIBA) Plan of Work define that design and building are sequential and independent functions (Istephan, 2004; Allen et al., 2005). The designer is thought to have a unique and specific expertise in the planning, schematic design, and contract administration functions. The builder's expertise is in turn limited to the implementation of the means and methods of construction to manifest the design intent in the built structure. The disparate functions of the design and building team hinder the designers' capability to identify and mitigate health and safety risks during early design stages. Szymberski (1997) notes that the impact of design changes are less disruptive and costly early in d design than during later design phases. To assist the design team in the preparation of design documents, the UK CDM regulation assigns a planning supervisor at the beginning of the design phase (Duffy, 2004).

Traditional constructability reviews are scheduled at specific times – milestones in the duration of the project – to incorporate budget, schedule, and quality considerations. A number of case studies (Duffy, 2004; Hecker et al., 2004), research reports (Gambatese, 2000), and design-for-safety review tools (CHAIR), suggest that safety in design, is conducted in the form of design reviews which roughly coincide with the main phases of design (e.g., 30%, 60%, 90% of the design progress) (Gambatese, 2000). However, oftentimes the design process results in multiple iterations through the redundant spiral of design reviews, constructability analysis, and value engineering that may compromise the design intent. For example, some of the elements incorporated in designs which have undergone review during the early stages in the process are sometimes lost or changed by others through a value engineering exercise, eliminating some of the better design solutions not actually transferring to the construction process (Istephan, 2004). To address this problem, innovative firms like Foster and Partners have integrated a feedback loop into their Q.A. system to analyze and reexamine health and safety implications of design changes.

A key factor that contributes to such an iterative design process is the division of design responsibilities between various types of designers. Ku et al. (2008), distinguish between the internal design team (which is hired by the designer who is responsible for the planning, schematic design, and contract administration functions) and the external design team (which is hired by the owner and thus not in contractual relationship with the designer). Gibb et al. (2004) define four types of designers such as the permanent works designers, materials designers, equipment designers, and temporary works designer. Pietroforte (1995) focuses on the role of trade contractors who are responsible for producing shop drawings. The design process typically spreads the design of complex building components throughout the construction activities beyond the bid stage. The fabrication, assembly, and erection of steel structures, façade systems, mechanical and electrical services, require design by specialist contractors who communicate via shop drawings (Pietroforte, 1995). The division of design phases and design responsibilities indicates that different types of designers have different levels of influences on reducing risk. Such a design process also necessitates the need for effective procedures and tools to share information between various types of designers. Thus, design teams need to collaborate with trade contractors for risk assessment, and trade contractors must include health and safety recommendations from the planning supervisors and designers into their construction methodologies.

BIM Support for Design-for-Safety

Computer-aided-design (CAD) has enabled architects to produce more accurate drawings, more quickly and easily, offering increasing support during the stages of design development and production of construction documents. BIM allows various analyses during early design phases to engage clients and to support facility management and life-cycle costs analyses. During the construction phase, information technology can prove crucial to the success of a project by effectively controlling schedule, budget, and quality, and by reducing risks. Information flow from design to construction is critical and, when efficiently controlled, it allows for design-build and other integrated project delivery methods to be favored. BIM is the most recent terminology for these CAD tools and processes that has gained acceptance in the AEC industry. Examples show that BIM is used to enhance sustainability, to enhance geometry control in non-standard buildings (Ku et al., 2008), and to assist construction planning, scheduling, and estimating. The impact of BIM processes has been more evident in cutting-edge buildings and innovative processes. A number of case studies have illustrated how leading international designers, who are recognized for their design and aesthetics, have implemented collaborative work via 3D modeling with contractors to enhance constructability. It is noteworthy that some of the same design firms and engineering firms also strive to influence safety and health during construction. This paper suggests that BIM offers opportunities to assist design teams to automate hazard recognition and design optimization processes.

Architects, engineers, and contractors utilize today a large number of tools which have potential to be used for design-for-safety or PtD purposes. Existing computer tools that have been used for tasks related to 3D visualization, constructability reviews and digital fabrication can be divided into the following categories: (1) 2D drafting (AutoCAD, MicroStation) (2) 3D modeling (Rhino, Maya, etc.); (3) BIM software (Revit, ArchiCAD, MicroStation, etc.); (4) 4D CAD (VICO, Synchro, NavisWorks, etc.); (5) interference checker (NavisWorks); and (6) Design Development programs (CATIA, Pro/Engineer, SolidWorks, etc.).

