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Policy, Practice, Education and Research Issues in Designing for Safety

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Abstract

Design is a complex process involving several stages from conceptual design through to construction and commissioning. In this process, the design is checked and passed to different people who may further pass it on to others for integration. Designing for safety can reduce injuries and fatalities on construction sites. This paper reviews the *designing for safety* concept and alternatives on policy, practice, education and research and suggests which issues should be developed by designers, safety practitioners and researchers. In order to better understand the concept, policy, practices, education and research issues are examined with a view to designing for safety and health in general and with particular emphasis on construction. The study concludes that safety will improve provided *designing for safety* is adopted and policy, practices, education and research issues are embraced and developed.

Keywords

Design, Construction, Designing for safety, Policy issue, Practice issue, Education issue, Research issue

1. Introduction

In 1985, the International Labor Organization recommended that consideration be given by those responsible for design to the safety of workers who will be employed to erect proposed buildings and other civil engineering works (ILO 1985). Since then, improving jobsite safety has become a major concern in construction primarily due to high costs associated with injuries and fatalities including increase in third party lawsuits resulting from construction site accidents. Many construction companies around the world have implemented safety, health, and environmental management systems to reduce injuries, eliminate illness, and to provide a safe work environment on their construction sites (Choudhry *et al*., 2008). Whilst significant improvements in safety performance have been made in the past decade, designers were not directly involved in the safety efforts (Gambatese *et al*., 1997). In an early study, Hinze and Wiegand (1992) addressed the role of designers in construction safety which showed that most designers do not address construction safety during the design phase. A large gap exists between the constructors and designers in the knowledge of and commitment to safety on-site (Gambatese and Hinze 1999).

The European Foundation for the Improvement of Living and Working Conditions (1991) concluded that about 60% of the fatal accidents in construction arise from decisions made upstream from the construction site; specifically due to shortcomings in design and organization of the work. This document provided the first claim that the design and design process are linked to construction accidents. Following that, Jeffrey and Douglas (1994) reviewed the safety performance of the UK's construction industry and argued that in terms of causation there is a definite link between design decisions and safe construction. Szymberski (1997) stated that the ideal situation for construction safety is to be a prime consideration in the conceptual and detailed design phases. His time-safety influence curve hypothesizes that the ability to influence construction site safety decreases rapidly as a project progresses from feasibility, conceptual design and detailed design, to construction and post construction. Nonetheless, the validity of Szymberski's model has not been empirically tested. However, researchers (e.g. Behm 2005) have discussed how the ease and effectiveness of designing for safety depends significantly on design stages and agreed that the ability to affect worker safety is exponentially lost over the design process.

Addressing worker safety in the design of a project referred to as *designing for safety* is gaining popularity in construction. Nonetheless, there is no consensus on what designing for safety is, and what designing for safety policy, practice, education and research are there. In order to better understand the *designing for safety* concept, a number of past studies have been examined (see Table 1). While not an exhaustive list, it is thought that the related nine (9) studies selected for this review constitute a true representation for the purpose of this study.

Table 1: List and Summary of Prior Designing for Safety Research

Reference	Summary of Research
Gambatese *et al*., (1997)	Presents over 400 design suggestions titled "Design For Construction Safety Toolbox" that can assist designers in recognizing project-specific hazards and implementing the design suggestions into a project's design.
Behm (2005)	Focuses on establishing link between construction fatalities and the design for construction safety concept. Two hundred and twenty four fatality reports were reviewed and the analysis revealed that 42% of fatality cases could be linked to the design for construction safety concept.
Kinnersley and Roelen (2007)	Show that the accidents and incidents in the aircraft and nuclear industries with a root cause in design are about 50%. The proportions for the aviation and nuclear industries are about 51% and 46% respectively.
Hale *et al*., (2007)	The paper reviews the principal findings of the twelve papers in the special issue on 'safety by design' and revealed the gap in the knowledge of the design process. The paper ends with a call for more research to study designing for safety.
Howe (2008)	Discuss suggestions of workshop participants on policy issues in 'prevention through design' emphasizing benefit-cost analysis and incentives; culture; standards, codes and regulations; and strategic alliance development.
Manuele (2008)	Discuss in short the 'prevention through design' initiative in historical and future perspective.
Lin (2008)	Discusses practice issues in 'prevention through design' highlighting issues such as business success, liability, best practices, changing culture and involving workers.
Mann III (2008)	Presents suggestions of workshop participants that 'prevention through design' education should include instruction at secondary school level, as well as work force education, and that all types of teaching, both formal and informal, classroom teaching, and practical training be included.
Gambatese (2008)	Presents many and varied 'prevention through design' research needs for which a combined effort is suggested for continued research on the topic to gain further understanding of the concept.

