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Motivation for Prevention through Design (PtD): Experiential Perspectives and Practice

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ABSTRACT

Studies show that application of the Prevention through Design (PtD) concept with respect to construction worker safety, while compulsory in some countries, is inconsistent throughout the United States (US). This paper presents a study that explored the impacts and experiences on a construction community resulting from PtD implementation in order to benefit those countries where PtD is predominantly absent. Informed by a comprehensive review of PtD literature and governing regulations, the researchers conducted a structured, randomized survey of the construction sector in the United Kingdom where PtD is prevalent. Based on analyses of 228 survey responses, it is clear that PtD is viewed as a positive enhancement to design practice, project team collaboration, and safety. Those experienced in its application hold it in high regard. Obstacles to implementing PtD may be present but can be overcome. PtD provides an opportunity to change the way safety is viewed and practiced in the US to be more inclusive of the entire project team with active participation consistent with current project team roles and responsibilities. The research reveals how the construction industry can make this change and the impacts to be expected. Doing so will create a supportive and participatory safety environment throughout the design profession.

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INTRODUCTION

Much has been written and discussed about Prevention through Design (PtD) as an intervention to eliminate injuries and fatalities on construction sites. For the US construction industry, PtD is an intriguing concept; it is both recognized and highly valued by the safety community as a means to eliminate and reduce risk of injury, yet a change to traditional design practice that some view as a threatening prospect and impractical to implement. However, PtD's promise and the desire to further reduce the high number of construction worker injuries and fatalities that occur on an annual basis (BLS 2013) continue to motivate efforts to study PtD and expand implementation of PtD across the construction industry.

Possessing an understanding of impacts, barriers, enablers, and attitudes towards PtD implementation can facilitate its acceptance and diffusion. A recent study by Tymvios (2013) successfully captured the state of practice and sentiment of the US construction industry with respect to PtD. Based in part on an extensive, nationwide survey of owners, designers, and constructors, the study revealed that all industry participants acknowledge that design decisions have an impact on the occupational safety and health (OSH) of construction workers. However, when considering actually implementing PtD, the findings reveal that fewer architects and engineers (AEs) agree that designers should participate in such OSH efforts. Additionally, the AE's perspective is that obstacles to PtD implementation exist in three key areas: legal, economic, and contractual. Prior research supports the findings of Tymvios with respect to PtD in the US construction industry (e.g., Gambatese et al. 2005; Hecker et al. 2005; Toole et al. 2016; Behm 2004a).

The studies by Tymvios and others provide a strong foundation for which to understand PtD as it currently exists and is perceived in the US. Given the current limited application of PtD in the US, of interest as well are the knowledge and experience of construction communities that have fully integrated PtD into the project delivery process. Gaining an understanding of how PtD is received and practiced in international communities will facilitate disseminating PtD in the US and other countries where formal PtD implementation in construction is minimal or lacking. Examples of widespread PtD implementation exist in various countries and regions around the world. The European Union, Australia, Singapore, and South Africa, for example, currently have regulations that mandate the practice of PtD in construction (Aires et al. 2010; Toole et al. 2016).

This paper presents a study that explores PtD practice outside the US, specifically in the United Kingdom, where widespread and sustained implementation of PtD exists. The intent of the study is to determine the practical impacts and experiences of implementing PtD on the construction community. Meeting this goal is expected to support development of resources and efforts to promote PtD diffusion in the US. The UK was selected as the target location for the study because of its relatively long-term and sustained experience under the Construction (Design and Management) Regulations that were enacted in 1994 and which prescribe PtD efforts on construction projects (CDM 1994). A valuable opportunity is present to learn about PtD implementation from those owners, designers, and health and safety professionals who have implemented PtD in the UK over the years.

CURRENT KNOWLEDGE AND PRACTICE

Examples of PtD implementation in practice exist in some instances across the US construction industry. Research findings are available that describe PtD tools and resources that have been created, PtD processes that have been developed, and suggestions for how to design for safety (Hecker et al. 2005; Zou et al. 2008; Istephan 2004; Angelo 2004; Toole et al. 2016; WorkCover 2001; Toole and Gambatese 2008). Researchers have found that the origins of construction accidents and injuries are often upstream of the construction process and have their roots in project planning, scheduling, and design activities (Whittington et al. 1992; Suraji et al. 2001). Based on an investigation of the safety performance in the UK construction industry, a definite link exists between decisions made during design and the conditions experienced by workers on the construction site with respect to safety (Jeffrey and Douglas 1994). Trethewy and Atkinson (2003) found that designers influence, both directly and indirectly, the OSH performance of construction workers. In a study of a safety in design process implemented for a microchip fabrication facility, decisions made upstream of the construction phase during design, planning, scheduling, and material selection likely contributed to the presence of safety hazards during construction (Hecker et al. 2001). Quantifying the connection between design and construction worker safety (e.g., determining the percentage of injuries that could have been prevented through the design) has been attempted, with mixed results (Lorent 1987; Gibb et al. 2004; Haslam et al. 2003; Behm 2004b, 2005; Smallwood 1996; Churcher and Alwani-Starr 1996; Driscoll et al. 2004). Szymberski (1997), as represented in a time-safety curve, suggests that safety should be a primary concern of planners and designers during the early (conceptual and preliminary) design stages. According to Szymberski, the ability to influence safety in a positive manner is greatest when the hazards can be eliminated so that they do not appear on the worksite. It is too late to utilize this ability when safety is not considered until the contractor begins determining and planning the work operations and worksite conditions.

Prevention through design is a recognized best practice in the OSH field and well-known amongst safety professionals. However, due to the structure and customary practice of the US construction industry, its implementation within the construction industry is limited (Gambatese et al. 2005). Formal implementation across the industry is minimal (Toole et al. 2016; Gambatese et al. 2017). Research has additionally identified specific barriers to implementation of PtD in the US construction industry that exist at the employee, project, and organizational levels. These barriers include: designer education and training, professional liability for safety, a lack of regulatory requirements, an industry culture and structure that separates designers from involvement in construction worker safety, unavailability of PtD resources/tools, lack of designer training on how to implement PtD, and budget impacts associated with reviewing and modifying a design for safety (Gambatese 2003, 2008; Gambatese et al. 2005; Hecker et al. 2005; Hinze and Wiegand 1992; Toole 2005; Behm 2004a, 2005; Everett and Slocum 1994; Tymvios 2013).

One particular barrier that is often cited is the potential for increased exposure to liability associated with construction worker injuries. In response to advice from their legal counsel, design professionals often cite the potential for increased liability as a reason for not becoming involved in construction worker safety in any way, including pursuing PtD thinking in their designs. (Hinze and Wiegand 1992; Gambatese et al. 2005). Within the industry, insecurity associated with becoming involved in construction safety to any extent is a product of current legal and insurance practice in the construction industry (Korman 2001). One of the initial investigations of the extent to which designers are adopting PtD revealed that the number of adopters is small due to the liability issue (Coble 1997). Since then, interest in PtD has expanded (Tymvios 2013). However, in response to its significant perception as a barrier, fear of increased professional liability resulting from PtD implementation has been explored by numerous researchers to further confirm its presence and expose ways to mitigate the barrier (e.g., Behm 2004; Gambatese 2008; Gambatese et al. 2005; Hecker et al. 2005; Hinze and Wiegand 1992; Toole 2005).

