ELSEVIER
www.elsevier.com/locate/jsr

Journal of Safety Research 39 (2008) 225 – 230

www.nsc.org

The Trajectories of Prevention through Design in Construction

T. Michael Toole [a,*], John Gambatese [b,1]

[a] Civil & Env. Engineering, Bucknell University, Lewisburg, PA 17837
[b] Civil, Construction & Env. Eng., 202 Apperson Hall, Room 108C, Oregon State University, Corvallis, OR 97331

Available online 20 March 2008

Abstract

Introduction: Construction Hazards Prevention through Design (CHPtD) is a process in which engineers and architects explicitly consider the safety of construction workers during the design process. Although articles on CHPtD have appeared in top construction journals, the literature has not addressed technical principles underlying CHPtD to help designers better perform CHPtD, to facilitate the development of additional CHPtD tools, and to predict the future path of CHPtD. *Method:* This theoretical paper uses the existing literature on CHPtD and current action research associated with several CHPtD workgroups to analyze how CHPtD will likely evolve over the coming decades. *Results:* There are four trajectories along which CHPtD will progress. (a) Designs will increasingly facilitate prefabricated construction; (b) designers will increasingly choose materials and systems that are inherently safer than alternatives; (c) designers will increasingly perform construction engineering; and (d) designers will increasingly apply spatial considerations to reduce worker hazards. *Impact on Industry:* By understanding how CHPtD may be manifested in the engineering-procurement-construction (EPC) industry, practitioners can better prepare for adopting CHPtD within their organizations and construction and engineering educators can better prepare their graduates to perform CHPtD.

Keywords: Prevention; Design; Safety; Constructability; Trajectories

1. Introduction

Construction Prevention through Design (CHPtD) is a process in which design professionals (namely, engineers and architects) explicitly consider construction worker safety while designing a facility. Traditionally, design professionals have sought to design buildings or other facilities that ensure the safety of occupants, meet functional needs at expected quality levels, are cost-effective, and can be constructed to meet the client's deadline. CHPtD adds another item to architects' and engineers' design criteria: the facility should not include unnecessary construction risks and project documents should alert constructors to unavoidable hazards. One can therefore think of CHPtD as another aspect of designing for constructability (i.e., the design is reviewed to ensure it can be constructed safely, as well as meet cost, schedule, and quality goals).

CHPtD appears to offer three sets of compelling benefits, all ultimately associated with reduced hazards on construction sites. First, as is true for cost, quality, and schedule, project decisions that dramatically influence project safety occur early in the project life cycle and are usually made by designers and owners. It is commonly held in the safety and health profession that eliminating safety hazards through design is better than trying to protect workers from hazards or to get them to avoid hazards that are present. In short, proactive identification and elimination of a hazard is safer and more cost effective than is reactive management of a hazard. This proactive elimination of hazards must be made by designers during the conceptual and detailed design of a facility.

Second, because many site hazards are associated with forces, stresses, dynamic motion, and electricity, it makes sense to expect that individuals with a strong educational background in these topics would consider site safety as they make their design decisions. For example, the hazards and protection mechanisms associated with soil cave-ins are related to stresses within soils and within protection systems. Crane safety and fall protection revolve around static forces and dynamic motion. Many craftspeople have a tacit understanding (i.e., gut feel) for

* Corresponding author. Tel.: +1 570 577 3820.
E-mail addresses: ttoole@bucknell.edu (T.M. Toole), john.gambatese@oregonstate.edu (J. Gambatese).
[1] Tel.: +1 541 737 8913.

0022-4375/$ - see front matter © 2008 National Safety Council and Elsevier Ltd. All rights reserved.
doi:10.1016/j.jsr.2008.02.026

forces and motions associated with their trade, but only design professionals have had formal schooling in physics and engineering.

Third, having all entities associated with a construction project—including designers— actively concerned about worker safety is important for both symbolic and substantive reasons. Safety is affirmed as a project priority for everyone, not just something that one or two entities are thinking about. Because it is recognized that construction is one of the most dangerous industries, it makes sense to assume that all professionals associated with the construction process—including owners, contractors and designers—should be willing to work toward reducing construction injuries. Model contract paragraphs—such as found in the AIA A201 and the EJCDC E-500—explicitly state the designer has no responsibility for site safety, but this does not prevent designers from voluntarily considering safety during their design. Given that reduced site hazards ultimately reduce the total cost of a project, client-focused designers should acknowledge that CHPtD is compelling for both ethical and practical reasons.

