Prevention through Design (PtD) Project 1: Benchmarking Management Practices related to PtD in the US and UK

Final Report – Activity 2: Assess the Effects of PtD Regulations on Construction Companies in the UK

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EXECUTIVE SUMMARY

Prevention through design (PtD) is an occupational safety and health (OSH) intervention in which OSH needs are addressed in the design of a product or process to prevent or minimize work-related hazards and risks. For the construction industry, PtD entails designing a facility such that it is safer to build, operate, and maintain. By addressing worker health and safety (H&S) during the design phase, hazards can be eliminated or reduced during construction, use, and maintenance of the facility. Traditional architecture and engineering design practice in the US utilizes PtD extensively with respect to the end-user of a facility, e.g., the building occupant, motorist, or facility operator. Potential benefits of PtD to construction worker H&S have been identified, and examples of successful PtD implementation for construction safety exist in practice. However, the current structure and culture within much of the US construction industry inhibit application of the PtD concept to construction site safety. Consequently, the impacts of designs on construction worker H&S are often left up to the constructor to address and mitigate after the design is complete. This model of OSH management ignores the tremendous benefits that PtD can provide to eliminating hazards from construction jobsites. Based in part on this current practice, the National Institute for Occupational Safety and Health (NIOSH) established a national initiative to explore how to further diffuse and implement PtD throughout the US.

The research study presented in this report looks outside the US to the UK to understand how the PtD concept can be further diffused throughout the construction industry. The Construction (Design and Management) Regulations in the UK, implemented in 1994, place responsibilities on design professionals and others involved in the design of projects to address construction worker safety in their scopes of work. The many years of experience with the CDM Regulations in the UK construction industry presents a valuable opportunity to learn how the UK has adapted to PtD regulations and implemented the PtD concept. The research study was designed to capture the salient perspectives and knowledge about PtD from practitioners in the UK construction sector for evaluation and possible dissemination to US companies.

The strategy chosen for conducting the research study was to utilize a combination of targeted, open-ended, focus group interviews along with a structured industry-wide survey. The targeted participants were representatives of six different professional “communities” within the UK construction industry: architects, design engineers, facility owners/developers, constructors (general contractors and trade contractors), manufacturers/suppliers, and health and safety
consultants. Research questions posed in the study explored: the effects of the CDM Regulations; common PtD practices; impacts of PtD on project performance criteria, project team member roles, and organizational and professional culture; innovation as a result of PtD; enablers and barriers to PtD; and notable lessons which the US can learn from the UK experience. Fourteen focus group sessions were conducted with a total of 110 participants, and 228 usable survey responses were received. Both efforts provided data from a diverse segment of the UK construction industry representing all of the major stakeholders in construction projects. During the course of the study, two additional research activities were undertaken: a site visit and interviews on the Sellafield, England nuclear facility construction projects, and interviews of design and construction personnel in Australia where similar PtD regulations exist.

The study findings reveal that PtD impacts the construction industry in numerous ways. According to those involved in PtD efforts, implementing PtD in practice either does not change or increases design cost and duration, and leads to improvements in constructability, workmanship/quality, and productivity, and less rework. Importantly, PtD results in fewer construction worker H&S hazards on jobsites as well. When implemented, the design impacts are typically expressed in increased modularization of the design, and in modified designs to accommodate and promote safer construction methods. PtD promotes and leads to prefabrication away from the jobsite to eliminate safety hazards on the jobsite. Such prefabrication also results in better quality and lower total project cost and duration. To implement PtD, firms have developed a variety of design process tools, primarily to aid in identifying hazards and assessing risks.

Perhaps the most significant impact of implementing PtD has been changes in the project team members. There is more and improved communication and collaboration, greater integration of the design and construction disciplines, increased involvement of constructors in the design stage (involving the “right people at the right time”), and better overall professional practice. Designers are more knowledgeable about construction site hazards, putting more thought into how their designs impact construction worker H&S, and more involved in safety discussions. These changes are the success of PtD, and what ultimately have led to safer construction sites and improved construction worker H&S.

The changes to the project team and industry culture with regards to construction safety and professional practice are important results, and one of the successes attributable in part to the CDM Regulations. There are many ways to address safety. The traditional model for construction worker H&S risk management in the US has been to rely solely on the constructor to implement primarily downstream, lower-level safety controls. Injury and fatality rates in the construction industry show that improvements in safety performance are still needed. The results of the present and previous PtD research reveal that PtD is one effective intervention that can be part of a new model to successfully address and improve construction worker H&S. Much like the current trend towards integrated project delivery (IPD) and building information modeling (BIM), it is a model which involves integration of design and construction, collaboration between all project team members, and all parties playing a role. It is also a
model in which a choice is made to design out the hazards before construction begins rather than protecting against them during construction.