While barriers to PtD exist, its implementation is enabled by a variety of factors and practices as well. Examples of enablers of PtD include: a designer mindset that includes construction safety as a design criterion; the availability of PtD design resources and tools; support for PtD implementation from the project owner/client; the use of integrated project delivery methods such as design-build and CM-at-risk; and the use of 4-D computer-aided designs (CAD), the application of building information modeling (BIM) to the design and construction process, and the use of virtual and augmented reality to assist with visualizing the design (Hinze 2000; Anderson 2000; Baxendale and Jones 2000; Toole et al. 2016; Ash 2000; Atkinson and Westfall 2000). Due to the difficulties associated with experimental research in construction and especially related to PtD, research on enablers, as well as barriers, to date is primarily founded on observational evaluations and projections supported solely by anecdotal evidence. Continued efforts are needed to quantitatively confirm the presence or absence of identified barriers and enablers.

Absent legislation mandating the implementation of PtD, voluntary adoption of PtD will increase through recognition of the impact of its implementation. Companies within the US construction industry that have implemented PtD to date have recognized and reaped the related benefits. In a study of PtD implementation on a microchip fabrication facility project, Weinstein et al. (2005), assessed whether the PtD program implemented had any impact on construction. During the design of the facility, 26 design changes were made in order to improve safety. The researchers found that 14 of the 26 design changes (54%) were recognized by trade contractors as benefiting the safety of the workers during construction. It should be noted that it is difficult to make the connection between a design element and improved OSH; many confounding factors exist due to the complexity of the construction process, multiple organizations involved, work site conditions, and human-related factors. Many of these confounding factors contribute to both the safety of workers and to the cause of injuries. Moreover, other safety control measures are implemented during construction as well as PtD. The overlapping impacts of multiple safety control measures implemented simultaneously complicate the connection between design features and safety performance. Therefore, researchers commonly rely on case studies, surveys, historical data analysis, and document reviews to expose potential links in support of PtD.

Worker safety during other facility lifecycle phases besides construction is important as well. The OSH of workers who participate in the operations and maintenance phases is expected to also improve with the implementation of PtD (Gambatese et al. 2005). This additional benefit is absent with other types of safety controls that are implemented during construction and then removed at the completion of construction. There is no value to the subsequent lifecycle phases when the safety measures are only present during construction. In addition to benefitting OSH, improvements in other project attributes as a result of implementing PtD accrue. Additional positive impacts to project cost, productivity, quality, and constructability have been realized (Levitt and Samelson 1993; Hinze 2006; Toole et al. 2006; Lam et al. 2006).

The research presented in this paper departs from previous studies of PtD in the US in that the present research utilizes the knowledge and experience of construction industry participants who are experienced in PtD implementation. Those involved in the UK construction industry, an industry that is similar to the US in structure and technological advancement, have gained insights into PtD, made adjustments in the project delivery process to incorporate PtD, and understand the impacts of PtD to a project. The extensive knowledge and experience provides a high level of confidence in the results. Additionally, while prior studies have targeted mostly the input of owners, designers, and constructors, the present research adds manufacturers/suppliers and health and safety consultants to the populations included in the study.

RESEARCH OBJECTIVES AND METHODS

In support of continued dissemination of the PtD concept in the US, the goal of the research study was to investigate the concept following its implementation over a sustained period of time. Specifically, the researchers were interested in gathering industry-wide data on common PtD practices across a construction sector that complements that from prior research. To do so, the researchers aimed at gathering the following information:

- The types and number of resources typically utilized to implement PtD in practice on projects
- The points within the project design phase when project personnel typically address PtD
- The practices and tools that are commonly used to address safety in a design
- Personal, project, organization, and industry barriers to PtD implementation
- Products, processes, and capabilities that enable PtD implementation
- The extent to which safety and other project properties are impacted, both positively and negatively, due to PtD implementation and the nature of the impacts

As noted above, PtD is implemented in a variety of forms in other countries. Perhaps the most structured and comprehensive implementation occurs in the UK. PtD implementation in the

UK was initially driven by the European Union (EU) Temporary or Mobile Construction Sites Directive of 1992. This directive instructed EU member states to address OSH risks through duties placed on those who design projects or oversee the design of projects (Anderson 2000). To meet this requirement, in March 1995 the UK enacted the Construction (Design and Management) Regulations (CDM) (Legislation 2011). In order to overcome fragmentation and lack of coordination between parties in the industry, the regulations are designed to bring all who can have an impact on OSH into the efforts to improve OSH (Hetherington 1995). Overall, the CDM Regulations are designed to decrease the total amount of OSH risk present on construction sites through the implementation of effective management of OSH upstream of the construction activity. For design professionals (e.g., architects and engineers), the Regulations prescribe a duty to ensure that their designs do not create unnecessary risk to those who will construct and utilize the design (e.g., construction workers and facility users) (MacKenzie et al. 2000). In 2007, the UK revised the CDM Regulations, reducing the amount of paperwork required and making the process more efficient. Subsequently, in April 2015, additional changes to the Regulations were made to more closely map the Regulations to the original EU Directive (HSE 2015). Based on the extensive implementation of the CDM Regulations, and therefore extensive experience of UK project teams with implementing PtD, the researchers selected the UK construction community as the focus of the present study. The present research was conducted while the 2007 CDM Regulations were still in place. The findings from the study do not take into account the changes made to the Regulations in 2015.

To conduct the research, the researchers elected to deploy a structured, randomized survey of the UK construction sector. This survey method affords collecting data from a wide spectrum of the UK construction sector within a short period of time. Additionally, the researchers felt that the research questions posed could be answered through closed-ended questions contained in an on-line survey.

The research design targeted six professional communities for the survey. The target communities were the following: architects, design engineers, facility owners/developers (clients), constructors (principal contractors and trade contractors), manufacturers and suppliers, and H&S consultants. To identify and contact the professionals, the researchers utilized industry associations that represent each of the targeted communities. The specific industry associations selected were as follows: Chartered Institute of Building (CIOB), Royal Institute of British Architects (RIBA), Institution of Civil Engineers (ICE), British Safety Council, Association for Project Safety (APS), Institution of Structural Engineers (IStructE), Institution of Mechanical Engineers (IMechE), Chartered Institution of Building Services Engineers (CIBSE), and Royal Institution of Chartered Surveyors (RICS). Therefore, the target population for the study consisted of the members of each of the listed industry association. It should be recognized that there may be overlap between industry association memberships, i.e., a person may be a member of more than one of the selected associations. However, given the unique focus of each professional community, the researchers expect that the amount of overlap is negligible.

A sample size of 200 randomly selected participants from the membership directories of the industry associations was established for the study. However, e-mail and contact information was not available from all of the association directories due to data protection and confidentiality requirements. Consequently, the researchers contacted the association office personnel to request that the survey be distributed via the association newsletters or placed on industry association websites. In addition, the researchers included their own personal contacts in the sample, especially those personnel who work at organizations known to be involved in design and construction. Lastly, the researchers recruited participants at in-person forums/events that regularly take place at different locations throughout the construction sector. Due to the sampling process, the researchers are not able to determine the exact response rate for the survey. The size of some of the targeted groups that received the request for participation is unknown. All interested participants were allowed to participate in the survey. Other than requiring the participants to be a member of an identified industry association, the researchers made no attempt to include or exclude participants.

The data collection instrument utilized for the survey was on-line questionnaire. The questionnaire was organized into several sections related to the following information: (1) demographic information about the participant, and (2) input related to each of the research questions listed above. To permit efficient and effective analysis of the survey data, each question was written to facilitate statistical analyses (e.g., Yes/No and Likert scale). Lastly, to ensure that the questions were clear and not overly burdensome to answer, a pilot test of the survey questionnaire was conducted. Five randomly-selected names from the sample were identified for the pilot test. The survey was distributed to the pilot test participants. Responses from the pilot test participants, and recommendations solicited from the participants for improving the questionnaire, were then used to modify the questionnaire prior to its distribution to the entire sample.