While CHPtD is still not commonly performed in the United States, there are many signs that it is gaining momentum. The Construction Industry Institute funded the development of a CHPtD computer program in the mid-1990s (Gambatese, Hinze, & Haas, 1997). The National Institute for Occupational Safety and Health (NIOSH) NORA Construction Sector Council named CHPtD as one of its Top 10 priority areas and NIOSH held a national workshop on Prevention through Design in July 2007 in Washington, DC (which is the focus of this special issue of the JSR). This workshop identified six large U.S.-based design-build contractors who have initiated CHPtD programs. OSHA has a CHPtD workgroup—called the Design for Construction Safety workgroup—that has met quarterly since 2004 and made presentations at conferences across the United States (OSHA, 2007). One professional organization representing one set of design engineers—the American Society of Civil Engineers—has recently established a CHPtD Committee within the Engineering Directorate of the Construction Institute.

Yet the United States continues to lag other countries in the diffusion of CHPtD. The UK passed a law requiring designers to perform CHPtD in 1995, which has been adopted throughout the European Union. Australia is also moving toward mandating CHPtD and has demonstrated leadership in this area by making practical CHPtD resources for designers available on the Web. These countries faced some of the same barriers to the diffusion of CHPtD that are present in the United States, such as designers' lack of safety expertise and additional costs associated with implementing CHPtD, but designers' fear of liability may be a uniquely strong barrier in the litigious United States (Toole, 2005).

Although articles on CHPtD (summarized in the next section) have appeared in top construction journals, the literature has not addressed technical principles underlying CHPtD to help designers better perform CHPtD, to facilitate the development of additional CHPtD tools, and to predict the future path of CHPtD. The goal of this paper is to address this gap in the CHPtD literature by suggesting there are four trajectories along which CHPtD will likely evolve. The structure of the paper is straightforward: the existing literature on CHPtD is reviewed, the four CHPtD trajectories are explained, and the implications of these trajectories on engineering design practice and education needs are discussed.

2. Literature Review

Although the premise that significant reductions in injuries can occur when safety is designed into a product, service, or process has been established within the general occupational safety field for many decades (Manuele, 1997), the application of the concept to construction is a more recent development. The journal article that garnered construction industry attention was published in the *Journal of Construction Engineering and Management* in 1992 by Frances Wiegand and Jimmie Hinze (1992). Gambatese completed his doctoral dissertation in 1996 (Gambatese, 1996) and drew industry attention to the topic through papers published shortly thereafter (Gambatese, 1998, 2000). A 2003 symposium in Portland, Oregon focused on CHPtD attracted over 100 engineers, architects, safety researchers, and government employees (Hecker, Gambatese, & Weinstein, 2004). In 2005, articles on CHPtD were published in *Safety Science* (Behm, 2005), the *Journal of Construction Engineering and Management* (Weinstein, Gambatese, & Hecker, 2005) and the *Journal of Professional Issues in Engineering Education and Practice* (Rubio, Menendez, Rubio, & Martinez, 2005; Toole, 2005). (An extensive list of CHPtD articles can be found at www.designforconstructionsafety.org, which is maintained by the authors.)

Although these publications in leading journals and other CHPtD publications have articulated the concept and application of CHPtD and shown it to be viable despite the existence of significant practical barriers, no article has articulated how the principles and processes that underlie CHPtD will likely evolve over time. By understanding how CHPtD may be manifested in the engineering-procurement-construction (EPC) industry, practitioners can better prepare for adopting CHPtD within their organizations and construction and engineering educators can better prepare their graduates to perform CHPtD.

3. CHPtD Trajectories

The American Heritage® Science Dictionary defines trajectory as "The line or curve described by an object moving through space." It is a deterministic concept, that is, it presumes the state of an object at any point in time reflects completely a set of antecedent causes. A classical problem in physics is to calculate the trajectory of a moving body, such as a projectile fired from a cannon. If one knows the initial velocity and direction of the projectile and environmental variables such as wind, one can calculate when and where the projectile will land. Social science constructs such as innovation have also been discussed as following trajectories (Dosi, 1982; Toole, 2001).

The concept of trajectories can also be applied to gain insights into how CHPtD may evolve. Using the analogy of a projectile, if we know the initial direction of the CHPtD projectile (i.e., the underlying concept or goal), the initial velocity (the current publication rate and breadth of professional organizations promoting CHPtD), and the environmental conditions (the engineering design task and process, the construction task, and the structure of the EPC industry), we can better predict how CHPtD may evolve as it is diffused within the industry. The authors have identified four specific trajectories that CHPtD is likely to follow:

1. Increased prefabrication
2. Increased use of less hazardous materials and systems
3. Increased application of construction engineering
4. Increased spatial investigation and consideration

Each trajectory will be explained and illustrated using examples. Also, the factors influencing how fast progress may be made along each trajectory will be discussed.

