

Can User Centered Design Methods Improve Construction Safety?

Somik Ghosh, PhD and Suchismita Bhattacharjee, PhD
University of Oklahoma
Norman, Oklahoma

Safety of construction industry has been a source of concern for a long time. The high number of mortality and morbidity makes it one of the most dangerous industries to work for. Evidence shows that fatalities in the construction industry can be linked to decisions taken during the design phase. This realization has invoked a movement towards involving the designers in safety of workers and users. In recent years, academics and professionals have focused on the concept of Construction Hazards Prevention through Design (CHPtD) in which designers consider improving the safety of construction workers by reducing hazards during the design phase. In the absence of any legislative requirement for the designers to practice CHPtD, there is lack of clarity about the responsibilities the designers have to undertake in the process. So far most of the publications related to CHPtD offer solutions in the form of design recommendations to the designers or as an expert system that is connected to a knowledge base. However, none of these offer any suggestions to integrate safety consideration with the design process. The authors have looked into user centered design methods as a probable method that will facilitate the designers to integrate safety consideration during design process.

Keyword: Construction safety, user centered design, Prevention through Design, designer

Introduction

Occupational Safety and Health Administration's (OSHA) increased pressure, awareness of the owners, and increased economic damage due to accidents have forced the contractors to pay attention to the safety and wellbeing of the construction workers. The contractors have sought to increased safety training enforcements on the workers to avoid accidents in the job site. These efforts have indeed produced positive effects in terms of declining construction accidents in the recent past. However, it is still an alarming statistics that the US construction industry accounts for the lives of three construction workers every work day (BLS 2014). The current approach to accident prevention is largely based on OSHA prescribed safety programs including trainings, inspections, enforcements, penalties, etc. to increase compliance with safety rules. This approach has its limitations and need to be improved beyond what is required by OSHA standards and regulations (Saurin, Formoso, & Guimaraes, 2004).

The current approach to improve safety by reducing workers' exposure to hazards using physical and procedural barriers is reactive in nature. Instead of reducing the hazards, the current approach prevents the workers from being exposed to those hazards. On the contrary, a proactive approach would attempt to reduce/eliminate the hazards from the system. A proactive approach will look into a less hazardous methods rather than relying into increased safety efforts of the workers. Increasing safety efforts of the workers increase the cost of compliance. The increased cost of compliance sometimes brings in compromises and ultimately noncompliance. In reality, the current approach replaces one type of unacceptable costs (incurred due to accidents) by a form of more acceptable costs (incurred to maintain compliance). Moreover, compliance always does not ensure safety (Prichard 2002). Thus, in terms of cost effectiveness the safety approach does not add value to the system. In comparison to some of the well-structured and technical systems, construction is a loosely coupled system (Rasmussen 1997) where product and process designs are separately accomplished. While products are designed by the designers, the process design is left to the contractors who cannot overcome the legacy of the designs. The current setup encouraged by OSHA places the burden of the construction workers safety on the contractors. Most contractors see their responsibility towards workers safety and wellbeing as merely a requirement that they must fulfill in order to avoid penalties. As a result, they often neglect the proper implementation of these plans (Wang et al., 2006; Saurin, Formoso, & Cambraia, 2008). The current setup fails to recognize that the safety of the workers are, to a large extent, influenced by the product design. Analysis of accident reports by Behm (2005) demonstrated that more than forty percent of construction fatalities could be linked to decisions taken during the design phase. Some other studies conducted around the world also confirms that construction fatalities are caused by decisions taken during the design phase