For PtD in the US, an environment of acceptance is needed for it to diffuse throughout the industry. Those in architecture, engineering, and construction who are involved in its implementation must accept that current practice is insufficient and should be augmented with the inclusion of PtD. Causing this change, a change that requires internal reflection by the design community on its own practices, has so far been slow to occur and spurned by many. Continued reflection and consideration by the design community, and diligence by industry organizations in PtD promotion, are needed.

Stimulating this change in the diffusion and implementation of PtD requires attention to four key attributes: knowledge, desire (motivation), ability, and execution. Project team members, and especially designers, need to have knowledge of the PtD concept, the importance and application of the hierarchy of controls, and the expected outcomes of PtD implementation. After gaining a thorough understanding of PtD, a desire to implement PtD must exist. Motivation to implement PtD can be established through contract, financial gain (return on investment), recognition, regulation, a sense of duty, moral/ethical obligation, and a desire for innovation. Given the current structure and environment in the construction industry, and recommendation from those in the UK who participated in the study, regulation is not recommended at this time. The proper industry environment and establishment of best PtD practice must be attained prior to regulation. Project teams must also have the ability to implement PtD. Ability is provided through PtD resources and tools, competency in recognizing safety hazards and identifying safe designs, PtD input and practice at the right time in the project lifecycle, and foreseeability. Lastly, successful diffusion and implementation require that PtD be actually implemented. The execution of PtD is supported when safety is given priority as a project performance criterion, when standard practices have been developed, when authority and responsibility for PtD are formally assigned, and when project team members are able to innovate to develop safe designs. It is recommended that all or a subset of these components be selected and pursued in order to address and accentuate each key attribute.

For diffusing and enhancing implementation of PtD in the US, a combined approach strategically designed with measurable targets, public involvement, and educational programs is recommended. As a result, and with widespread and continued implementation, it is expected that the occupational safety and health performance of the US construction industry will improve. Importantly, PtD provides an opportunity to establish a new, more effective, comprehensive, and collaborative model for construction worker H&S management.
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DEDICATION

This report is dedicated to those construction workers who have been injured or died as a result of construction site accidents. We commit our efforts to prevent further injury and loss on current and future construction projects. To those who have lost their lives, you are still in our memories.
I. INTRODUCTION

Whether working on or just walking across a construction site, a construction worker is exposed to many safety and health hazards. A steel erector who erects structural steel at elevation, for example, is exposed to fall hazards. Additionally, as the worker connects the beams and columns, tight clearances and awkward positions needed to install bolts can lead to strains and sprains. If connections are welded, the presence of welding fumes poses a health hazard. The hazards to which the steel erector is exposed are not limited to just the steel elements that the erector is working on. While walking across exposed rebar and conduit in slabs and around floor openings to get to the work area, for example, the steel erector is exposed to trip and fall hazards. It is clear that construction sites can be hazardous work places for all workers.

The rate of injuries and fatalities in construction compared to other industries reflects the hazardous nature of construction work. The Bureau of Labor Statistics (BLS) reports that in 2011 (the most recent year in which data is available), there were 738 worker fatalities in construction (BLS 2013), the second highest number of fatalities in all work industries for the year. Given the level of employment in construction, this amounted to 9.1 fatalities per 100,000 workers (BLS 2013). This fatality rate puts construction fourth highest amongst all work industries for the year, behind agriculture, forestry, fishing and hunting (24.9), mining (15.9), and transportation and warehousing (15.3). Most other work industries experienced a much lower fatality rate in 2011. The fatality rate of all work industries combined in 2011 was 3.5 (BLS 2013). In terms of non-fatal injuries, construction consistently experiences one of the highest numbers of injuries per year for all work industries. On average, from 1951 to 2011, construction has employed about 6% of the US workforce but accounted for approximately 19% of the fatalities and 11% of the disabling injuries (NSC 1952-2013).