3.1. Prefabrication

Construction has traditionally involved the assembly of relatively small pieces (i.e., pieces that can be lifted by one worker or at least transported on a truck) in their permanent location. Prefabrication involves the assembly of pieces in temporary locations, such as specialized manufacturing facilities, followed by the transportation of the assembled components to their permanent location and the final fit up to create the completed facility. Prefabrication has increased steadily over the past 100 years because it facilitates improvements in cost, schedule, and performance (CII, 2002; Hewitt & Gambatese, 2002; Toole, 2001).

Prefabrication may reduce the hazard level of a task in two ways. First, prefabrication allows the location of the work to be shifted to a lower hazard environment (Gambatese et al., 1997). One application of this principle is that work can be shifted from a high elevation to the ground, where fall injuries are much less likely. Using roof trusses instead of roof rafters and assembled roof panels, for example, reduce the number of connections that workers must perform while more than 6' above the adjacent surface. A second application is shifting work from inside an excavation to grade, where there is no risk of soil cave-in. Preassembling sections of freshwater, sanitary or steam pipe in a plant or on site, then placing the assembly into the trench using power equipment, for example, reduces the number of connections that must be made inside the trench. A third application is shifting work from inside a confined space to an open space, where there is less risk of hazardous air quality. Pre-assembling water or steam pipe sections, pumps and valves, for example, reduces the number of connections that must be made inside a vault and therefore the number of person-hours spent inside a space where air quality hazards may develop.

The second way that prefabrication may reduce the hazard level of a task is that it allows the work to be shifted from the field to a factory, which allows the use of safer, automated equipment in improved environments. Permanent factory equipment for bending, drilling, cutting, welding, nailing, screwing, and bolting is typically safer than portable field equipment that perform these tasks because designs are less constrained by cost and weight and can include improved safeguards. The factory setting facilitates the use of engineered ventilation (e.g., consider coatings applied in the field versus paint booths in a factory) and the use of material handling equipment, which reduces air quality hazards and muscoskeletol injuries, respectively.

Bridge segments, structural steel column trees, steel stairs, concrete or wood wall panels, metal and wood joists, HVAC ducting, and plumbing pipe trees are additional common examples of components that can be prefabricated and erected using inherently safer processes and environments.

How fast will CHPtD through prefabrication diffuse? It is important to note that prefabrication will increase gradually due to cost, schedule, quality, and performance benefits regardless of whether CHPtD diffuses through the industry. Although shipping costs and size limitations will continue to limit the growth of prefabrication, improved application of information technologies to facilitate information flow and mass customization will drive increased prefabrication. Such information flow may play an important role in the growth of CHPtD because designers typically lack sufficient knowledge about specific opportunities to design and specify prefabricated assemblies on their projects. Due to the fact that designers are not yet seeking safety-related aspects of prefabricated assemblies and manufacturers of prefabricated assemblies are not yet using information technologies to communicate the safety benefits of their products, it will likely be at least 10 years before significant diffusion of CHPtD through prefabrication occurs.

3.2. Increased use of less hazardous materials and systems

Engineers and architects typically specify *materials* based on perceived or experienced performance and cost (or sometimes simply by what text is included in boiler plate technical specifications such as Masterspec), rarely on the inherent safety of the materials for construction or maintenance workers. Progressive owners and designers are becoming increasingly aware that some materials offer essentially similar performance and cost as that of competitive products, yet are considerably less hazardous to install or apply. This is particularly true for coatings, adhesives, and cleaners, which are associated with air quality, flammability and skin hazards (Weinstein et al., 2005). As information technology makes it easier for designers to obtain information about the inherent hazard level of various building materials, designers will increasingly be expected to apply this information in their design decisions.

Designers may also be expected to consider in their designs the inherent hazard level of various building *systems*, that is, assembled components or portions of the facility, not individual materials. Safety research will eventually identify the conditions that make concrete, steel, or wood building systems safer than alternative systems, and designers will be expected to consider this criterion along with cost, quality, and schedule. Prefabricated, integrated products (i.e., such as wall or roof panels that provide both structural and exterior finish functions) are other examples of building systems that may offer inherently safer installation processes and will therefore need to be considered by designers.