(European Foundation 1991, NSW Workcover 2001). With these evidences, the authors believe that the roles of the designers (architects and engineers) are not utilized to the fullest to reduce hazards for the construction workers (Bhattacharjee et al. 2011). In recent years, academics and professionals have focused on the concept of Construction Hazards Prevention through Design (CHPtD) in which designers consider improving the safety of construction workers by reducing hazards during the design phase (Howard 2008). In this paper, the authors have specifically used the term Construction Hazards Prevention through Design (CHPtD) over Prevention through Design (PtD) to avoid confusion from PtD efforts in other industries.
American Society of Safety Engineers defined prevention through design as “addressing occupational safety and health needs in the design process to prevent or minimize hazards and risks associated with the construction, manufacture, use, maintenance, and demolition of a facility.” While this definition provides the overarching premise of the concept of prevention through design, there is lack of clarity about the responsibilities the designers have to undertake in the process (Tymvios and Gambatese 2015). Manuele (2008) offered some clarification by describing prevention through design as “the integration of hazard analysis and risk assessment early in the design and engineering stages” to reduce or eliminate hazards to the construction workers in the production stage. However, there is a lack of literature addressing the technical responsibilities of the designers in the CHPtD process and help them to perform better CHPtD (Toole and Gambatese 2008). So far, most publications related to CHPtD have offered ‘design solutions’ in the form of recommendations for direct implementation in the design. Scholars, such as Gambatese and Hinze (1999) have formed a repository of such recommendations to facilitate the adoption of CHPtD by the designers. While these recommendations for direct implementation aim at facilitating the designers, Frijters & Swuste (2008) expressed concerns over taking away the creative liberty of the designers and possible impediment of the usual design process. Available literature on CHPtD shows a lack of effort on exploring the integration of integrating hazard analysis and risk assessment in the design phase. There is a need for further exploration of possible tools and processes the designers can sough to integrate hazard recognition and design optimization (Gambatese 2008). Designers being more used to methodical approach (Thorpe 2005), it will be functional to identify a method to integrate hazard consideration as part of a regular design process. The current paper will present a review of the different approaches suggested by various scholars so far. Subsequently, the authors will explore the various user centered design methods as possible avenues to integrate hazard recognition during the design phase.

Literature Review

Identification and assessment of hazards are key to safety in the construction projects. Carter and Smith (2006) attempted to integrate safety consideration during the ‘far-in-advance’ planning phase of construction projects in the UK. Based on their investigations on hazard identification levels of three different industry sectors of the UK including construction, they concluded there is a gap in the number of hazards actually identified and assessed to the number that should have been identified and assessed. Based on their findings, Carter and Smith concluded that knowledge management and lack of standardized procedure of hazard identification and assessment were the critical barriers towards identifying and assessing hazards. To overcome the barriers, they recommended a web based tool to help engineers assign hazard indices to work items based on their description, location, sequence, resources used, and hazard assessment. The hazard identification will be done using a central safety database that contains knowledge relating to safety that exists within the entire organization that is construction tasks, hazards, and the relationships between them. The web based tool would examine all the tasks associated with the schedule and return all the possible hazards. Subsequently the user can review the assessment report and add, delete, or modify the possible control measures suggested by the tool.

A similar web based tool developed by Cheung et al. (2004) in Hong Kong could be used to detect potential hazards of construction activities that need corrective actions. The investigators claimed that the web based tool can be used in conjunction with regulatory safety and health management guidelines to identify safety and health hazards as early as possible. Similar to the one developed by Carter and Smith (2006), Cheung et al. connected a database of rules, guidelines, best practices of safety management to the web based tool for the assessment of hazards. The investigators claimed that the web based interface enabled speedy collection of data using internet and instantaneous assessment based on the database. The output to the users were in the form of report containing instruction and advice to reduce occupational hazards. Automating hazard seems to be the most common types of tools available to facilitate prevention through design. Cook et al. (2008) developed a web based expert reasoning through argument analysis to assess fall hazards during roof maintenance works. Nussbaum et al. (2009) developed an analytical tree to identify high levels of musculoskeletal disorder risks while working in panelized residential walls. The expert system associated with the analytical tree is based on laboratory based simulations and mathematical models to calculate ergonomic hazards.