The construction industry takes many steps to address safety on its construction sites. Best practices for improving safety and health have been identified (e.g., CII 2003), and tools to assist constructors in eliminating jobsite hazards and ensuring safe work practices have been developed (Gambatese 2004). The Occupational Safety and Health Administration (OSHA) supports these efforts through its services and regulatory activities. OSHA’s workplace safety training, hazard alert resources, and employer programs, such as the Voluntary Protection Program (VPP) and green jobs hazard awareness initiative, provide easy access to safety and health information, target high risk activities, and keep safety and health practice in stride with the changing industry. The industry’s concern for and priority given to worker safety and health is commonly highlighted in construction company literature and on construction sites with the slogans “Safety First” and “Safety is #1”. As a result, many projects and companies are achieving multiple millions of worker-hours without experiencing a lost-time injury.

However, the safety performance across all sectors of the construction industry is not consistent. For example, the safety-conscious culture and efforts within the buildings sector have resulted in better performance, in terms of fatality rate, compared to the heavy and civil engineering sector (CPWR 2013). Using number of employees as the metric, the rate of non-fatal injuries for firms with less than 250 employees is approximately double that of firms with
greater than 250 employees (CPWR 2013). Further reducing the number of construction injuries and fatalities across the entire construction industry requires innovations in occupational safety and health. One means to improving construction safety and health is to look beyond just the constructor and the construction means and methods. Korman (ENR 2001) reported that one of the innovations to improve construction safety and health is to have architects and engineers become involved in worker safety considerations when preparing project designs. This practice is known as prevention through design (PtD), and also commonly referred to as “design for safety” (DfS) and “safety in design” (SiD). NIOSH defines prevention through design as:

“Addressing occupational safety and health needs in the design process to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of facilities, materials, and equipment” (NIOSH 2013).

PtD overlaps with the concept of inherently safer design (ISD), which emphasizes avoiding hazards rather than keeping them under control through passive means (Kletz 2003). PtD recognizes that, in some cases, safety and health hazards may be “designed into the project” as a result of the design features. That is, the features of the permanent facility may be designed such that they create a hazardous environment for workers who construct the design. The safety and health hazards to which workers are exposed on a building containing a masonry façade, for example, may be greater and more numerous than if the building was designed with a precast concrete panel exterior. Following safety-focused pre-planning and design review, altering the design may eliminate safety and health hazards from the jobsite. By addressing safety and health during the design phase, hazards can be eliminated or reduced during construction, thereby improving construction site safety and health performance. This is the prevention through design concept as applied to construction worker safety and health.

Architects and engineers regularly design the permanent features of the facility for the safety and health of the facility’s end-users, e.g., the building occupant, motorist, or facility operator. Implementation of the PtD concept in regards to construction worker safety and health, however, is currently limited (Tymvios et al. 2012). Traditional industry practice places the role and responsibility for worker safety and health implementation and oversight on the constructor’s shoulders. Standard industry contracts, project delivery methods, design professional education and training, and an attempt to limit liability exposure are some of the factors among others that shape current practice and lead to minimal implementation of PtD for construction in the industry. It is clear that the current structure and culture of much of the construction industry inhibit application of the PtD concept in regards to construction site safety. As a result, architects and engineers who design the permanent features of the facility commonly focus solely on the safety and health of the facility’s end-user. Consequently, the impacts of their designs on construction site safety and health are often left up to the constructor to address and mitigate after the design is complete.

While potential benefits of PtD to construction worker safety and health have been identified, and examples of successful and continued PtD implementation exist in practice, further
diffusion of PtD throughout the construction industry is needed. There are barriers to PtD implementation in construction, yet none are insurmountable (Gambatese et al. 2005; Toole 2005). There are also enablers that facilitate its implementation, and benefits that motivate project team members to apply it in practice (Gambatese et al. 2005; Toole et al. 2012).

The research presented in this report is intended to further understand and address these current conditions. The research was undertaken to understand how the PtD concept can be further diffused throughout the construction industry and expanded in practice to benefit construction worker health and safety. The research is part of an initiative by the National Institute for Occupational Safety and Health (NIOSH) to move the PtD concept forward within the US. The goal of the initiative is to promote the PtD concept and highlight its importance in all business decisions (NIOSH 2013). As part of this initiative, NIOSH began an expansive research study on the topic within the National Occupational Research Agenda (NORA) on occupational safety and health. The NORA PtD research study contains multiple parts, of which the present research is one part.