There are also several research teams in universities conducting research on tools. While the focus is not exclusively on safety, the proposed research suggests that there is potential to address different aspects of computational support for PtD. We can classify these approaches into one of five categories: (1) model checkers (e.g., using tools like the Solibri software to automate code compliance checking associated with PtD); (2) virtual prototyping (e.g., integrating planning and visualization of construction plans of building projects. Utilizing tools like DELMIA adopted from the manufacturing industry, allows product, process, resources to be simulated); (3) virtual worlds (e.g., customizing immersive, real-time multi-user environments such as Second Life, for design review collaborations); (4) multidisciplinary design analyses and optimization tools (e.g., Phoenix integration's ModelCenter and AnalysisServer to integrate geometry models and analysis tools); (5) agent-based modeling tools (e.g., applying concepts of autonomous learning agents to embed safety and construction knowledge into modeling systems. This approach can be integrated with virtual worlds environments). Table 2 categorizes these developments into two areas of computational support – design review and simulation – which may enhance design-for-safety processes. The table illustrates that design review tools in computational applications are focusing on adding safety hazards to 3D geometry objects with the support of database systems. As an example, such tools can easily be configured to attach specifications attributes which can identify hazardous material that should be substituted. The simulation tools focus on construction planning processes to visualize and simulate material, equipment, and worker movements that can be used to evaluate worker access and falls, etc.

The area of simulation shows various possibilities of modeling safety factors for specific process breakdown levels. Modeling safety factors involves the development of taxonomies and task analysis that link product and processes to allow for mathematical and computational implementation of decision support systems (Slaughter, 2005; Nussbaum et al., 2009).

Table 2

Developments in BIM and Computer Tools for Safety

Type	**Tool**	**Research Description**	**Strategic Focus of BIM use**
Design review	BIM integrated checklists	Construction 3D component integration with potential hazards and prevention strategies (Hadikusumo & Rowlinson, 2002)	Hazard identification
	Virtual worlds	Immersive training programs (Ku & Gaikwat 2008; Lucas & Thabet, 2008)	Training for hazard identification
Simulation	Dynamic process simulation model	Systematic evaluation of design and technology alternatives on construction process (Slaughter, 2005)	Impact of design alternatives on construction cost/schedule/safety
	Virtual prototyping	Integrated planning and visualization of construction plans (Huang et al., 2007)	Evaluation of alternative construction plans
		Decision support system for residential construction using panellised walls (Nussbaum et al., 2009)	Early assessment of ergonomic and productivity concerns
	Agent-based modeling	Simulation based on autonomous 'agents' that interact with each other and their environment (Sawhney et al., 2003)	Simulation of human behavior under alternative construction planning scenarios

The authors suggest in Table 3 that future research in the areas offers opportunities to improve commercial BIM tools for safety adoption and implementation. Design review tools can be improved by developing custom rules for hazard identification and integrating those with geometric components. Current 4D modeling tools lack the integration of construction equipment and workers while alternative virtual prototyping tools adopted from the manufacturing industry such as Delmia can provide such functionalities for detailed analysis and scenario evaluation of safety considerations.

Table 3

Research Suggestion for future BIM Tools for Safety

Type	Commercial BIM Tools	Example Tools	Suggestions for Future Research
Design review	Design Authoring Tools	Revit, ArchiCAD, Digital Project, etc.	4D model integration with hazards database
	Model checkers	Checking model against program and rule-based requirements (e.g., Solibri)	Development of custom rules for safety considerations
Simulation	4D Modeling Tools	Navisworks, Synchro, Solibri, etc.	Incorporate and develop various levels of details such as construction equipment and workers, etc. that are related to design phases
	Virtual prototyping	Delmia	Integrate agent-based modeling with construction planning to simulate impacts of design changes, delays, etc., of various design options