While majority of the literature offer several tools to facilitate hazard analyses during the planning phase, a few offer methodical approach for the same. Frijters & Swuste (2008) offers one such recommendation through the combination of a multiple British standards: BS8800, EN 1050, EN 292-1. The EN 1050 is the standard for "Safety of machinery - Principles for risk assessment," the EN 292-1is the standard for "Safety of machinery - Basic concepts, general principles for design," and BS 8800 is a plan for risk inventory and evaluation. EN 1050 and EN 292-1 help in minimizing risks by taking appropriate measures during the design of machineries. The same principles could be applied towards minimizing hazards to construction projects as while using the BS8800. The BS8800 provides an opportunity to the designers to create an inventory of hazards for each of the building components at the preliminary design phase. Subsequently, the designers can compare among multiple building components to determine the level of risks. To modify or eliminate components posing high risks during construction, the designers should review the preliminary designs. This method of integrating hazard analysis during the preliminary design phase by examining building component was tested to evaluate the workability of the method. Two construction forms (wide slab floor and hollow core beam floor) and falling hazard were only considered during the test run. Based on the feedback of the participants, Frijters & Swuste (2008) concluded that the designers could compare the hazardous aspects between the two components and determine the level of risks. Most importantly, the method did not interfere with the creative expression of the designers. While the method is labor intensive, the workability of the method can be improved by developing a robust database of health and safety knowledge would reduce re-analyzing similar components in future projects and speed up the process.

Characteristic of the Design Process

There is no doubt that the construction industry is in pursuit of new approaches to improve the current status of occupational safety. While CHPtD offers the framework to achieve the desired improvement, current tools and processes lack integration of safety consideration during design phase. This means that design is prepared using other criteria and then checked for safety. The safety consideration, if any, is sequential in nature and comes as an afterthought. The American Institute of Architects (AIA) B141: Standard Form of Agreement between Owner and Architect supports the notion that design and construction are sequential and independent functions. The overall process of considering safety by the designers can be delineated in three steps (Figure 1). Firstly, the design is proposed based on the technical solution of the designer. Once the design is proposed, the probability of hazards from different components of the proposed design are analyzed. The designers typically rely on their professional experience to determine the hazard levels of the components (Manuele 2005). The designers who collaborate with contractors, as facilitated by some delivery methods, may consider the construction process to identify the probable hazards. However, the common notion that contractors' experience is predominantly in the means and methods and limited to the design and aesthetics come in the way of modifying the design to reduce the hazards arising due to the proposed design. The disparate roles played by the designers and the contractors forced by the traditional contractual relationship hinders the integration of safety consideration during the design phase.

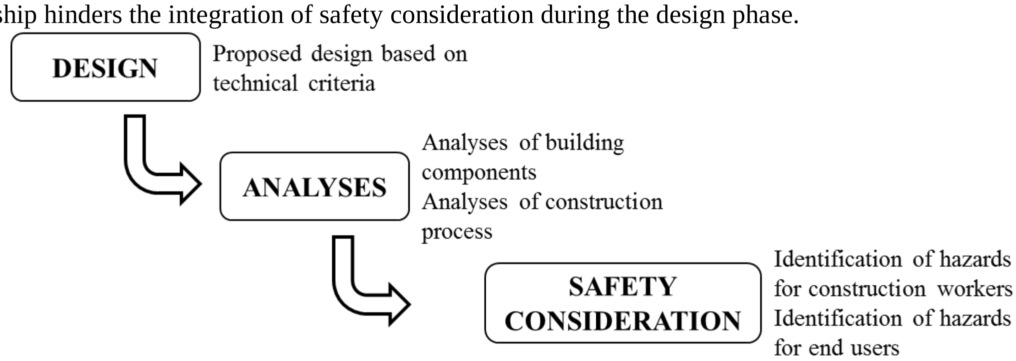

Figure 1: Sequential consideration of safety by designers

The standard design process is linear in nature starting with schematic design through development of construction documents having multiple reviews at different stages of design development. Typically, the design reviews are scheduled at 30%, 60%, and 90% of the design development. If hazard analysis has to take place, those are conducted during the scheduled design reviews (Duffy 2004, Gambatese 2000). However, what sounds to be a simple process is complicated by the reiterative nature of design development process where several options of the design may go through the process of reviews before being eliminated. The involvement of multiple designers (for base building, building systems, civil, structural, and so on) add more complexities to the reiterative process. Subsequent to the bidding process, contractors for specific trades such as fabrication, assembly, and erection of steel structure, façade systems, mechanical systems, and similar prepare shop drawings based on the construction documents that are used for actual execution. Due to the division of design responsibilities, Toole and Gambatese (2011) recommended involving all the different designers, trades, and owners during the design review processes. In order to move away from the sequential consideration of safety and encourage integration, Toole and Gambatese suggested considering different aspects of CHPtD during each of the scheduled reviews as shown in Figure 2.