The present research study looks outside the US to understand the PtD concept in practice. Formal application of the PtD concept, while not extensive here in the US, is common practice in some other countries and regions around the world (Aires et al. 2010, Toole et al. 2012). The European Union (EU) is one example. The EU’s Temporary or Mobile Construction Sites Directive (Directive 92/57/EEC) requires all parties involved in EU projects, including designers, to address occupational safety and health hazards and risks on construction sites. As a result, EU member countries have enacted legislation in response to the directive (Aires et al. 2010). In Great Britain, the Construction (Design and Management) Regulations were put in place in 1994 (CDM 1994). The Regulations place responsibilities for construction worker safety on design professionals and others involved in the projects. The CDM Regulations place a duty on designers to ensure that foreseeable hazards and risks to construction workers are avoided (MacKenzie et al. 2000). A detailed description of the CDM Regulations is provided in the Section II of this report.

The many years of PtD experience among UK architects and engineers (A/E), owners, constructors, and health and safety professionals presents a valuable opportunity to learn how the UK has adapted to PtD regulations and implemented the PtD concept. This information is useful to the US construction industry, particularly in support of the NIOSH PtD national initiative. The present research activity captures the salient perspectives and knowledge from UK companies in the construction sector for evaluation and dissemination to US companies. This report describes the research methods utilized to study PtD in the UK, the research data gathered, analysis of the data, and conclusions and recommendations from the study. In addition, this report provides recommendations for the US construction industry in regards to integrating the PtD concept into design practice.
II. BACKGROUND AND PREVIOUS STUDIES

Hazard Mitigation

The “hierarchy of controls” or “order of precedence” is well-known by safety and health professionals as a guide to follow to provide a safe and healthy work environment. Manuele (1997) presents this order of precedence as follows, with the items listed from 1 to 5 in order of decreasing priority, reliability, and effectiveness:

1. Design to eliminate or avoid hazard,
2. Design to reduce the hazard,
3. Incorporate safety devices after the fact,
4. Provide warning devices, and
5. Institute training and operating procedures.

This principle has been similarly stated in terms of a safety hierarchy as follows (Andres, 2002):

1. Eliminate the hazard,
2. Provide engineering controls,
3. Warn,
4. Train, and
5. Provide personal protective equipment.

The above lists indicate that it is best to eliminate the hazard if possible, as doing so will remove the risk associated with the hazard. In addition, the reliability of the control in regards to assurance that workers will not get injured increases with the higher level of action taken. If it is not possible to eliminate the hazard, mitigation measures that are lower in the list may be employed with a corresponding assumption of risk due to their lower reliability and effectiveness. Taking no action will expose those who interact with the design to uncontrolled risk.

Like many work industries, construction industry attitudes and actions incorporate an adherence to the hierarchy of controls. For example, as part of their contractual obligations and professional duty, architects and engineers regularly develop designs that meet the requirements set forth in published design codes and standards of practice. The codes and standards primarily incorporate the highest priority levels in the hierarchy of controls (design to eliminate or reduce the hazard) for risk mitigation. The codes and standards allow for risk mitigation measures that are lower in the hierarchy in some cases. It is important to note that these codes and standards are developed primarily to ensure that the facility created is safe to inhabit, use, and interact with after it is complete. That is, the codes and standards are a formal mechanism to provide for the safety and health of the end-user, i.e., the office worker, motorist, facility operator, and neighboring public.
Similarly, for those who construct the facility, safety and health standards are also available and adhered to. The OSHA Safety and Health Standards for Construction (29 CFR 1926) describe safe and healthy work environments and practices for construction workers. The OSHA standards present the actions that construction employers must take in regards to the safety and health of their employees. The standards predominantly address work practices during construction, and also the design and implementation of temporary measures used in the construction process (e.g., temporary ladders, access points, personal protective equipment, etc.). All levels within the hierarchy of controls are incorporated into the OSHA standards. However, similar to design codes and standards, the OSHA standards are limited in their scope. The extent to which the OSHA standards address the design of the permanent facility which the constructors are building is limited in some aspects and non-existent in many other areas (Toole and Gambatese 2002; Gambatese et al. 2003).

The gaps and inconsistencies identified in the previous two paragraphs are important to understand as they directly relate to the primary issue addressed in this research. When designing a building, bridge, roadway, or other part of the country’s built infrastructure, the hazards associated with the facility are mitigated in one or more ways identified in the hierarchy of controls. Two questions relating to the design are: (1) what level in the hierarchy of controls is used to mitigate the risk; and (2) whose safety is being addressed. Architects and engineers (A/E)s designing the permanent facility commonly utilize the two highest levels of the hierarchy (design to eliminate or reduce the hazard) when addressing the safety and health of the end-user after the facility is constructed. When considering the safety and health of the construction workers, however, it is common practice for architects and engineers to not utilize the two highest levels of the hierarchy in the design of the permanent structure. Instead, A/E/s commonly pass risk mitigation on to the constructor who must use the lowest three levels of the hierarchy. This practice in regards to construction site safety is not consistent with the occupational safety and health principles associated with the hierarchy of controls. Reasons for this practice in the construction industry have been identified and are presented and discussed below.