The researchers revised the survey questionnaire accordingly, and prepared and placed the survey on-line for ease of distribution. The on-line survey tool SurveyMonkey was used to host the survey. To be consistent with the terminology used in the UK, the term “design for safety” was used in the survey instead of “prevention through design”. The UK researchers involved in the study indicated that the term design for safety” is more universally understood in the UK construction industry. The researchers also focused the survey solely on worker safety (as opposed to safety and health) to match the term "design for safety" and minimize misinterpretation of the responses. Institutional Review Board approval for research with human subjects was acquired, and then the researchers distributed a link to the on-line survey via e-mail. In order to enhance internal validity, included in the e-mail was a description of the research and instructions for completing the questionnaire and submitting a response. Participation in the survey was voluntary. Reminder e-mails were distributed to participants if they did not respond within two weeks of receiving the initial request to participate in the survey. Multiple additional reminder e-mails were sent as needed in order to obtain at least 200 responses.

RESULTS

The research process generated a total of 258 responses to the questionnaire. In some cases the questionnaires were incomplete. Incomplete questionnaires were discarded which left 228 responses with complete information that were retained for the analysis. Given the nature of the questions, simple frequency comparisons and Chi-square inference tests were conducted. The tests explored PtD practices and experiences, especially with respect to the impacts on project performance and safety. Both univariate and, when possible given the number of data points available, multivariate analyses, were conducted. The results of the statistical analyses, along with content analyses of the responses to open-ended questions, were used to draw conclusions from the research.

The survey participants represent a diverse cross-section of the UK construction community. Approximately 37% of the 228 respondents work in construction organizations, while 30% work in organizations that provide primarily engineering services. All of the targeted industry associations are represented. The Institution of Civil Engineers had the majority of representatives (36%), followed by 30% membership in the Institute of Occupational Safety and Health, 11% in the Association of Project Safety, 10% in the Chartered Institute of Building, and 8% in the Institution of Structural Engineers. A small portion of the respondents (5%) are members of the Royal Institute of British Architects. The majority of respondents (24%) indicate that their current role is as a design engineer. Principal contractors make up 21% of the sample, and CDM coordinators constitute 15% of the respondents. Only a small number of participants (4%) are architects. In terms of the size of the companies represented by the survey respondents, over half of the respondents (54%) work in large organizations with >1,000 employees. The types of projects most often conducted by the respondent organizations are infrastructure/heavy rail (42%), industrial (28%), and commercial buildings (27%). Lastly, the number of years of experience of the respondents ranged widely. Design engineer respondents had a mean of 15 years of experience. Other levels of experience within the respondent pool were (mean values): 11 years as H&S consultant, 10 years as architect, 10 years as principal contractor, and 9 years as project manager.

The survey questionnaire asked respondents to identify the tools and resources that they utilize for PtD-related efforts. Such tools can vary significantly from simple checklists to 3D/4D visualization software. Since documenting risk assessments is a required component of the CDM Regulations, the use of standardized risk assessment forms is used most often (81% of respondents). These forms are typically developed in-house. Other commonly used tools and processes are: periodic design reviews (65%) and constructability reviews (53%), which are also often implemented by organizations in countries where there is no obligation to implement PtD. Other highly-used tools include: design checklists (54% of respondents), risk matrix (51%), and in-house design guide (48%). Some tools are publicly available through UK organizations and associations. Those commonly used are: British Standards (76% of respondents), HSE Guidance – Health and Safety in Construction (74%), and Approved Code of Practice (72%).

A question that has been posed by prior researchers aims to assess impacts of PtD on other project performance criteria besides safety. Other criteria that are commonly tracked are cost, duration, quality, and productivity. The respondents were asked their opinion about how PtD impacts project performance related to various criteria, including safety. Almost all of the respondents believe that PtD has a positive impact on both construction worker safety (87% of respondents) and end-user safety (87%). Impacts to quality and productivity were perceived to be mostly positive as well. Sixty-four percent of the 228 respondents believe that PtD increases construction quality while 32% feel that there is no change. Similarly, 50% of the respondents indicated that PtD improves worker productivity and 36% stated there was no change. Figure 1 shows the results related to design and construction cost. As shown in the figure, a large percentage of the respondents believe that PtD leads to increases in design cost, total project cost, and construction cost. However, many respondents indicated that there are no changes to these project characteristics when implementing PtD. Lastly, as shown in Figure 2, construction duration, design duration, and total project duration were identified as not being impacted or increasing as a result of implementing PtD. One indicator commonly used to measure project quality is the amount of rework required. The respondents were not asked in the survey about the impacts of PtD on rework. The researchers, however, believe that the implementation of PtD is likely negatively correlated to rework, i.e., as the extent of PtD implementation increases, the amount of rework required decreases.

< Insert Figure 1 here >

< Insert Figure 2 here >

In addition to impacting project performance criteria, the researchers explored the presence of an impact on the project personnel themselves. Respondents were asked to provide their perspective of how implementing PtD has impacted each of the major project team members. For all project team members, the respondents indicated their belief that PtD efforts have had a positive or very positive impact on the roles of the project team members. Positive impact was believed to be the greatest for principal contractors; some or very positive impact of PtD on principal contractors was indicated by 88% of the respondents. Responses regarding the impact of PtD on other project roles were as follows: positive impact on design engineer's role (87% of respondents), and positive impact on manufacturer/supplier role (33% of respondents).

Similar to that investigated in previous research, the present survey explored whether the design and construction of projects, e.g., the specific design features and the specific construction tasks, have changed as a result of implementing PtD along with the extent to which there has been change. The respondents feel strongly that there has been significant positive impact from PtD implementation. Regarding impact on design, 59 of the 228 respondents (26%) indicated very positive impact, while 60% of the respondents stated that there has been some positive impact. When considering the impact on construction, the results were as follows: 33% stated very positive impact, and 56% stated some positive impact. It should be noted that the percentage of respondents indicating no impact amounted to 6% for design and 4% for construction.

The extent to which a new process or product is diffused within the construction industry is dependent in part on the obstacles to implementation and the presence of factors that facilitate implementation. As described above, prior research has identified both barriers and enablers of PtD implementation. Table 1 shows the percentage of respondents who indicated the extent to which a factor is a barrier or enabler of PtD implementation for those factors most often cited. As shown in the table, lack of knowledge and priority given to other project objectives are seen as barriers by many respondents. In addition, knowledge of construction means and methods, especially those to be used on the specific project being designed is identified as facilitating PtD implementation. While knowledge and skills related to PtD were identified as important to its implementation, the effort to implement PtD was not viewed by a large number of respondents as a barrier. The magnitude of the effort needed to address construction worker safety was only viewed as a barrier by 15% of the respondents. The results related to questions about barriers and enablers expose a need for educating and training designers about PtD and its implementation. In addition, designer understanding of construction means and methods, and especially related to the project at hand if possible, is important to PtD implementation. This understanding can come from the participation during design of personnel who have construction experience, whether the actual contractor for the project or not. Lastly, the influence provided by the owner/client, and the culture of the design organization, also play significant roles in PtD. Promoting positive views of safety and the role of design in safety, both by the owner/client and within the design organization, will benefit PtD implementation.