As was the case with the diffusion of CHPtD through prefabrication, diffusion of CHPtD through designers' explicit decisions to use safer materials and systems may not be significant for at least 10 years because designers are not yet seeking such information and manufacturers are not effectively providing it. On the other hand, it is possible that the CHPtD could experience a portion of the same dramatic rate of diffusion that the green building movement has seen. The diffusion of innovations often exhibits a positive feedback loop that results in a rapid increase in use of an innovation. As progressive architects and consumers began asking for information regarding how "green" a building product is, more building manufacturers began providing such information, which caused architects and consumers who had not previously sought such information to start demanding the information of the building products they were considering using.

The start of this feedback loop began with a feeling among architects that it is desirable—or even ethical—to consider environmental sustainability in their designs. It is possible that the PtD concept may strike a similar cord with progressive design professionals. Indeed, the reader is likely aware that sustainability is typically believed to be based on three "pillars:" environmental equity, economic equity, and social equity. Designers who view reducing unnecessary risk to construction workers as a valid social equity issue may initiate a positive feedback loop similar to the one that has driven green building. Consequently, CHPtD through safer materials may begin to increase significantly in as little as five years.

3.3. Increased application of construction engineering

There are numerous instances during the construction process when engineering is required to plan or execute the construction task. Soil retention systems, crane lifts and other major material handling tasks, soil bearing analysis for supporting construction equipment, temporary structures, fall protection anchorage points, and temporary load analysis are all examples of construction tasks that require the application of engineering principles because they involve forces and stresses. Traditionally, contractors have been required to provide these construction engineering tasks through in-house employees or consultants and design professionals relied on typical contract clauses that they had no responsibility for construction means, methods, or safety.

The industry seems to be changing in the area of construction engineering. It is the authors' perception that OSHA and progressive owners are realizing that when design engineers perform no engineering related to the construction process, important construction engineering tasks may be performed by unqualified personnel or not performed at all. Many industry professionals have witnessed instances where cave-in protection, scaffolding, falsework, or crane picks were planned and/or executed without the engineering expertise needed to ensure a reasonable level of risk. Industry standards that require the involvement of qualified individuals in planning and/or executing engineering-related tasks may be increasingly enforced in the coming decade.

There are several reasons why designers are increasingly likely to be involved in construction engineering on the projects they designed. One reason is that the growth of design-build has led to an increase in construction engineering capability among designers who had previously been less involved during the construction stage of their projects. Another reason is that they should be able to perform construction engineering less expensively and more effectively than contractor personnel because they already have a detailed understanding of the structure and the construction site.

There are conflicting factors influencing how fast progress along this trajectory is likely to occur. Progress may be driven within the next few years by an initiative of several national construction trade organizations to have the locations and details for fall protection anchorage devices shown on structural drawings (Behm, 2005; Gambatese et al., 1997). On the other hand, several factors may slow the progress along this trajectory, namely, designers' fear of incurring liability and their lack of sufficient knowledge of construction means, methods, and hazards. In other words, many design engineers do not want to and do not know how to perform many construction engineering tasks (Toole, 2005). Legislation that would allow designers to perform CHPtD without incurring inappropriate liability, insurance policies that provide coverage for potential increased liability, and the increased use of information technology that provides a graphical depiction of the construction process (i.e., process visualization) or Building Information Modeling (BIM) will help alleviate these barriers.

3.4. Spatial investigation and consideration

It has been the authors' experiences that when design civil engineers are asked if they consider during the design process the proximity of site hazards such as overhead power lines, underground pipes and adjacent structures, most respond affirmatively. Conversations the authors have had with dozens of construction professionals, however, suggest site hazards are often not considered by designers. For example, although design engineers typically obtain from the local municipality or the site owner site utility plans that contractors do not obtain, existing utilities are often not shown on plans (ostensibly to reduce design fees and not clutter up drawings), much less considered during the design phase.

The growth of both CHPtD and design-build may elevate the standard of care for designers to include communicating potential site hazards to the constructor on the project drawings or through other project documents. In addition, design engineers may be expected to possess and incorporate into their designs at least a crude understanding of necessary working distances for each of the various construction trades and common tools. Examples include the minimum legal proximity for cranes to powerlines, the minimum trench width necessary to allow efficient pipe placement and connections, the minimum spacing between electrical raceways and adjacent structures to allow safe and efficient installation, and the minimum clearance between steel bolts and adjacent steel members to allow the use of typical positioning and bolting tools or field welding (National Institute of Steel Detailing and Steel Erectors Association of America [NISD/SSEA], 2001).