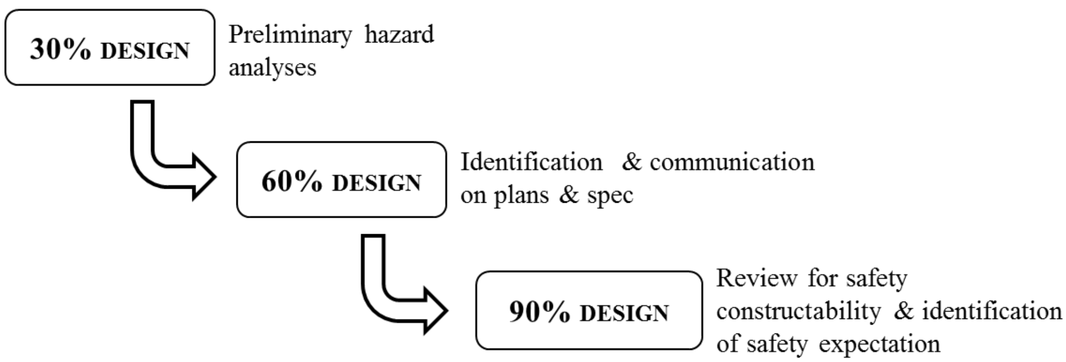

Figure 2: Integration of safety during design reviews (adapted from Toole & Gambatese 2011)

In order to integrate safety consideration in the design process, there has to be a constant feedback loop towards the design based on the hazard analyses and identification in each stage. At each of the scheduled reviews, the designers along with specific trades and other owners should make a concerted safety review and make modifications (if deemed necessary) to the design to reduce or eliminate the hazards. The authors suggest the constant feedback loops as necessary to integrate safety consideration in the existing design process (Figure 3). Modifications of the design based on the feedbacks will prove to be less disruptive and less costly early in the project as compared to a sequential approach where safety is considered at the completion of the proposed design (Figure 1).