< Insert Table 1 here >

While conditions may exist that enable PtD implementation, motivation for designers and project team members to modify a design for safety must also be present. In the UK, this motivation is present through the CDM Regulations. In other countries that lack similar regulations, motivation must come from other sources. The survey exposed other motivations for PtD. As shown in Table 1, enhanced firm reputation was viewed as the greatest motivating factor, listed as a motivator by 93% of respondents. Other factors that a significant portion of the respondents listed as motivators were improved construction worker safety (92% of respondents), and improved facility occupant safety (85%). It is encouraging to see that safety, both of construction workers and facility occupants, is recognized as a top motivator by the industry personnel. Cost and schedule are certainly concerns on projects, yet reduced costs and shorter schedules were identified as motivators by fewer respondents; a result that may be due to the respondents' concerns about the potential impacts of PtD on cost and schedule as described above.

Without regulations in place, and unclear data regarding return on investment, making a change in design practice is to a large extent a personal decision. A person's moral perspectives regarding their role and safety can be a motivator or lack thereof. One survey question asked, "What is your perspective of Design for Safety?", and provided multiple potential responses related to personal motivation that the participants could select. In response to this question, almost all of the respondents (94%) feel that PtD is not just a legislative requirement that they must abide by, but is a fundamental, "moral" imperative. This large percentage may reflect the appreciation that industry professionals in the UK have gained for PtD and protecting the safety of workers. However, self-selection as a participant in the study may be an impacting factor that affects internal validity. Those who volunteered to participate in the study may inherently have a greater appreciation for safety controls. When generalizing to the population at large, the actual percentage may be less.

In an attempt to control for the impact of the CDM Regulations, one survey question asked whether the participants would practice PtD if there were no Regulations. In addition, continuation of designing for safety if the CDM Regulations were abolished was also explored. The results related to these questions are as follows:

- 217 of the 228 respondents (95%) stated that they would still practice PtD if there were no Regulations. Of the 217 respondents, 51% indicated that they would practice PtD in its current form, while 44% would change how they practice PtD.
- 221 of the respondents (97%) would still take steps to design for safety if the CDM Regulations were eliminated in the future; sixty-seven percent would do so as currently practiced while 30% would modify how it is currently implemented.

Overall perception of and attitude toward PtD was positive. Only less than 10% of the respondents felt that the barriers to PtD are so numerous compared to the benefits that it makes PtD ineffective. Conversely, a large percentage (60%) view PtD as an important aspect of ensuring the safety of construction workers and should receive greater priority by project teams. However, this positive result is tempered by a smaller portion of the respondents (27%) who indicate that they expect the benefits of PtD to offset the effort required to implement it. This result is consistent with the lack of clarity regarding the impacts of PtD on project cost and schedule as indicated above.

ANALYSIS AND DISCUSSION

Using their experience and judgment, the researchers analyzed the survey responses with respect to the research questions established for the study. In addition, the analyses aimed to explore how survey responses related to PtD performance and perspectives correlate to respondent demographics. Simple frequency statistics (number and percent of responses) were used to analyze the data with respect to each research question. The results of the analyses along with discussion of the findings are provided below.

Types and Magnitude of Resources Associated with PtD in Practice

Design utilizes human resources to a great extent. As a design intervention, PtD involves design professionals and is supported by those who have knowledge of both construction safety and construction means and methods. The survey respondents indicated that general contractors, design engineers, and CDM coordinators contribute the most to PtD implementation. The extent of input of each participant may differ based on the company, project, and individual. A person's attitude, experience, and knowledge impact the extent of their role in PtD. For most of the companies represented in the survey, in-house staff and constructors provide the greatest amount of input to PtD in practice. Design consultants external to the organization are utilized less often. Primarily utilizing in-house staff is an encouraging finding; organizations are willing to take on their role in PtD rather than subcontract it out. This inclusion of PtD within staff roles may indicate a view that it is intrinsic to their business and services provided. Involving constructors is likely needed to incorporate the necessary construction knowledge regarding safety hazards and construction means and methods. The relative participation of designers and constructors in practice may not be ideal due to available resources and capabilities. The survey results show, however, that some project team members are viewed as more valuable for PtD implementation than others.

Timing of PtD Efforts

As a design intervention, PtD is envisioned as primarily occurring during the design phase of a project. PtD's applicability and effectiveness are contingent upon it being implemented at the appropriate time. Analysis of the survey data reveal that PtD activities occur throughout the project lifecycle. Initially, PtD activities are undertaken during project planning (preparation) before detailed design. Eighty-one percent of those respondents who are either partially or fully involved in PtD conduct the activities during the planning phase. The greatest extent of implementation occurs during design and pre-construction; 89% and 96% of the respondents indicated conducting PtD activities in design and pre-construction, respectively. Addressing safety in the design commonly extends into construction as well, with 90% of the respondents indicating PtD activities in construction. Due to the nature of the PtD concept and the presence of the CDM Regulations, it is expected that PtD activities will take place early in the project. Implementing PtD during construction may be a result of needed design changes, the added benefit of having construction knowledge on the project, the exposure of hazards not identified during design, the difficulty of envisioning hazards during design, or other project factors. Therefore, PtD should also be considered as an integral part of pre-construction and construction activities in addition to those activities that occur during planning and design.

PtD Practices and Tools

Experience implementing PtD has led to the development of processes and tools that facilitate its implementation and increase its impact. To be effective, the processes and tools implemented must fulfill basic needs associated with designing for construction safety. One need is for information about construction means and methods to be implemented and the safety hazards to which workers will be exposed. Those implementing PtD must have the ability to visualize the construction operations and identify the corresponding safety hazards. Once the hazards are identified, an ability to objectively assess the associated risk is imperative. An ability to generate alternative designs that mitigate the risk is needed as well. Lastly, those implementing PtD should have the capability of evaluating the feasibility of each identified alternative and then selecting the best alternative for the project.

The survey results reveal that a variety of processes and tools have been developed that vary in type and format. Risk assessment matrices, design guides and checklists, and databases of lessons-learned are the most commonly used tools for addressing safety in a design. Survey respondents indicated that implementation of the tools occurs both formally as part of a planned design process and informally on an ad-hoc basis. External references are common, especially those published by government organizations, regulatory bodies, and professional associations. Computer visualization/simulation software and on-line design resources, while commonly used for other project activities, are used less often for implementing PtD. Reasons for their lack of use may include factors related to ownership and operating cost, applicability to the project, usability, time and effort required to implement, a lack of incentive to vary from current practice, and other issues.

PtD Enablers and Barriers

Efficient and effective implementation of PtD is predicated upon sufficient motivation and resources. Analysis of the survey responses reveals that the extent of PtD implementation increases when sufficient resources such as time and funding for design reviews, risk assessments, and alternative evaluation and selection are present. Design durations must be set to allow project personnel to work together to review and revise the designs to account for worker safety. In addition to allowing sufficient time for design personnel to create safe designs, adequate time needs to be devoted to conducting thorough constructability reviews in order to permit construction knowledge to be incorporated into the design.

Knowledge of safety requirements and the conditions that workers need to work safely also enables PtD implementation. Lacking such knowledge, safe designs cannot be created. Supplementing knowledge about safety is the need for those creating the design to know the means and methods of construction, and how to create safe designs to accommodate the planned construction operations. All of this knowledge is needed in order to utilize safety measures that are higher on the hierarchy of controls (Manuele 1997) and associated with PtD. When this knowledge is in place, the effort needed to address worker safety in the design phase decreases, which is another enabler identified by the survey respondents, and a design that is safer and more accommodating of the construction effort results.