**Barriers to PtD in Construction**

While the PtD concept is well-known and recognized as a best practice in the field of occupational safety and health, numerous systemic conditions and practices exist in the US construction industry which limit its formal and widespread implementation. Barriers to PtD in regards to construction worker safety that have been identified in previous research are related to: education and training, professional liability, regulatory requirements, industry culture and structure, resource/tool availability, designer capabilities, and financial constraints.

**Education and Training**

Current formal education and training received by design professionals typically does not include construction worker safety (Gambatese 2003). While architects and engineers learn how to design many different types of facilities, the design focus is typically on the performance
of the facility after construction is complete and on end-user and public safety. An already full curriculum, a lack of PtD knowledge amongst faculty teaching design courses, an absence of PtD from accreditation requirements, and a lack of appeal from industry advisory boards for including PtD in the curriculum, are some of the reasons why PtD is not explicitly included in academic design programs (Gambatese 2003). In addition, academic curricula for architects and engineers typically contain minimal content on construction means and methods and on constructability, two prerequisites for knowing how to design for safety. Future A/Es are predominantly not taught the construction process and how their designs impact the construction work. Therefore, A/Es entering the workforce have minimal understanding of not only the safety and health hazards that can exist on construction sites, but also how to design to enhance construction site safety and health.

When A/Es enter the workforce, they commonly work for architecture or engineering firms that specialize in design. When they go out on construction sites, their exposure to construction provides a valuable display of how their designs are received and impact the construction process. This exposure can be helpful for incorporating PtD in future designs. However, their assigned work duties regularly keep them in the design office with minimal exposure to construction sites. Additionally, on-the-job training received often centers around efficiency and skill in creating a design and developing design documents, not construction-related issues. As a result, similar to their education, training of A/Es commonly includes minimal focus on construction site safety and construction means and methods.

As a result of the education and training commonly received by A/Es, their ability to design for construction site safety is inhibited. The lack of education and training in the areas of safety, construction means and methods, and PtD, is viewed as a barrier to implementing PtD in practice (Gambatese 2008; Hecker et al. 2005; Gambatese et al. 2005; Hinze and Wiegand 1992; Toole 2005).

Efforts to overcome this barrier are being undertaken. As part of the NORA research project within its national initiative, NIOSH has developed education modules on several design topics (structural steel, reinforced concrete, mechanical/electrical systems, and architectural features). NIOSH is also working with authors to insert PtD content (case study examples and problems) in textbooks used in university design courses. In response to NIOSH’s efforts, safety in design academic programs have recently been created at some universities (for example, see University of Alabama at Birmingham, http://www.uab.edu/engineering/professional-programs/asem/details). Professional development courses and resources on PtD for A/Es currently working in the industry have also been developed. Two examples are the Overview of Construction Prevention through Design course available through East Carolina University (http://cpeprograms.ecu.edu/CourseStatus.awp?&course=ARCH001), and the 2-4 hour training presentations available on the Prevention through Design website (http://www.designforconstructionsafety.org/).
Professional Liability

In an effort to limit their exposure to third-party lawsuits, many design professionals indicate that legal counsel specifically advises them to not become involved in construction worker safety (Hinze and Wiegand 1992; Gambatese et al. 2005). By doing so, designers attempt to distance themselves from possible third-party liability associated with an injury to a construction worker. The focus of this counsel is typically aimed at actions and engagement during the construction phase. That is, during construction designers are advised not to supervise the construction work or recommend to the constructor how the work should be conducted safely.

However, the recommendation from legal counsel is commonly expanded by designers to include the designer’s actions during the design phase as well. Designers hesitate to take any action regarding construction safety as part of their contracted design scope of work before construction commences. Korman (2001) reported that the current legal and insurance system has caused designers to be uninterested to the point of being afraid of getting involved in safety to any extent. According to Coble (1997), due to the liability issue, only a small number of designers are taking the lead regarding PtD. The liability issue has been viewed as the greatest barrier to implementation of the PtD concept in the US. Many papers on the topic have identified fear of increased liability as a barrier to implementing PtD in practice (e.g., Gambatese 2008; Hecker et al. 2005; Gambatese et al. 2005; Hinze and Wiegand 1992; Toole 2005).