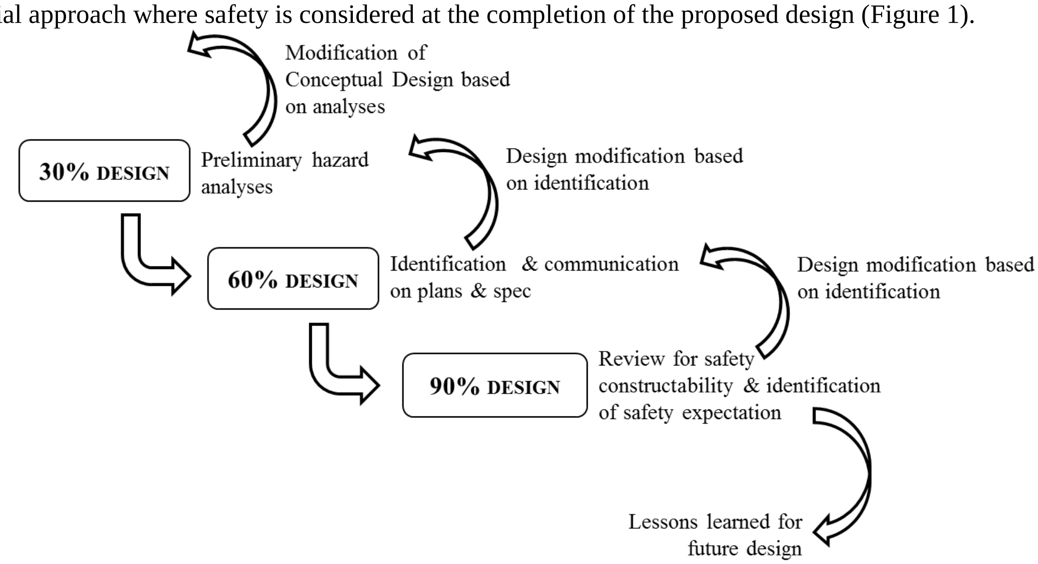

Figure 3: Feedback loops during integration of safety in design process

The recommendations of the authors as shown in the above figure point towards proactively integrating safety consideration unlike a reactive approach of dealing with safety in the hindsight. This approach is a combination of hazard analyses in the proposed design and making modifications based on anticipated conditions faced by construction workers and occupants as a result of the design. Thus, the suggested recommendations to reduce or eliminate hazards have to be user focused. This recommendation for integrating construction hazard prevention stems from user centered approach of designing. This approach is aimed at preparing design by adapting to technical systems to the best possible way for the users. The user centered design approach demands greater knowledge about the user characteristics with a view to reduce the users' exposure to hazards and thereby avoiding accidents. In order to do that requirements of the users need to be taken into account in more ways than just 'user satisfaction' assessments. The objective of considering user centered design methods is to provide the optimum design solution to the users that will ensure minimal or no exposure to hazard. However, accomplishing the objective raises several valid questions. How do the designers build up appropriate user representation during design development? To what extent will the designer allow user characteristics to impact design? What rules and criteria will be used to prioritize the user characteristics? What level of risks faced by the users should be anticipated by the designer? Will the users be willing to spend extra resources (if needed) to reduce identified hazards? and similar questions. While user centered design approach seems to be a rational methodical approach to integrate safety considerations specific to user characteristics in the design process, there is a lot of questions to be answered before it can be implemented by the designers.

User Centered Design Method

For a built facility to be reliably usable, it is important that the designer has taken into consideration the context of use. Designing a built facility is a creative and complex activity, and the success is decided by the satisfaction and reliance of the users. For the designers trying to incorporate user characteristics, it is essential to actively involve the users for a clear understanding of their requirement. The users in this context will not only be limited to end users, but the variety of other users throughout the life cycle of the built facility (such as the trade specific designers, construction workers, and similar). The authors have explored a few of the available user centered design methods. These approaches allow the designers to be aware of the user characteristics and consider those while preparing the proposed design. One such method is the Evidence based Design in which design decisions are based on research and data. As defined by Hamilton & Watkins (2009) *"it is a process for the conscientious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual project."* Traditionally introduced in health care design, it has been identified as a designing tool for a variety of building types, where design decisions are clearly based on facts collected through performance research and performance data. As mentioned by Nussbaumer (2009) it is important to research what other designers have done in the past and learn about similar situations before finalizing a design idea. This approach can be utilized to investigate about the user characteristics, research other projects specifically for the safety aspect, and learn from the performance of previously completed projects.

Very similar to evidence based design, contextual design is a user centered design process which involves the process of using ethnographic data to make design decisions. This process is more commonly applicable as an alternative solution to engineering and feature driven model. Contextual design process evolves from the concept of contextual enquiry, where decisions are based on how users of a product interact with the product in a normal work environment (Beyer & Holtzblatt, 1998). Inquiry such as this will enable the designers to anticipate the hazards the users may face. Other forms of user centered design methods are critical incident technique, heuristic evaluation, kano analysis, and so on. While none of these methods have been utilized in the design and construction industry, they offer formal frameworks to gather facts about the users and the interface of the users and the system. The inquiries can generate user characteristics that can be used for hazard analysis of building components and safety performance analysis.

The authors do not know which form of the user centered design will be most appropriate for integration of safety consideration in the design process. Further exploration of each of the different types of user centered design methods is necessary to adopt the most appropriate for the purpose of design and construction industry. Specific consideration has to be given to the type of user information needed to anticipate hazards faced by the users, how to translate those information to be applied in the design phase, and so on.