Obstacles to PtD implementation are present. Barriers commonly cited by the survey respondents include: inadequate design time, insufficient design for safety knowledge and skills, a lack of knowledge of construction means and methods, and other project performance criteria (e.g., cost, schedule, and productivity) given higher priority. It is important to note that the barriers cited are simply obstacles that limit effective PtD implementation but do not prevent its implementation. While no regulations exist in the US to mandate PtD implementation, it is implemented by some firms successfully. Effective and comprehensive implementation is affected by the barriers. Diffusion of the PtD concept, application in practice, and effectiveness resulting from its application will improve with the barriers eliminated.

Impacts of PtD Implementation

An important finding from the survey is that the respondents recognize that PtD has a positive impact on construction worker and end-user safety. Improving safety is the main goal. Recognition that safety is improved also creates a positive view of PtD as opposed to just another part of the design process that has questionable benefit. The respondents indicate that secondary benefits accrue as well, including improved quality of the work and higher construction productivity. These secondhand positive impacts perhaps encourage designers to think critically about how their designs impact the whole project.

The survey data reveal that PtD also affects the resources input into a project. Additional design reviews, risk assessments, reviews for constructability, and design changes to improve safety require more time and cost for the design. When the contractor is involved in the process, construction costs increase as well. While initial costs may increase, those surveyed perceive a long-term positive impact. Enhanced productivity, better work quality (less re-work), lower insurance costs due to improved safety, and greater efficiencies during facility operation and maintenance are all expected. These benefits ultimately offset the initial costs and time of implementation.

PtD is also credited with having a positive effect on the attitude and professionalism of project team members. Survey respondents report that, as a result of implementing a PtD process, there is greater consideration of the needs and limitations of all members of the project team. Designer appreciation for the safety of construction workers is also said to increase. These are both positive changes that are encouraging for the industry. When designers increase their understanding of construction site hazards and the important role that they can play in eliminating the hazards, the whole project benefits as well as the design profession. Survey respondents report greater collaboration, improved communication, and a spirit of working together.

Additional Impacts

The researchers conducted statistical analyses of the survey results to explore whether particular responses are connected to respondent characteristics. Understanding the perspectives of PtD based on demographic qualities of the respondents can help in identifying diffusion strategies in the US. Given the nature of the survey data, Chi-square tests were conducted. Of particular interest in the analysis is the attitude of the respondents towards PtD and the perceived impact on project performance criteria. As dependent variables, the analyses focused on responses related to the following items of interest:

- Impact of PtD on performance criteria;
- Impact of PtD on project team roles;
- Impact of PtD on design and construction;
- Impact of CDM legislation on PtD; and
- Attitude toward PtD (aggregate of responses from more than one question).

Utilizing the responses related to respondent demographic information, the researchers conducted Chi-squared odds ratio tests to determine the odds in which one distribution of respondents is different than another. For categorical variables, the Chi-squared test was used to determine the odds that one respondent distribution (e.g., those who are "involved in PtD") was more or less likely to provide a specific response (e.g., design costs increase) than another respondent distribution. For each test, a p-value is calculated to determine the possibility that the test result is due to chance. The p-value is an indication of the level of confidence that the odds ratio is different than 1.0, with a ratio of 1.0 indicating that they have the same odds. The lower and upper bounds of the 95% confidence interval for the odds ratio are also calculated to provide another indication of the strength of the test results. Confidence intervals in which an odds ratio of 1.0 is not within the lower and upper bounds indicate a greater level of confidence that the test result is not due to chance. For survey response variables such as number of years of experience (i.e., quantitative variables), the researchers performed ordered contingency Chi-squared tests. The ordered contingency test reveals whether the dependent variable varies with respect to the magnitude of the independent variable. For this test, a one-sided p-value is similarly calculated to indicate the possibility that the observed variation is due to chance.

The dependent variables studied are divided into two categories – personal and organization – based on whether the variable represents a condition that exists at the individual employee level or as part of the organization as a whole. In some cases the variable investigated was aggregated from multiple similar questions to provide greater confidence in the results. Those dependent variables at the personal level that were explored are: years of work experience; extent of involvement in PtD (aggregate); timing of involvement in projects; role on project team; and project performance criteria priority. Dependent variables at the organizational level that were explored include: industry sector; type of organization; organizational capabilities; and size of organization (# of employees). Summary descriptions of the results of the Chi-squared tests are provided below for those comparisons in which there is at least suggestive evidence of an association between the variables (one-sided p-value < 0.05), and in which the 95% confidence interval for the odds ratio does not include 1.0.

Number of Years and Type of Work Experience

Working in the construction industry provides a perspective of the industry that is not available to those who work in other industries. In addition, a greater number of years of experience can provide industry personnel with a more detailed and comprehensive view of the industry. Therefore, it was hypothesized that those with more years of experience have a different view of PtD that those with fewer years of experience. The results related to years of experience are as follows:

- No statistically significant relationship was found between the respondent's number of years of work experience (in any discipline) and the respondent's attitude towards PtD and perception of how PtD impacts project team member roles, design, and construction.
- The perception of the impact of PtD on project performance related to cost, duration, quality, etc. was found to correlate to the number of years of work experience for various disciplines:
    - Those without architectural experience are more likely to perceive PtD as leading to increases in design cost, construction duration, and total project duration.
    - Design engineers who possess any amount of work experience are more likely to indicate that construction cost and total project cost increase.
    - Those with any amount of construction experience are more likely to indicate a decrease in construction duration.

- Subcontractors who possess low (<5 years) or medium (5-10 years) amounts of experience are more likely to indicate an increase in worker productivity.

Magnitude and Duration of Respondent Involvement

Several survey questions were asked related to the respondent's extent of involvement in PtD. The responses to these questions were combined into an aggregate variable reflecting the type of involvement in PtD, extent to which PtD is part of the respondent's role, and the amount of time which the respondent has worked with the CDM Regulations. Both magnitude and duration of involvement in PtD are included in the aggregate variable. The Chi-squared tests revealed the following results:

- Greater involvement in PtD results in a more positive attitude towards PtD and a better understanding of the impacts of PtD.
- Respondents are more likely to have an opinion that construction duration, construction safety, and end-user safety improve as the respondent level of involvement in PtD is greater.
- Respondents are more likely to recognize positive impacts to team member roles (specifically the owner/client, manufacturer/supplier, principal contractor, and subcontractors) if they are more highly involved in PtD (have regular PtD involvement, PtD is all or part of their project role, and have 3 or more years of experience working with the CDM Regulations).
- Respondents are more likely to exhibit a positive perspective regarding the impacts to design and to construction from PtD if they are more highly involved in PtD.

The results related to the aggregate variable representing the extent of involvement in PtD suggest that after initial involvement occurs, appreciation for PtD and its benefits is present. In addition, this appreciation increases as involvement in PtD increases. Therefore, getting over the initial hurdle is imperative for PtD diffusion to occur. After this initial hurdle is overcome, diffusion is likely to occur at an increasing rate.

Timing of Respondent Involvement

As mentioned previously, the timing in which PtD efforts occur is important to the success of being able to modify a design for safety. The Chi-squared tests revealed that those who are involved in the planning/preparation stage are more likely to indicate increases in design cost and construction duration due to PtD implementation. This result is expected given the intimate knowledge that these individuals have about planning and design compared to those who do not participate in the planning and design stages. The statistical test results also reveal that planners and designers (i.e., those not involved in the construction stage) are more likely to respond that there are increases in design and construction cost as a result of implementing PtD, and that there is no change in the quality of the work. Involvement in construction creates a different perspective of PtD; respondents who are involved in the construction process to any extent are more likely to indicate an increase in construction quality and a decrease in total project cost. Lastly, a somewhat surprising result was found regarding those who have regular involvement in both design and pre-construction: they are more likely to possess a positive or very positive attitude towards PtD than those who are not involved in both stages. Pre-construction often involves interaction with constructors, especially on how to improve the project to meet construction needs. This interaction, which is often collaborative and forward-looking in nature, coupled with knowledge of the design, may positively affect attitude towards PtD.