2. Defining Design

There is no simple definition of designing for safety. Numerous definitions of *designing for safety* exist in the academic literature, and examples of selected definitions are presented in Table 2. There is no clear agreement on *designing for safety,* which aspects of the design process are covered – where it starts and where it ends (Hale *et al*., 2007). Kinnersley and Roelen (2007) indicated that, in aviation, the operating procedures for a plane or system were considered as part of the design. The European standard on safety in machinery design also consider the instruction manual as part of the design (CEN 1991). Blanquart (2003) indicated that the space industry have an even wider definition; where designers were asked to consider how the crew and controller of a spacecraft could use the craft outside the planned design envelope. Consequently, errors related to procedure development, are considered design errors in the space industry.

Table 2: Sources of Designing for Safety Definitions

Reference	Definition of designing for safety concept
Behm (2005)	The design for construction safety concept is defined as the consideration of construction site safety in the design of a project.
Kinnersley and Roelen (2007)	'Design' is the process by which detailed specifications sufficient for unambiguous production of an entity (e.g., software item; hardware; visual display; subsystem; system) are developed to satisfy the concepts, requirements, assumptions and constraints for that entity.
Hale *et al.*, (2007)	Safe design means a design that allows and conditions as far as feasible, safe use across the whole life cycle of the product, from manufacture, construction, transportation and installation, through use, maintenance and modification, to decommissioning, demolition and disposal.

The issues for construction are numerous, which makes a definition particularly difficult. For instance in construction, designers raise queries about *designing for safety*, would it be considered part of design or would it contribute redesign. Are all engineering controls considered under the umbrella of *designing for safety*? For example, if someone designs a better working platform, is that *designing for safety*? Is *designing for safety* looking for methods to reduce work at heights through better project design? Do both examples belong to *designing for safety*? Whether the design for safety concept only includes design modifications to eliminate or reduce a hazard/risk or whether it also includes the identification of residual risk, documentation of risk and communication of this information to other stakeholders, e.g. the constructor. Additionally, whether design for safety refers to the design of the product to be constructed or the process by which it is to be constructed or both. This is another fundamental and unresolved question. Nevertheless, the concept of design in construction includes: attention during the preparation of plans and specifications for construction in such a way that construction site safety is considered; modifications to the permanent features of the construction project in such a way that construction site safety is considered; the utilization of specific design for construction safety suggestions; and the communication of risks regarding the design in relation to the site and the work to be performed (Behm 2005). Then there are issues of the uses of faulty design. Nonetheless, while the case for incorporating safety at the design stage is strong, it is not universally accepted. Therefore, the definition needs to depend on the context and purpose for which it is being used.

Various studies (Gambatese and Hinze 1999, Hale *et al*., 2007, Howard 2008, Toole and Gambatese 2008) indicated that by addressing safety during the design process, hazards can be eliminated or reduced during construction, thus improving the safety performance of the constructor. Howard (2008) states that one of the best ways to prevent and control occupational injuries, illnesses, and fatalities are to "design out" or minimize hazards and risks early in the design process. Their studies insisted that there is a need to create design documents which address worker safety throughout the design process. These studies call for the contract documents would include special details rather than typical plans and technical specifications which would facilitate worker safety. From a US perspective, Gambatese (2005) argued that many safety hazards were "designed into" construction projects. For example, when the height of parapet wall was designed to be 42 in., the parapet acted as a guardrail and enhanced safety. When roof perimeters did not contain permanently designed-in fall protection features (e.g. guardrails), worker safety was compromised. It showed that designers are in a position of to influence improving construction safety. Designers need to take the due responsibility concerning designing for construction worker safety. They need to address the complexity of the design process in construction including multiple inputs or iterative decision making. Nonetheless, policy governing to roles and responsibilities of designers in construction are in very early stages of development and ripe for some considered debate.