Conclusion

BIM for PtD tools illustrate the potential benefits of supporting both designer-led and constructor-led design processes to improve construction worker safety. The authors believe that BIM can facilitate earlier collaboration between architects/engineers and constructors, via automated checklists of rule-based safety information such as codes and regulatory information. Additionally, visualization of construction processes assists the constructor in early identification of hazards and communication with the design team to evaluate design alternatives that can be cost effective and safer. Nevertheless, there is a need for better PtD tools that can support integrated design-construction teams to better recognize hazards and to handle the complexity of specific jobsite conditions and activities. Rapid advancements in technology seem to have the potential to improve PtD tools. Previous research efforts on PtD have investigated the barriers to PtD and a few tools have been developed. However, as BIM continues to diffuse into practice, there is need to examine how BIM can support and integrate with PtD. BIM and computational tools can assist with hazard recognition, rapidly evaluate safety factors of design alternatives and enhance communication between the various design stakeholders. These tools can also integrate a feedback system that formalizes the dependencies of design decisions and allows tracking the impact of design changes associated with safety. The authors acknowledge that there is a lack of understanding of the role of the designer for safety design. Future research will address which aspects of these tools can be utilized by the designer or which functionalities may need to expand the traditional knowledge domain of designers. These areas will need to be covered by new research of integrated practices and BIM tools.

References

Allen, R., Becerik, B., Pollalis, S., Schwegler, B. (2005). Promise and Barriers to Technology Enabled and Open Project Team Collaboration, *Journal of Professional Issues in Engineering Education and Practice*, *131*(4), 301-311.

Behm, M. (2005). Linking construction fatalities to the design for construction safety concept, *Safety Science*, 43, 589–611.

Behm M. (2008). Rapporteur's Report; construction sector, *Journal of safety research*, 39, 175–178.

Cooke, T. Lingard, H. Blismas, N. Stranieri, A. (2008). ToolSHeD™: The development and evaluation of a decision support tool for health and safety in construction design*, Engineering, Construction and Architectural Management, 4*, 336 – 351.

Design Best Practice (2010, January 28). Case Studies [WWW document]. URL http://www.dbp.org.uk/

Diven, R., Taylor, M. (2006). Demolition planning, *The Architect's Handbook of Professional Practice*, 143- 153.

Drogemuller, R., (2008). Virtual prototyping from need to preconstruction, *Virtual Futures for Design, Construction, and Procurement*, Blackwell Publishing, 113 – 130.

Duffy, M. (2004). From Designer Risk Assessment to Construction Method Statements: Techniques and Procedures for Effective Communication of Health and Safety Information, *Proceedings of the Designing for Safety and Health in Construction Research and Practice Symposium*, Eugene, OR: University of Oregon Press, 118 – 135.

Gambatese, J. (1998). Liability in Designing for Construction Worker Safety, *Journal of Architectural Engineering*. *4*, 107-112.

Gambatese, J. (2000). Safety Constructability: Designer Involvement in Construction Site Safety, *Proceedings of the American Society of Civil Engineers (ASCE) Construction Congress VI*, Orlando, FL, 650-60.

Gambatese, J. (2004). An Overview of Design-for-Safety Tools and Technologies, *Proceedings of the Designing for Safety and Health in Construction Research and Practice Symposium*, Eugene, OR: University of Oregon Press, 109 – 117.

Gambatese, J., Behm, M., Hinze., J. (2005) Viability of Designing for Construction Worker Safety, Journal of Construction Engineering and Management, 131 (9), 1029-1036.

Gambatese, J. (2008). Rapporteur's Report; Research Issues in Prevention through Design, *Journal of Safety Research, 39,* 153–156.

Gambatese, J., Behm, M., Rajendran, S. (2008). Design's role in construction accident causality and prevention: perspectives from an expert panel, *Safety Science, 46*, 675–691.

Gambatese, J. Hinze, J. Haas, C. (1997) Tool to design for construction worker safety, *Journal of Architectural Engineering, 3*(1), 32-41.

Gibb, A, Haslam, R., Hide, S., Gyi D. (2004). The Role of Design in Accident Causality, *Proceedings of the Designing for Safety and Health in Construction Research and Practice Symposium*, Eugene, OR: University of Oregon Press, 11 – 21.

Hadikusumo, B., Rowlinson, S. (2002). Integration of virtually real construction model and design-for-safety-process database, *Automation in Construction, 11*, 501-509.