Respondent Role and Discipline

As described above, previous research suggests that a person's role on projects impacts his/her perspective of PtD. Involvement in the architecture role on a project stood out in terms of perspective of PtD. A negative or poor attitude towards PtD was found to more likely exist with those who participate in the architect's role on projects. This result was also consistent with those who participate in both the architect's or engineer's role. On the other hand, a positive or very positive view of PtD is more likely to be held by those who participate in the principal contractor role on projects. The difference in the extent to which perception of, and attitude towards, PtD is based on participant role is clear. As found in previous research, those involved in the construction operations are more enthusiastic and supportive of PtD than those involved in other phases of a project. In addition, those in design roles perceive PtD as requiring additional construction cost and time. This finding brings greater attention to the need to address the attitude of designers towards PtD given that the design is the primary focus of the PtD concept.

Priority of Safety Compared to Other Project Performance Criteria

Safety is just one of multiple priorities optimized on a project. As PtD aims to improve safety, the regard to which safety is held compared to other project performance criteria (e.g., cost, schedule, quality) can impact the level of acceptance and implementation of PtD. Designing for construction safety as an outcome may not be viewed as favorably if construction worker safety is held as a lower in priority than other criteria. When evaluating the respondent's attitude towards PtD with respect to the level of priority placed on different project criteria (safety, cost, duration, quality, aesthetics, and productivity), the statistical analyses reveal the following:

- Those respondents, regardless of project role, who place aesthetics lower as a priority (predominantly engineers and constructors) are more likely to have a positive or very positive attitude towards PtD.
- The attitude towards PtD becomes more positive and supportive as the level of priority given to construction worker safety increases.

Industry Sector of Respondent Organization

Industry sectors within construction have different safety performance. Power generation and petro-chemical sectors, for example, are commonly found to have better construction safety performance than other sectors due to their heightened focus on safety throughout the entire facility lifecycle and significant operational ramifications of industrial accidents. Less of a focus on construction safety is typically found in other industry sectors due to the nature of the work and demographics of the organizations in the other sectors. In addition, in the industrial sector, engineer-procure-construct (EPC) firms are employed to a greater extent, possibly leading to greater designer-constructor collaboration and therefore improved safety. The statistical analyses reveal that respondents employed in the industrial sector are more likely to state that there is an increase in construction duration, total project duration, and construction quality as a result of implementing PtD. For those respondents involved in the commercial buildings sector, there is a greater likelihood that they perceive PtD as leading to better construction quality.

Discipline of Respondent Organization

Closely related to the respondent's role and timing in which they are involved in PtD is the discipline of the respondent's organization. Organizational culture can have a significant impact on worker attitudes and performance. Statistical analysis of the survey data show that there is a greater likelihood that those who work in design engineering firms will indicate that PtD increases the duration of construction on a project. With regards to the owner's role on a project, a positive impact to the owner's role is more likely the perspective of those who do not work in a design firm, and those who work in a construction firm. In addition, employment in a construction firm correlates to a more likely response of a positive or very positive attitude towards PtD. Consistent with previous research that indicates less acceptance of PtD from the design community, those who work in an architecture or engineering firm were found to be more likely to view PtD negatively or with a poor attitude.

Capabilities and Services provided by the Respondent's Organization

Construction industry organizations provide a variety of services to clients and have different capabilities. Some services are provided with in-house staff, and may or may not be used on construction projects depending on their availability and the nature of the projects. When architectural design is present within the respondent's organization, the respondent is more likely to state that implementing PtD results in increased construction cost, greater total project cost, and enhancements to the architect's role on a project. In firms with owner/developer capabilities, the respondents are more likely to state that there is a positive impact on the facility owner/developer role as a result of implementing PtD. On the construction side, there is a greater likelihood that those in organizations with principal contractor responsibilities will indicate an increase in design cost. Lastly, with regard to having subcontracting capabilities in-house, there is a greater likelihood that employees of such firms will indicate that PtD implementation results in higher worker productivity. Contrastingly, without subcontractor capabilities present in-house, the respondents are more likely to indicate that the roles of the architect, engineer, and material manufacturer/supplier are positively impacted.

Number of Employees in Organization

The size of an organization may impact the level of available resources and organizational capabilities, as well as the safety culture within the organization. Advantages with respect to PtD may be present within a larger organization compared to a smaller organization. Larger organizations may have sufficient resources to implement and promote PtD within its employee base while at the same time meeting other competing performance criteria. The impact of organization size on construction safety performance is evident in safety performance statistics in the US (CPWR 2013). The statistical analyses of the survey data reveal that a respondent is more likely to indicate that PtD leads to a decrease in construction duration as the size of the organization increases. With respect to construction quality, when an organization has 10 or more employees, the respondent is more likely to indicate that PtD implementation results in improved quality of the work. Lastly, for large organizations (greater than 500 employees), the respondents in these organizations are more likely to state that there is an increase in construction worker safety as a result of implementing PtD.

CONCLUSIONS AND RECOMMENDATIONS

Preventing construction worker injuries and fatalities through the design of a facility is of interest as employers look for additional means to improve safety for their workers. Knowledge and understanding of the PtD concept, practices, and tools, and likely impacts of its implementation are prerequisites for widespread diffusion and acceptance of the concept in the construction industry. When PtD is implemented, the present study revealed the resulting safety perception, role, and culture outcomes at the individual, organizational, and industry levels. These findings provide industry professionals with further guidance and understanding of PtD that facilitate its implementation. To assist with implementing PtD in practice, the study also revealed design processes and products that have been developed and which are commonly used. The resources and tools identified could be further developed for industry-wide use.

An important organizational requirement for deciding whether to implement any new process or tool is to have a clear understanding of the return on investment of implementation. Of primary importance is the outcome and recognition that implementing PtD leads to lower risk on construction work sites and an expected reduction in construction worker injuries and fatalities. This outcome is realized for end-users as well. The results of the present study suggest that PtD has an effect on not only the safety of construction workers but also on other costs and benefits of construction projects. Those participating in the study, characterized by intimate involvement in the construction industry and a high level of experience implementing PtD, indicate that implementing PtD either does not change or increases design cost and duration. However, clarity regarding PtD impacts on construction cost and duration is not present, and likely dependent on factors specific to each project or organization. There is a clear trend, however, that those involved in PtD implementation recognize secondary benefits associated with improved work quality, worker productivity, project team collaboration, and constructability of the design. It can be concluded that, overall, the physical and operational aspects of both design and construction are impacted positively as a result of implementing PtD in practice.