3. Policy Issues

In view of policy issue, Toole and Gambatese (2008) identify four trajectories through which designing for safety will evolve in the construction industry. These are: increased prefabrication, increased use of less hazardous materials and systems, increased application of construction engineering, and increased spatial investigation and consideration. Howe (2008) suggested four policy areas that are required to integrate *designing for safety* into business and governmental organization which include: 1) benefit-cost analysis and incentives; 2) culture; 3) standards, codes, and regulations; and 4) strategic alliance development. In the benefit-cost analysis and incentives area, Howe (ibid) included that *designing for safety* certification needed to be established on an individual and organizational level. He suggested that there is need to encourage government entities to adopt *designing for safety* principles and methods; suggesting the Occupational Safety and Health Administration (OSHA) of USA modify the Voluntary Protection Programs (VPP) to include *designing for safety*. He argues that cultural change must begin from the top of an organization and the CEOs must be engaged to move *designing for safety* forward. Additionally, standards, codes and regulations often have a significant impact on business performance as well as on health and safety. The impact of European and international standards on almost all countries, including on United States, business practices, is quite evident, as seen in ISO 9001 and ISO 14001. He argues that the next step should be the development of a generic American National Standard Institute (ANSI) consensus standard on *designing for safety* applicable to all sectors. The standard can be used as the basis for organizational and individual certification. Nonetheless, launching an effort to develop an ANSI standard can better define *designing for safety* and raise awareness of *designing for safety* by generating ongoing discussion and publicity. Best practices of *designing for safety* need to be developed including internal design guidelines, organizational models, management systems, design review processes, model contracts and bid documents, specifications, and assessment tools. A strategic alliance for *designing for safety* should be built for working collectively to implement design initiatives.

4. Practice Issues

Some standardized tools are available and utilized in practice, including the Design for Construction Safety Toolbox (CII 1996), the Construction Hazard Assessment Implication Review (CHAIR) process developed in Australia (WorkCover 2001) and the ToolSHed - a decision support tool for health and safety in construction design (Cooke *et al*., 2008). Gibb (2004) reported that in UK, a renowned designer Ove Arup has produced "Work sector guidance for designers" for the Construction Industry Research and Information Association (CIRIA). The report provides advice for designers of various elements of building and civil engineering projects (CIRIA 1997/2003). Companies who currently have *designing for safety* processes in place also utilize design reviews, constructability reviews, checklists, risk assessment processes and forms to prepare design with interactive tools.

Further practice issues in *designing for safety* are discussed by Lin (2008). He described that products developed with a *designing for safety* concept in mind can become a good selling point. With the *designing of safety* concept, productivity can increase when the system is analyzed or engineering improvements are built into company operations. According to Lin (ibid), workers' compensation and other direct costs can be reduced, as well as indirect costs, such as overtime pay and other costs involved with non-injured workers. Finally, return on investment (ROI) is a clear driver for businesses; therefore, solution that involves *designing for safety* will ensure returns.

5. Education Issues

Formal education has become almost mandatory for one to gain entrance to the job market, advance in the job market, or to maintain access to the job market. Mann III (2008) identified education as one of the main avenues needed to make *designing for safety* successful. He agreed that the disciplines of engineering, architecture, and business are the prime opportunities for *designing for safety* education. Gambatese *et al*., (2008) indicate that education efforts are to cover continuing education and university education. In 2006, the Australian Safety and Compensation Council (ASCC 2006) published *Guidance on the Principles of Safe Design for Work* and launched an educational resource package *Safe Design for Engineering Students* (ASCC 2006). Mann III (2008) indicates that the *designing for safety* concept is to be tied to other similar course content, such as sustainability and environmental issues. According to Mann III, *designing for safety* also need to be included in courses such as corporate social responsibility particularly to ensure its connection to other matters of corporate good citizenship. In business schools, lessons involving the principles of *designing for safety* are needed to be used to teach subjects such as finance, human resource management, and organizational behavior. Universities, colleges, and professional schools should also focus to companies for *designing for safety* training. Educating leaders in companies is critical to the success of *designing for safety* as they drive the adaptation of *designing for safety* into all parts of a company's operation. Course work for continuing education (i.e. formal education to people who are no longer full-time under-graduate or graduate students) can be the best opportunity for multi-disciplinary approaches to *designing for safety*. It was also argued that community education be used to raise awareness of *designing for safety* among consumers, so that they would be able to assess the qualifications of contractors in terms of their implementation of safety principles. It was recommended that drivers of change be identified at all levels and across various industry sectors. For example, licensure and certification authorities are the essential drivers in all of the economic sectors when they can drive education by requiring that some portion of the training include *designing for safety* concepts.

6. Research Issues

Gambatese (2008) indicates that research is central in designing for safety concept. He appraised and discussed seven topic areas which include: (1) the economic and business case; (2) design-related causality; (3) the development of devices, tools, and processes; (4) worker, machine, structure, and environment interaction; (5) diffusion, sustainability, and communication of design innovations; (6) methodologies of research; and (7) leveraging methods and technologies from other industry sectors. These topics from Gambatese (2008) and Gambatese *et al*., (2008) are summarized in short in the followings:

Understanding 'the economic and business case' of *designing for safety* is critical to its acceptance and implementation when designing and implementing a new process, product, or system that involves consideration of many competing priorities. Developing and comparing benefits and costs provide a means to assess *designing for safety* from a financial perspective. According to Gambatese (2008), anecdotal evidence suggests that *designing for safety* can improve productivity, quality, and cost; nevertheless, further research is needed to quantify the economics of implementing *designing for safety*. Also, research is required that examines the costs associated with both the process of *designing for safety* and the manufacturing, construction of specific safe designs while emphasizing the economic impact of not integrating safety early into the design process.