In an effort to determine whether the fear of liability was substantiated, Behm (2004a) reviewed case law associated with designers. Behm found that there is not a clear legal precedent regarding A/E’s use, misuse, or lack of use of the PtD concept. Two legal terms that frequently came up in the case review were negligence and foreseeableability. Negligence is the failure to exercise a reasonable amount of care in a situation that causes harm to someone or something. Foreseeability is the degree to which the consequences of an action could have been identified beforehand. For example, in Mallow v. Tucker (245 Cal. App. 2d 700), a construction worker died when he was electrocuted while jackhammering footings at the exact location called for in the design documents. The jackhammer penetrated an underground high-voltage transmission line. The plaintiff alleged negligence on the part of the designer in failing to warn of the existence and location of the high-voltage line, specifically by not showing it on the plans prepared for construction. This negligence was claimed to be the proximate cause of the accident. The court found in favor of the injured worker. Upon appeal, the appeals court also found the designer negligent, calling this case a paradigm case of a designer’s negligence.

In another case (Frampton v. Dauphin, 436 Pa.Super. 486), the court sought to answer the question, “Does an architect who has been hired to prepare construction drawings have a duty to warn construction workers of the presence of an existing overhead power line?” Similar to Mallow v. Tucker, as a general rule, an architect may be held liable only if he/she failed to exercise the ordinary skill of his/her profession and this failure results in the erection of an unsafe structure that causes injury to an individual who is lawfully on the premises.
Pennsylvania courts have consistently refused to impose a duty on an architect to protect workers from hazards on a construction site in the absence of an undertaking by the architect, either by contract or course of conduct, to supervise and/or control the construction, and to maintain safe conditions on the construction site. However, the court differentiated the present case from *Mallow v. Tucker* by stating that the power lines were observable to the construction workers while in *Mallow*, the utility line was underground and therefore not observable. The court found the architect had no greater knowledge of the hazard caused by the overhead electric power line than the contractor, the subcontractor, or any of the workers. Because there was no greater knowledge of the hazard, the architect was not found to be negligent. Interestingly, though, one of the justices in the case filed a dissenting statement regarding an architect’s duty to warn construction workers of known hazards. Justice McEwen stated, “Rather, it strikes me that the architect, in this era of an enlightened concern for the safety of the worker, has a duty to the workers who will perform the construction delineated on the plans to highlight upon those plans the life-threatening aspects of their working environment.”

*Regulatory Requirements*

OSHA places the responsibility for compliance with safety standards on the employer. In a typical contracting arrangement for a construction project, the A/E firm is not the employer of the construction workers, except on design-build projects. Therefore, A/E’s are commonly not concerned with adherence to the OSHA safety standards in regards to the safety of the construction workers. This separation is identified as another inhibitor to designers’ interest and involvement in the PtD concept (Hecker et al. 2004a; Hecker et al. 2005; Gambatese et al. 2005). Unlike in the UK, Australia, Singapore, and other countries, in the US there are no other regulatory requirements currently in place that obligate a design professional to address the safety and health of construction workers who are not their employees. While the lack of specific PtD regulations is seen as a barrier (Gambatese et al. 2005; Hecker et al. 2005; Behm 2005a), it is not necessarily desired (PtD 2013; Toole 2005).

The likelihood of new or revised OSHA regulations that would broadly specify the inclusion of architects and design engineers is remote. Cavanaugh (2004) reported that this type of regulation is not on OSHA’s forefront. Hecker et al. (2004b) summarized symposium deliberation and concluded that such mandates in the US were not likely in the future. However, OSHA has recognized the impact of the design professional on construction safety through recent regulatory changes. In the safety standards for structural steel, Subpart R of 29 CFR 1926, OSHA recognizes the project structural engineer of record. This title is defined as the registered, licensed professional responsible for the design of structural steel framing and whose seal appears on the structural contract document. Specifically, OSHA now mandates a design criterion that requires all columns be anchored by a minimum of four anchor rods/bolts. In the public comment period, several commenters objected on the grounds that this section imposes design requirements for the structure. In their view, it is inappropriate for OSHA to set such requirements. Additionally, commenters indicated that engineers and designers specify by contract that the means and methods of construction are the contractor’s responsibility. Another commenter questioned whether engineers and designers will follow the regulations in
the design of the structure since the engineers and designers are not identified as being required to follow Subpart R since they are not the employer of the construction workers. Furthermore, it was added that engineers and designers design structures for compliance only with building codes and other related industry standards in mind to assure public safety after completion of the structure. OSHA, however, strongly believes that it is as appropriate for the Agency to require that avoidable safety hazards be engineered out for the protection of those erecting the building as it is for local jurisdictions to set design criteria for the safety of the building's occupants (Federal Register, 2001). This is a noteworthy step for OSHA in recognizing the significant impact a design professional can have on construction site safety.