One of the unique aspects of PtD as a construction safety management tool, and which remains a highlight of PtD when applied to construction worker safety, is the positive and long-term impact that PtD has on operations and maintenance safety also. Other common construction safety interventions are only present during the construction stage and thus provide little or no benefit to the users and maintainers of the facility later in its lifecycle. The practice of implementing PtD for construction worker safety provides longitudinal benefits by helping to lower safety risk during use and maintenance of the facility. In addition, the lessons learned during the design of one project can be re-used to benefit subsequent projects. While it may not be explicitly evident, PtD implementation should decrease the need for implementing safety measures during construction and other downstream phases. “Add-on” safety measures needed during construction may not be required as a result of implementing PtD; construction site safety hazards are eliminated before the construction operations begin. It is expected that this outcome ultimately results in lower construction cost and shorter construction duration. The construction professionals who participated in the study suggest this outcome through their experience implementing PtD. The long-term positive impacts to project cost and duration are also expected based on the nature of PtD and principles of risk management and cost engineering. It is recognized that for an organization to realize such benefits in practice, its implementation of PtD would likely need to be optimal, involve a highly integrated and collaborative project team, and be supported by effective design tools and practices. Given the unique nature of most construction projects and fragmentation of the industry, measuring this benefit is especially difficult. When any modification is made to the design, it is unlikely that there exists an accurate initial cost associated without the enhanced design change present that can act as a baseline to measure any variation.

Design process tools have been developed by organizations to facilitate and optimize PtD implementation. Examples of PtD-related tools are design checklists, risk assessment forms, and lessons-learned databases. The process of designing for construction safety typically involves multiple design and construction personnel integrating these tools within design and constructability reviews during the planning and design phases of a project. Hazard identification and risk assessment is performed through "safety constructability" reviews. Such reviews utilize input from the designer, constructor, and end-user. The outcome is a modified design and design documents. The physical features of the design account for the safety needs of workers who construct the designs. When the safety risk cannot be eliminated, the design documents include hazard and safety information to alert the constructor of safety hazards to expect during construction and to communicate suggestions for safety measures to be taken or regulations to follow.

Explicit impacts resulting from implementing PtD are difficult to pinpoint. Those involved in PtD implementation, however, broadly recognize positive impacts to the project team, and especially the design profession. Attitude toward and acceptance of PtD varies depending on an individual's role within a project team and professional discipline. Those involved in and responsible for construction of a project almost universally feel that the benefits resulting from PtD implementation outweigh the costs. The study reveals that those who purely provide design services, e.g., consulting architects and engineers, regard PtD less favorably. The efforts to increase diffusion of PtD in the construction industry must recognize this result as a key hurdle. With a primary if not the central role associated with project planning and design, architects and engineers are critical participants in implementing the PtD concept. Therefore, a foundational component of any effort to further expand PtD in the US must positively affect how designers perceive and accept PtD and facilitate their implementation of PtD. Examples of ways to possibly change designer attitude and behavior include mandating PtD implementation through design contracts, expanding PtD within professional liability insurance coverage, incorporating PtD for construction safety into design codes, and enhancing designer education to include PtD.

The PtD experience in the US to date is mixed; some individuals, firms, and organizations have embraced and integrated PtD in their culture and practice while others have rejected it as an unreasonable approach that is potentially detrimental to current design practice. As a result, PtD is not embraced by the US design profession as a whole. Based on the present and previous research, there exists a pre-occupation with third-party liability and the barriers associated with PtD implementation. However, such viewpoints, whether they exist with respect to PtD or any other safety concept and practice, are detrimental to creating safe work environments and improving worker safety. Too much of a focus on barriers and preventing negative outcomes inhibits taking active, positive, and needed involvement (Hummerdal 2015). The identified barriers are not insurmountable. Changing the way safety is viewed to be more inclusive of the entire project team, with active participation consistent with the current roles, is needed. For the design profession or any other profession, current common practice is not necessarily synonymous with prudent practice (Eastern Transportation Co. v. Northern Barge Corp., 60 F.2d 737). It is time for the industry to change and wholeheartedly support PtD, to truly place safety paramount in design practice, and to actively participate in order to create a supportive and participatory safety environment throughout the design profession.

Further research is needed to explore the impacts of PtD in various settings and under different regulatory requirements. As a next step, an investigation of PtD in other EU countries, Australia, Singapore, and South Africa where PtD is currently regulated and implemented would provide additional insights into the expected impacts of greater implementation here in the US.

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REFERENCES

Aires, D.M., Gamez, C.R., and Gibb, A. (2010). "Prevention through design: The effect of European Directives on construction workplace accidents." *Safety Science*, 48(2), 248-258.

Anderson, J. (2000). Finding the right legislative framework for guiding designers on their health and safety responsibilities. *Proc. of the Designing for Safety and Health Conference*, sponsored by C.I.B. Working Commission W99 and the European Construction Institute (ECI), London, England, June 26-27, 2000. ECI Pub. TF005/4, 143-150.

Angelo, W. F. (2004). "Design-builder builds safety into total jobsite approach." *Engineering News-Record*, June 28.

Ash, R. (2000). CDM and design: Where are we now and where should we go? – A personal view. *Proc. of the Designing for Safety and Health Conference*, sponsored by C.I.B.

Working Commission W99 and the European Construction Institute (ECI), London, England, June 26-27, 2000. ECI Pub. TF005/4, 151-158.

Atkinson, A., and Westall, R. (2010). “The relationship between integrated design and construction and safety on construction projects.” *Const. Mgmt. and Econ.*, 28(9), 1007-1017.

Baxendale, T. and Jones, O. (2000). Construction design and management safety regulations in practice – Progress on implementation. *International Journal of Proj. Mgmt.*, 18, 33-40.

Behm, M. (2004a). “Legal and Ethical Issues in Designing for Construction Worker Safety.” In: Hecker, S., Gambatese, J., and Weinstein, M. (Eds.). *Designing for Safety and Health in Const.: Proc. from a Res. and Prac. Symp.*, Sept. 15-16, Portland, OR, pp. 165-177.

Behm, M. (2004b). “Establishing the Link between Construction Fatalities and Disabling Injuries and the Design for Construction Safety Concept.” PhD dissertation, Department of Public Health, Oregon State University, Corvallis, OR.

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

BLS (2013). “Census of Fatal Occupational Injuries Charts, 1992-2013.” U.S. Department of Labor, Bureau of Labor Statistics.

CDM (1994). *Construction (Design and Management) Regulations*, SI 1994/3140 HMSO.

Churcher, D.W. and Alwani-Starr, G.M. (1996). “Incorporating construction health and safety into the design process”. *Proc. of the First International Conf. of CIB Working Commission 99: International Conf. on Implementation of Safety and Health on Construction Sites*, Lisbon, Portugal, Sept. 4-7, 1996. Rotterdam: Balkema.

Coble, R. (1997). “Knowing Your Role in Construction Safety to Avoid Litigation.” *Journal of the American Institute of Constructors*, AIC, 21(3), 25-28.

Driscoll, T., Harrison, J.E., and Bradley, C. (2004). *National Occupational Health and Safety Commission: The role of design issues in work-related injuries in Australia 1997-2002*. National Occupational Health and Safety Commission, Canberra.

Everett, J.G. and Slocum, A.H. (1994). “Automation and Robotics Opportunities: Construction versus Manufacturing.” *Journal of Constr. Engrg. and Mgmt.*, ASCE, 120(2), 443-452.

Gambatese, J.A. (2003). “Safety Emphasis in University Engineering and Construction Programs.” Special Issue on “Construction Safety Education and Training – A Global Perspective”, Ed.: Hinze, J., *International e-Journal of Construction*, University of Florida, M.E. Rinker School of Building Construction, May 2003.

Gambatese, J.A. (2008). “Research Issues in Prevention through Design.” *J. of Safety Res.*, Special Issue on Prev. through Design, Elsevier and Nat. Safety Council, 39(2), 153-156.

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

Gibb, A., Haslam, R., Hide, S., and Gyi, D. (2004). “The role of design in accident causality.” In: *Designing for Safety and Health in Construction*, Hecker, S., Gambatese, J., and Weinstein, M. (Eds.). University of Oregon Press, Eugene, OR, 11-21.