Spatial considerations for constructability may also include ergonomic issues. For example, the design of structural steel, plumbing, HVAC, and electrical systems may include whether connections require the worker to work over his or her head or at an awkward angle that is more likely to result in muscoskeletol injuries (NISD/SSEA, 2001; Toole, Hervol, & Hallowell, 2006).

Progress along this trajectory will likely occur slowly over the next 10 to 15 years. With the exception of steel erection (as referenced above), the necessary clearances and ergonomic issues for specific trades have not been published. However, the NIOSH and OSHA PtD workgroups mentioned previously have discussed initiating a program to collect such data, which would likely involve collaboration with a half-dozen national trades organizations over a three to five year period. Designers' ability to cost-effectively include more complete site utilities data in construction drawings will be aided by the increasing number of owners (including municipalities and large industrial owners) who have created digital databases of utilities on their land.

4. Implications For Curriculum and Practice

Several factors that will slow the progress along these trajectories have been mentioned in this paper, chief among them being that most architects and design engineers possess neither the knowledge of construction safety nor the knowledge of construction processes necessary to effectively perform CHPtD (Hecker, Gambatese, & Weinstein, 2005; Toole, 2005). The primary implication of the evolution of CHPtD predicted in this paper, therefore, is that design professional curricula must be modified to include more construction courses, including site safety. Civil engineering and architecture educators must increase their emphasis on design for constructability and broaden it to include safety constructability.

Although educators often note their curricula are already too full, recent curricula developments may help motivate them to address construction safety. One development is the Accreditation Board for Engineering and Technology requirement that civil engineering programs include leadership, sustainability, public policy, and ethics in their curricula. All four topics support the CHPtD concept in some way. Another development is the formal approval that beginning in 2015, the minimum engineering education to become a registered professional engineer is a four-year bachelor of science program followed by 30 credit hours of graduate-level training. These additional hours may provide opportunities for construction safety to be addressed at both undergraduate and graduate levels. It should be noted, however, that because educators typically lack sufficient knowledge of CHPtD opportunities and processes, they will need to be provided with prepackaged teaching modules for relevant courses, such as building methods and materials, concrete design, steel design, and electrical systems.

The previous paragraphs refer to changes in engineering education on the national level. It is possible that factors influencing CHPtD diffusion may be initiated within individual states. Professional engineering licenses are granted by individual state boards and continuing education requirements for engineers to renew their licenses vary from state to state. A socially progressive state such as California could begin requiring continuous education in construction safety and sustainability. Similarly, a progressive state with their own state occupational safety program—such as California, Washington and Michigan—could incorporate CHPtD into their state safety regulations. With both professional engineering requirements and occupational safety requirements, the requirement to address CHPtD could be initiated by state legislatures, who have occasionally passed construction safety legislation. The Illinois Structural Work Act, which made is easier for injured construction workers to successfully file suit against all entities remotely associated with the project, is one such example. Many industry professionals familiar with this act believe it illustrates how well-intentioned legislation can lead to unintended results.

Another implication of the growth of CHPtD is that design professionals will need to become better information gatherers and communicators on project-related information that they currently do not sufficiently address. This change matches well with the vision of civil engineers as "master innovators and integrators" in Vision 2025, which was recently communicated by the American Society of Civil Engineers (ASCE, 2007). Project information needs to include site utility data from owners and municipalities, technical data on prefabricated components, and trade-specific safety input from contractors. For example, designers will need to establish procedures for communicating with prefabricators before projects are awarded in order to ensure their designs lend themselves to prefabrication whenever possible. These necessary capabilities point at the need for designers to embrace and invest in innovation, particularly information technologies. Owner clients will need to play a role in facilitating this project collaboration by allowing alternative delivery methods that are more conducive to collaboration than is the traditional design-bid-build method. Contractors on design-bid-build projects are typically not chosen until well after design is completed, which is why the needed communication about hazards between designers and builders cannot occur. Owner clients also need to facilitate collaboration by budgeting for project information technology infrastructures that promote efficient collaboration and integration.

The gaps in knowledge and communication channels that hinder CHPtD adoption will be less for one group of designers: those that are part of design-build teams. Dialogue between designers and builders regarding hazards associated with designs should—at least in theory—be frequent and candid. The growth and evolution of CHPtD is therefore expected to be led by the design-build market segment.