Conclusion

Academics and professionals have focused on the concept of CHPtD in which designers consider improving the safety of construction workers and users by reducing hazards during the design phase. This approach is based on the findings that more than forty percent of construction fatalities can be linked to decisions taken during the design phase. However, in absence of any legislative requirement for the designers to practice CHPtD, the industry has to rely on their self-motivation. The authors found a lack of literature addressing the technical responsibilities of the designers to practice CHPtD. Most of the publications offer recommendations in the form of 'design solutions' that inhibit the creative ability of the designers. Looking closely at the design process, the authors realized that the traditionally safety is considered sequentially in the design process. Considering safety sequentially does not integrate it with the design, but consider it almost as an afterthought. In order to adopt CHPtD effectively, it is important to integrate safety consideration during the design phase. Integrating design consideration can be achieved during the scheduled reviews of the design development. In addition, the authors suggested there has to be a constant feedback loop towards the design based on the hazard analyses and identification in each stage. To facilitate the process of acquiring information from the users, the authors explored the user center design method as possible options. While the authors identified a few user centered design methods, no instances of their application in the design of built environment could be located. Though not used too frequently in the design and construction industry, the user centered design methods can provide the formal framework of acquiring information of user characteristics that are important for the anticipation of hazards the users can face. The authors acknowledge that there is a lack of understanding how user centered design will be adopted to integrate safety. Future research will look into the usability of user centered design as a possible framework to facilitate adoption of CHPtD.

References

Behm, M. (2005). Linking construction fatalities to the design for construction safety concept. Safety Science, 43(8), 589−611.
Bhattacharjee, S., & Gosh, S. (2011). Safety improvement approaches in the construction industry: a review and future directions. In Proceeding of 47th ASC Annual International Conference.
Carter, G., & Smith, S. (2006). Safety hazard identification on construction projects. Journal of Construction Engineering and Management, 132(2), 197−205.
Cheung, S. O., Cheung, K., & Suen, H. (2004). CSHM: Web-based safety and health monitoring system for construction management. Journal of Safety Research, 35(2), 159−170.
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.
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.
Frijters, A. C. P., & Swuste, P. H. J. J. (2008). Safety assessment in design and preparation phase. Safety Science, 46(2), 272−281.
Gambatese, J. A. (2008). Research issues in Prevention through Design. Journal of Safety Research, 39(2), 153−156.
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. A., & Hinze, J. (1999). Addressing construction worker safety in the design phase: Designing for construction worker safety. Automation in Construction, 8(6), 643−649
Hamilton, D. K., & Watkins, D. H. (2009). Evidence-based design for multiple building types. John Wiley & Sons.
Howard, J. (2008). Prevention through Design - Introduction. Journal of Safety Research, 39(113).
Manuele, F. (2008). Addressing occupational risks in the design and redesign processes, Professional Safety, 29 – 40.
Manuele F A (2005) “Risk assessment and hierarchies of control.” Professional Safety, 50(5), 33–39.
NSW Workcover. (2001). “CHAIR—Safety design tool.” Gosford, NSW, Australia.
Nussbaum M A, Shewchuk, J P, Kim S, Seol H and Guo C (2009) “Development of a decision support system for residential construction using panellised walls: Approach and preliminary results,”Ergonomics,52:1,87-103
Prichard, R. (2002). “Debunking the 13 myths of construction safety.” International Risk Management Institute, May, http://www.irmi.com/expert/articles/prichard010.asp
Rasmussen, J. (1997). “Risk management in a dynamic society: A modeling problem.” Safety Sci., 27~2/3!, 183–213.
Saurin, T. A., Formoso, C. T., & Guimaraes, L. B. M. (2004). Safety and production: An integrated planning and control model. Construction Management and Economics, 22(2), 159−169.
Saurin, T. A., Formoso, C. T., & Cambraia, F. B. (2008). An analysis of construction safety best practices from a cognitive systems engineering perspective. Safety Science, 46(8), 1169−1183.
Toole, T. M., & Gambatese, J. A. (2008). The trajectories of prevention through design in construction. Journal of Safety Research, 39(2), 225−230.
Tymvios, N., & Gambatese, J. A. (2015). Perceptions about Design for Construction Worker Safety: Viewpoints from Contractors, Designers, and University Facility Owners. Journal of Construction Engineering and Management, 04015078.
Wang, W., Liu, J., & Chou, S. (2006). Simulation-based safety evaluation model integrated with network schedule. Automation in Construction, 15(3), 341−354.