Harvard University, (2010, January 28), Safety in Design and Construction: A Lifecycle Approach. [WWW Document] URL http://www.hsph.harvard.edu/ccpe/programs/SDC.html#register

Hecker, S., Gambatese, J., Weinstein, M., (2004). Life Cycle Safety: An Intervention to Improve Construction Worker Safety and Health Through Design, *Proceedings of the Designing for Safety and Health in Construction Research and Practice Symposium*, Eugene, OR: University of Oregon Press, 212 – 233.

Hecker, S. Gambatese, J. Weinstein, M. (2005) Designing for Worker Safety, *Professional Safety, 50*(9), 32-44

Her Majesty Stationary Office, Construction (Design and Management) regulations, Statutory Instrument 1994, 3410.

Huang, T., Kong, C., Guo, H., Baldwin, A., Li, H. (2007). A virtual prototyping system for simulating the construction process, *Automation in Construction, 16,* 576-585.

Istephan, T. (2004). Collaboration, Total Design, and Integration of Safety and Health in Design, *Proceedings of the Designing for Safety and Health in Construction Research and Practice Symposium*, Eugene, OR: University of Oregon Press, 264 – 279.

Ku, K. and Pollalis, S. (2009) Contractual standards for effective geometry control in model-based collaboration, *ITcon 14, Special Issue, Next generation construction IT: Technology foresight, future studies, roadmapping, and scenario planning*, 366-384.

Ku, K., Pollalis, S., Fischer, M., Shelden, D. (2008*).* 3D model-based collaboration in design development and construction of complex-shaped buildings, *ITcon 13*, *Special Issue Case Studies on BIM Use*, 258-285.

Ku, K., Gaikwad, Y. (2009). Construction Education in Second Life, *Construction Research Congress*, University of Washington, Seattle, WA, 1378 – 1387.

Lucas, J., Thabet, W. (2008), Implementation and evaluation of a VR task-based training tool for conveyor belt safety training, *ITcon 13, Special Issue, Virtual and Augmented Reality in Design and Construction*, 637-659.

Manuele, F. (2008a). Addressing occupational risks in the design and redesign processes, *Professional Safety*, 29 – 40.

Manuele, F. (2008b). PtD: History and Future, *Journal of Safety Research*, 39, 127–130.

Maloney, W., Cameron, I., (2004). Lessons Learned for the US from the UK's Construction (Design and Management) Regulations, *Proceedings of the Designing for Safety and Health in Construction Research and Practice Symposium*, Eugene, OR: University of Oregon Press, 69 – 80

National Construction Agenda (2010, January 28). NORA Document for Public Review and Comment. [WWW Document] URL http://www.cdc.gov/niosh/nora/comment/agendas/construction/

Nussbaum, M., Shewchuk, J., Kim, S., Seol, H., Guo, C. (2009) Development of a decision support system for residential construction using panellised walls: Approach and preliminary results, *Ergonomics*, *52*(1), 87-103.

Pietroforte R. (1995). Cladding systems: technological change and design arrangements, *Journal of Architectural Engineering*, *1*(3), 100-107.

Piven, P.,Silverman, S., (2006). Client perspectives: Federal Facilities, *The Architect's Handbook of Professional Practice*, 3 – 18.

Sawhney, A., Bashford, H., Walsh, K., Mulky, A. R., (2003). Agent-based modeling and simulation in construction, *Proceedings of the 2003 Winter Simulation Conference*, *2*, 1541-1547.

Slaughter, S. (2005). The link between design and process:Dynamic process simulation models of construction activities, *4D CAD and visualization in construction :developments and applications*, Gainesville, 145-164.

Szymberski, R. (1997). Construction Project Safety Planning, *TAPPI Journal*, *80*(11), 69 – 74.

Toole, M. (2005). Increasing Engineers' Role in Construction Safety: Opportunities and Barriers, *Journal of Professional Issues in Engineering Education and Practice*, *131*(3), 199-207.

Weinstein, M. Gambatese, J. Hecker, S. (2005). Can Design Improve Construction Safety? Assessing the Impact of a Collaborative Safety-in-Design Process, *Journal of Construction Engineering and Management*, *131*(10), 1125-1134.

WorkCover. (2001). *CHAIR safety in design tool*, New South Wales, Australia, [WWW Document] URL http://www.workcover.nsw.gov.au