Haslam, R., Hide, S., Gibb, A., Gyi, D., Atkinson, S., Pavitt, T., Duff, R., and Suraji, A. (2003). *Causal Factors in Construction Accidents*. Health and Safety Executive, RR 156.

Hecker, S., Gibbons, B., and Barsotti, A. (2001). Making ergonomic changes in construction: worksite training and task interventions. In: *Applied Ergonomics*; Alexander, D. and Rabourn, R. (Eds.). Taylor & Francis, London, 162-189.

Hecker, S., Gambatese, J., and Weinstein, M. (2005). "Designing for Worker Safety: Moving the Construction Safety Process Upstream." *Professional Safety*, Journal of the American Society of Safety Engineers (ASSE), 50(9), 32-44.

Hetherington, T. (1995). "Why Involve Design Professionals in Construction Safety." *Structural Survey*, 13(1), pp. 5-6.

Hinze, J. (2000). "Designing for the Life Cycle Safety of Facilities." *Proceedings of the Designing for Safety and Health Conference*, sponsored by C.I.B. Working Commission W99 and the European Construction Institute (ECI), London, England, June 26-27, 2000. ECI Pub. TF005/4, 121-128.

Hinze, J. W. (2006). *Construction Safety*. Pearson Education, Inc., FL.

Hinze, J. and Wiegand, F. (1992). "Role of Designers in Construction Worker Safety." *Journal of Construction Engineering and Management*, ASCE 118(4), 677-684.

HSE (2015). *The Construction (Design and Management) Regulations 2015*. Health and Safety Executive, http://www.hse.gov.uk/construction/cdm/2015/index.htm, April 2015.

Hummerdal, D. (2015). "Love Safety." Safety Differently: Innovative and critical safety thinking, http://www.safetydifferently.com/love-safety/, May 14, 2015.

Istephan, T. (2004). "Collaboration, total design, and integration of safety and health in design – Project case studies." In: Hecker, S., Gambatese, J., and Weinstein, M. (Eds.), Designing for Safety and Health in Construction: Proceedings from a Research and Practice Symposium, September 15–16, Portland, Oregon, USA. Eugene, OR: UO Press, 264-279.

Jeffrey, J. and Douglas, I. (1994). Safety performance of the United Kingdom construction industry. In: *Proc. of the Fifth Annual Rinker International Conf. Focusing on Constr. Safety and Loss Control*, University of Florida, Gainesville, FL, Oct. 12-14, 1994.

Korman, R. (2001). “Wanted: New Ideas. Panel ponders ways to end accidents and health hazards.” *Engineering News-Record*, McGraw-Hill, December 31, 2001, pp. 26-29.

Lam, P.T.I., Wong, F.W.H., and Chan, A.P.C. (2006). “Contributions of designers to improving buildability and constructability.” *Design Studies*, 27(4), 457–479.

Legislation (2011). “The Construction (Design and Management) Regulations 2007.” Legislation.gov.uk, http://www.legislation.gov.uk/uksi/2007/320/contents/made, July 2011.

Levitt, R.E. and Samelson, N.M. (1993). *Construction Safety Management*. John Wiley & Sons, New York, NY.

Lorent, P. (1987). Les conditions de travail dans l'industrie de la construction, productivité, conditions de travail, qualitié concertée et totale. CNAC, Brussels.

MacKenzie, J., Gibb, A.G., and Bouchlaghem, N.M. (2000). “Communication: The Key to Designing Safely.” *Proceedings of the Designing for Safety and Health Conference*, sponsored by C.I.B. Working Commission W99 and the European Construction Institute (ECI), London, England, June 26-27, 2000. ECI Pub. TF005/4, pp. 77-84.

Manuele, F.A. (1997). *On the Practice of Safety*, John Wiley and Sons, Inc. New York, NY.

Smallwood, J.J. (1996). “The influence of designers on occupational safety and health.” In: *Proc. of the First International Conf. of CIB Working Commission W99, Implementation of Safety and Health on Constr. Sites*, Lisbon, Portugal, September 4-7, 1996, pp. 203-213.

Suraji, A., Duff, A.R., and Peckitt, S.J. (2001). “Development of causal model of construction accident causation.” *Journal of Constr. Engrg. and Mgmt.*, ASCE, 127(4), 337–344.

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

Toole, T.M. (2005). “Increasing Engineers’ Role in Construction Safety: Opportunities and Barriers.” *Journal of Prof. Issues in Engrg. Educ. and Practice*, ASCE, 131(3), 199-207.

Toole, T.M. and Gambatese, J.A. (2008). “The Trajectories of Prevention through Design in Construction.” *Journal of Safety Research, Special Issue on Prevention through Design*, Elsevier and National Safety Council, 39, 225-230.

Toole, T.M., Hervol, N., and Hallowell, M. (2006). “Designing for Construction Worker Safety.” Proceedings of the 2006 North American Steel Construction Conference, American Institute of Steel Construction (AISC), San Antonio, TX, February 8-11, 2006.

Toole, T.M., Gambatese, J.A., and Abowitz, D.A. (2016). “Owners’ Role in Facilitating Prevention through Design.” *Journal of Professional Issues in Engineering Education and Practice*, ASCE, 142, 04016012, DOI: 10.1061/(ASCE)IE.1943-5541.0000295.

Gambatese, J.A., Toole, T.M., and Abowitz, D.A. (2017). “Owner Perceptions of Barriers to Prevention through Design Diffusion.” *Journal of Construction Engineering and Management*, ASCE, 04017016, DOI: 10.1061/(ASCE)CO.1943-7862.0001296.

Trethewy, R., and Atkinson, M. (2003). Enhanced Safety, Health, and Environmental Outcomes through Improved Design. *Journal of Occupational Health and Safety, Australia and New Zealand*, 19 (5), 465-475.

Tymvios, N. (2013). “Direction, Method, and Model for Implementing Design for Construction Worker Safety in the US.” PhD Dissertation, Oregon State University, July 2013, https://ir.library.oregonstate.edu/xmlui/handle/1957/41056.

Weinstein, M., Gambatese, J., and 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.

Whittington, D., Livingstone, A., and Lucas, D. A., (1992). "Research into management, organizational and human factors in the construction industry." *HSE Contract Research Rep. No. 45/1992*, HMSO, London.

WorkCover (2001). "CHAIR Safety in Design Tool." WorkCover, New South Wales, http://www.workcover.nsw.gov.au/formspublications/publications/Documents/chair_safety_in_design_tool_0976.pdf.

Zou, P.X.W., Redman, S., and Windon, S. (2008). "Case Studies on Risk and Opportunity at Design Stage of Building Projects in Australia: Focus on Safety." *Architectural Engrg. and Design Management*, Earthscan, www.earthscanjournals.com, 4, 221-238.

Table 1. Factors that Impede or Facilitate PtD Implementation (n=228)

Type of Impact	Description	% of Respondents
Barriers	Designer lacking requisite knowledge and skills	65%
	Other project objectives given higher priority by project owner/client	60%
	Construction means and methods not known during design	54%
	Other project objectives given higher priority by designer	52%
Enablers	Designer has requisite knowledge and skills	68%
	Adequate time available for designer to consider safety in design	61%
	Construction safety given as high a priority as other project objectives	57%
	Construction means and methods are known during design	55%
Motivations	Enhanced firm reputation	93%
	Improved construction worker safety	92%
	Improved facility occupant safety	85%
	Recognition from owner/client	84%
	Reduced project costs	53%
	Shorter project schedules	47%