**Industry Culture and Structure**

Historically, a construction project revolved around a “master builder” who provided the expertise and knowledge necessary to design and construct the project (Robson and Bashford 1997). The master builder acted as the architect, engineer, general contractor, and construction manager as defined today. Laborers representing various trades performed the construction work under the master builder’s direct supervision and employment. This project structure is similar to the design-build (“turnkey”) project development approach used today. With this all-encompassing role, the master builder sat at the focal point of a project and ultimately shouldered the responsibility for all aspects of a project’s success or failure (Gambatese 1998).

Today, the construction industry is fragmented. The evolution of the construction industry has resulted in the disintegration of the master builder system. The expertise and knowledge that was once solely provided by the master builder is now essentially divided between two distinct divisions within the industry: design and construction. Formalization of the divisions transpired with the establishment of The Royal Institute of British Architects in 1834 followed by the creation of other similar organizations in Europe and America in the mid-1800’s (Mitchell 1977). The boundary between the divisions in the US solidified with the passage of an amendment to The American Institute of Architects (AIA) by-laws in 1900 that required new candidates to have graduated from an approved school or to have passed an Institute examination (Kostof 1977). Shortly thereafter, professional licensing and registration laws enacted by most states ultimately secured the boundary between design and construction, and effectively replaced the master builder with a design professional and a constructor.

Partitioning the fields of design and construction requires refining and ultimately defining the work of each design discipline and constructor (Gambatese 1998). By combining their knowledge, design consultants conceptualize, engineer, and record a complete design that is then given to a constructor to build. On the construction side, the work is organized by trade with labor unions and contractor licensing laws playing major roles in defining the skills each trade incorporates. By defining a realm of expertise and knowledge, design disciplines and construction trades place borders around their work. The borders both limit the work that the designers and subcontractors are expected to perform, and surround the work to which they are entitled. The borders are fortified contractually and positioned by standards of practice (Gambatese 1998).
Through industry segmentation, the responsibility for a project is now contractually spread across many entities. Distribution of the responsibility for project success or failure reflects the work input. For example, a mechanical engineer is responsible for the design of the mechanical system, while the mechanical subcontractor is accountable for the construction of the mechanical system. Consequently, the boundary between design and construction, and the borders around design disciplines and construction trades, not only outline scopes of work, but also delineate responsibility. Each design discipline and construction trade shoulders the responsibility of carrying out the work contained in its realm of knowledge within the established borders. Acceptance and dismissal of the responsibility for all or a portion of the work is outlined contractually prior to performing the work (Gambatese 1998). The fragmentation that has occurred in the construction industry impacts PtD and is identified as a barrier to PtD implementation (Gambatese 2008; Hecker et al. 2005).

In regards to construction site safety, standard design and construction contracts reflect the industry fragmentation. Contracts for design services, for example, typically indicate that the designer shall not have responsibility for safety on the construction site and construction means and methods. Under this contract language, the designer designs the project for the client and is held accountable for the project’s level of safety for the occupants of the finished product, not for the safety of the temporary occupants (construction workers). Unless explicitly written in the contract, a designer participating in a design-bid-build project delivery arrangement is not responsible for overseeing construction worker safety (Gambatese 1998). On the other hand, standard contracts for construction stipulate that the constructor is solely responsible for safety on the construction site along with construction means and methods. The nature in which safety responsibility is apportioned in the standard design and construction contracts is recognized as an inhibitor to widespread PtD implementation (Toole 2005; Gambatese 2008; Hecker et al. 2005).

In the traditional design-bid-build project delivery method, constructors ideally begin their work with regards to site safety in the bidding phase as the design is reviewed and means and methods that include safety are considered and incorporated into the bid. Many times, however, safety is not considered until construction begins. Due to the changing nature of the site and the numerous construction trades intermittently on site, safety measures evolve periodically during a project. Additionally, the PtD concept requires that knowledge of the construction means and methods to be used on a project, and of the construction site hazards, be available during the design phase of a project. Lacking such knowledge, designers would not know how to modify their designs to improve construction safety.