To prevent work-related injuries and illnesses is the goal of *designing for safety* and understanding the connection between design features and occupational injuries is vital particularly to re-design work environment, tools, and systems, to eliminate the associated hazards. Gambatese *et al.*, (2008) suggested that research is needed to determine how to effectively assess design-related causality and to determine the connection between design features and worker injuries and illnesses. Results that show when, how, and why injuries and illnesses occur can then be used to modify work environment, tools, and systems.

Gambetese (2008) ask for research to develop design tools and processes, and supporting tools to assist with hazard recognition and design optimization. Research is also needed to investigate and develop new designs that create a safe and healthy work environment. Input of the workers affected by the designs can be an important aspect of this research. Modular design, light-weight assemblies, ergonomically beneficial tools, and low noise-emitting equipment are examples of beneficial designs. The designs are to consider not only the controlling system, but all sub-systems so that they are not negatively impacted.

In the context of *designing for safety,* research is needed to understand how to account for human interaction with machines and their work environment which can be accomplished through ethnographic studies. How to maintain *designing for safety* practices in the maintenance of the tools and throughout the lifecycle of a project, or within an organization, is to be investigated.

Research is needed to determine what avenues are available to disseminate *designing for safety* information and to measure their effectiveness. Use of the print media needed to be maximized, including: scientific journals, trade publications, websites, newsletters, and publishing case studies. Also providing the design community with an incentive to modify their designs to incorporate worker safety and health will create a demand for *designing for safety* knowledge. Research is required to investigate what drives the design community to act and how best to create this demand. Supporting resources, bidding and pricing requirements, and contractual language are all means for creating demand for the *designing for safety* knowledge.

There is a need to establish *designing for safety* research methods that result in reliable research findings under practical research limitations and resources. These methods can include cause and effect studies of specific design interventions, or focus group interviews to evaluate worker perspective and attitudes. Once new designs are implemented, evaluation of their effectiveness is necessary to determine the impact of *designing for safety*. Research is needed to: develop evaluation metrics, measure the performance of specific designs, identify benchmarks for safety and health performance, and assess the performance relative to the benchmarks. Also efforts should be made to coordinate studies under a common funding program. Collaborative research that involves multiple organizations and areas of expertise is a key part of ensuring comprehensive studies.

Innovation often occurs in an industry sector as a result of the integration of ideas and technologies from another industry. Research is needed to expose existing *designing for safety* practices in each industry sector, evaluate the practices in terms of their transferability to other industries, and develop the practices for application in other industries. Sufficient funds and resources are to be allocated that allow for in-depth examination of the *designing for safety* concept and its application in practice.

7. Concluding Remarks

Construction designers, who include architects, engineers and related technical experts, have not hitherto been required to give safety a high enough priority in their designs. It is generally argued that designers should enhance their role and take greater responsibility regarding designing for construction worker safety. To deal with worker safety in the design of a project is known as *designing for safety* and the concept is gaining popularity in construction. In order to better understand the concept; policy, practices, education and research issues were examined.

Practice issues reveal that products developed with a *designing for safety* concept in mind can become a positive selling point. To make the concept of *designing for safety* successful, education needs to be addressed to enhance the knowledge of designers and related stakeholders. Engineering, architecture, construction management and business disciplines need to incorporate *designing for safety* education in their existing courses from college to university levels.

The economic and business case of *designing for safety* for the design and implementation to a new processes, products, or systems that involve consideration of many competing priorities needs research. Development and comparison of the benefits and costs of *designing for safety* also needs to be explored to address financial perspectives. Connections between design features and occupational injuries need to be investigated particularly to re-design the work environment, tools, and systems, or to eliminate the associated hazards. Industries including the construction industry will need to develop measures for assuring the effectiveness of *designing for safety* implementation. Once new designs are implemented, evaluation of their effectiveness is necessary to determine their impacts.

The success of *designing for safety* depends upon the joint effort of owners, designers, contractors, researchers, educators, practitioners, manufacturers, and policy-makers. It appears that safety will improve if *designing for safety* addresses issues from many angles of including policy, practice, education and research.