5. Conclusions

This paper began by suggesting that the increasing national activities relating to researching and promoting CHPtD indicate CHPtD will become diffused in the EPC industry. To fill a gap in the growing CHPtD literature, this paper suggested that the application of CHPtD concepts will evolve along four trajectories: increased prefabrication, increased use of less hazardous materials and systems, increased application of construction engineering, and increased spatial investigation and consideration. Movement along these trajectories will lead to significant improvement in construction site safety and health; however, many significant factors may slow the progress being made in diffusing CHPtD. Continued leadership by NIOSH and OSHA and collaboration by owners, designers, and contractors will clearly be required to make significant progress along these trajectories over the coming decade.

References

American Society of Civil Engineers [ASCE]. (2007). *The Vision for Civil Engineering in 2025.* Downloaded on January 20, 2008 from http://content.asce.org/vision2025/index.html

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

Construction Industry Institute [CII]. (2002). Prefabrication, Preassembly, Modularization, and Offsite Fabrication in Industrial Construction: A Framework for Decision-Making. *Construction Industry Institute, Research Summary 171-1* Austin, TX: Author.

Dosi, G. (1982). Technological paradigms and technological trajectories. *Research Policy*, *11*, 147−162.

Gambatese, J. A. (1996). Addressing construction worker safety in the project design. Unpublished doctoral dissertation, Univ. of Washington.

Gambatese, J. A. (1998). Liability in designing for construction worker safety. *Journal of Architectural Engineering*, *4*(3), 107−112.

Gambatese, J. A. (2000, June). Safety in designer's hands. *Civil Engineering*, 56−59.

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

Hecker, S., Gambatese, J., & Weinstein, M. (2004). *Designing for Safety and Health in Construction.* Eugene, OR: University of Oregon Press.

Hecker, S., Gambatese, J., & Weinstein, M. (2005). Designing for worker safety: moving the construction safety process upstream. *Professional Safety*, *50*(9), 32−44.

Hewitt, M. M., & Gambatese, J. A. (2002, Sept.). Automation Consideration During Project Design. *International Symposium on Automation and Robotics in Construction (ISARC), Washington, D.C.* (pp. 23−25).

Manuele, F. A. (1997). *On the practice of safety.* New York: John Wiley & Sons.

National Institute of Steel Detailing and Steel Erectors Association of America [NISD/SEAA]. (2001). *Detailing Guide for the Enhancement of Erection Safety.* www.nisd.org and www.seaa.net

Occupational Safety and Health Administration [OSHA]. (2007). http://www.osha.gov/dcsp/alliances/roundtables/roundtables_construction.html

Rubio, M. C., Menendez, A., Rubio, J. C., & Martinez, G. (2005). Obligations and responsibilities of civil engineers for the prevention of labor risks: references to European regulations. *Journal of Professional Issues in Engineering Education and Practice*, *131*(1), 70−75.

Toole, T. M. (2001). The technological trajectories of construction innovation. *Journal of Architectural Engineering*, *7*(4), 107−114.

Toole, T. M. (2005). Designing for safety: opportunities and barriers. *Journal of Professional Issues in Engineering Education and Practice*, *131*(6), 199−207.

Toole, T. M., Hervol, N., & Hallowell, M. (2006). Designing for construction safety. *Modern Steel Construction*, *46*(6), 55−59.

Weinstein, W., 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, ASCE*, *131*(10), 1125−1134.

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

T. Michael Toole is an Associate Professor of Civil & Environmental Engineering at Bucknell University in Lewisburg, Pennsylvania. He received his BS in Civil Engineering from Bucknell University and his MS and PhD from the Massachusetts Institute of Technology. His research areas include construction safety, construction innovation and project management. Dr. Toole is a professional civil engineer registered in twelve states and an authorized OSHA Instructor for the Construction Industry. He is Vice-Chair of ASCE's Prevention through Design Committee and Co-Chair of the Construction Hazards Prevention through Design workgroup within the National Institute for Occupational Safety and Health NORA Construction Sector Council.

John Gambatese is an Associate Professor of Civil, Construction and Environmental Engineering at Oregon State University. He received his BS and MS in Civil Engineering from the University of California at Berkeley and his PhD from the Univ. of Washington. His research areas include construction safety and construction innovation. Dr. Gambatese is a professional civil engineer and has industry experience as a structural engineer. He is Chair of ASCE's Prevention through Design Committee, a member of the American Society of Safety Engineers, and a corresponding member of the Construction Hazards Prevention through Design workgroup within the National Institute for Occupational Safety and Health NORA Construction Sector Council.