8. References

Australian Safety and Compensation Council (ASCC). (2006). Safe design for engineering students. Retrieved November, 2008 from http://www.ascc.gov.au/NR/rdonlyres/DD7E1415-A581-404E-94A2-39F13A8A50ED/0/SafeDesignEngineering.pdf

Behm, M. (2005). "Linking construction fatalities to the design for construction safety concept". *Safety Science*, 43(8), 589-611.

Blanquart, J. (2003). "Design for safety and the way back". Paper to the New Technology and Work Workshop on Safety and Design, Blankensee.

CEN. (1991). "Safety of machinery – basic concepts, general principles for design – Part 1: Basic terminology, methodology". European Standard EN 292-1:1991, Brussels.

CII. (1996). "Addressing construction worker safety in the project design". Construction Industry Institute, RR101-11, Austin, TX.

CIRIA. (1997). (Edition 2003). "CDM: Work Sector Guidance for Designers". Ove Arup and Partners, Construction Industry Research & Information Association. London, UK, ISBN 0 86017 464 6.

Choudhry, M. R., Fang, D. P., and Ahmed, S. M. (2008). "Safety management in construction: Best practices in Hong Kong". *Journal of Professional Issues in Engineering Education and Practice*, 134(1), 20-32.

Cooke, T., Lingard, H., Blismas, N., and 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*, 15(4), 336-351.

European Foundation for the Improvement of Living and Working Conditions. (1991). "From Drawing Board to Building Site (EF/88/17/FR)". European Foundation for the Improvement of Living and Working Conditions, Dublin.

Gambatese, J. A. (2008). "Research issues in prevention through design". *Journal of Safety Research*, 39(2), 153-156.

Gambatese, J., and Hinze, J. W. (1999). "Addressing construction worker safety in the design phase - Designing for construction worker safety". *Automation in Construction*, 8(6), 643-649.

Gambatese, J. A., Hinze, J., and Behm, M. (2005). "Investigation of the viability of designing for safety", The Center to Protect Workers' Rights, Suite. Georgia Ave. Silver Spring, MD, USA.

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

Gambatese, J. A., Toole, T.M., and Behm, M. G. (2008). “Prevention through design practices and research: A US construction industry perspective”, *Proceedings of CIB Working Commission W99, International Conference on Evolution of and Directions in Construction Safety and Health*, 9-11 March 2008, Gainesville, FL. 93-102.

Gibb, A. (2004). “Designing for safety and health in construction – a European/UK view”. In: Hecker, S., Gambatese, J., Weinstein, M. (Eds.), *Designing for Safety and Health in Construction*: *Proceedings from a Research and Practice Symposium*, September 15-16, Portland, OR, USA, 44-57.

Hale, A., Kirwan, B., and Kjellén, U. (2007). "Safe by design: Where are we now?" *Safety Science*, 45(1-2), 305-327.

Hinze, J., and Wiegand, J. (1992). "Role of designers in construction worker safety". *Journal of Construction Engineering and Management*, 118(4), 677-684.

Howard, J. (2008). "Prevention through design - Introduction". *Journal of Safety Research*, 39(2), 113-113.

Howe, J. (2008). "Policy issues in prevention through design". *Journal of Safety Research*, 39(2), 161-163.

International Labor Office (ILO). (1985). “Safety and health in building and civil engineering work”. International Labor Office, Geneva.

Jeffrey, J., and Douglas, I. (1994). “Safety performance of the United Kingdom construction industry”. In: Issa, R., Coble, R. J., Elliot, B.R. (Eds.), *Proceedings of the Fifth Annual Rinker International Conference Focusing on Construction Safety and Loss Control*, , Gainesville, FL, USA, 233-253.

Kinnersley, S., and Roelen, A. (2007). "The contribution of design to accidents". *Safety Science*, 45(1-2), 31-60.

Lin, M.-L. (2008). "Practice issues in prevention through design". *Journal of Safety Research*, 39(2), 157-159.

Mann III, J. A. (2008). "Education issues in prevention through design". *Journal of Safety Research*, 39(2), 165-170.

Manuele, F. A. (2008). "Prevention through Design (PtD): History and Future". *Journal of Safety Research*, 39(2), 127-130.

Szymberski, R. (1997). "Construction project safety planning". *TAPPI Journal*, 80(11), 69-74.

Toole, T. M., and Gambatese, J. (2008). "The trajectories of prevention through design in construction". *Journal of Safety Research*, 39(2), 225-230.

WorkCover. (2001). Construction Hazard Assessment Implication Review (CHAIR): A Safety in Design Tool, Sydney. Retrieved January, 2009 from http://www.workcover.nsw.gov.au/Publications/OHS/SafetyGuides/pages/chairsafetyindesigntool.aspx