The traditional design-bid-build project delivery method exacerbates the problem of getting construction knowledge to the designers (Hecker et al. 2005). Everett and Slocum (1994) illustrate the problem in their comparison of the construction industry to manufacturing (see Figure 1). In manufacturing, the design of the product is conducted in parallel with the design of how the product will be manufactured (process design). However, in construction, the traditional process is to design the product and the process sequentially. As a result of the
sequential progression, the ability to modify the design to optimize the selected construction process is effectively lost. Constructors are left with only the ability to implement the lower three risk mitigation levels in the hierarchy of controls (warnings, training, personal protective equipment).

![Figure 1. Integration of Product and Process Designs: Comparison of Manufacturing and Construction (Everett and Slocum 1994)](image)

Figure 1. Integration of Product and Process Designs: Comparison of Manufacturing and Construction (Everett and Slocum 1994)

When construction trades implement the concept of design for safety, they utilize it during the construction phase. For example, subcontractors may submit change order requests that would enhance safety, and construct temporary anchorage points, trench and shore, and craft other engineering controls to reduce hazards during construction. However, implementing these design-for-safety initiatives during the construction phase is actually “re-design” in terms of the lifecycle of the project. In other words, many proponents of PtD feel that the design has failed if safety measures must be implemented after the design is complete; a successful design does not need to be re-designed or require extra safety measures to construct, maintain, or operate.
This perspective is important in understanding what PtD is and in realizing the benefits it can have when initiated at the earliest stages of a project’s lifecycle.

Two other aspects of construction industry culture are directly related to the practice of adding safety measures after the design is complete and have been identified as inhibitors to PtD. The first is related to the many competing priorities placed on a project (Gambatese 2008). Cost, schedule, quality, safety, and public recognition are examples of common project priorities that owners/clients place on their facilities. However, it is often difficult to meet the highest expectation for every priority. For example, higher quality often comes with greater cost. If a project goal is to reduce initial cost as much as possible, the level of quality may need to be lowered as well. When comparing different design alternatives, all of the priorities are considered concurrently. It is often the case in the construction industry that initial cost and schedule duration carry the greatest weight when compared to other project priorities. Costs and time impacts over the lifecycle of the facility are often ignored and/or difficult to quantify. Therefore, when a safe design is suggested which adds initial cost or time compared to safety measures that are lower in the hierarchy of controls, the lower level measures are selected in order to meet initial cost and schedule goals. Competing priorities can push selected hazard mitigation measures down the hierarchy of controls. This part of the construction industry culture inhibits the PtD concept.

The second aspect of construction culture that can facilitate not taking the time to design out safety and health hazards is related to the constructor’s own enthusiasm and desire to acquire and complete the construction work. The construction side of the construction industry is often identified with a “get it done” or “macho” behavior. With this type of conduct, constructors attempt to construct a project regardless of the inherent safety and health risks. The attitude leads to a high tolerance for safety risk. As a result, the constructor ignores or discredits the idea of the need to design out the hazard and voluntarily assumes the construction risks. This attitude, coupled with the potentially additional cost of designing out the hazard and the readily available risk mitigation measures lower on the hierarchy of controls, slows the acceptance and implementation of the PtD concept. While there is evidence of this inhibitor based on the researcher’s own industry experience and discussions with other industry professionals across the country about PtD, confirmation of this characteristic as a barrier to PtD was not found in the literature.

Resource/Tool Availability

As mentioned above, Behm (2004a) indicates foreseeability as the degree to which the consequences of an action could have been identified beforehand. In order to design out a hazard, A/Es must be able to foresee the hazard before the construction work begins. A/Es must also be able to connect the hazard to a specific design element, and then know how to modify the design element to eliminate the hazard. The ability to take these actions can be impeded in large part due to a lack of readily available tools to assist designers.
Buildings, bridges, roadways, and other types of facilities are complicated. The projects consist of many different parts and pieces, all of which are designed and integrated to work within a system. The plans, elevations, sections, and details developed as part of the design documents are extensive and highly detailed. In addition, the design documents show the facility in its final form; the configuration and shape of the facility at each intermediate step during construction is not shown. To identify the hazards related to construction, A/Es must visualize what the structure will look like at each intermediate step. Whether viewing the design documents in electronic format or on a hardcopy, it is often difficult to foresee what the hazards will be. After identifying hazards, to design out the hazard, A/Es need to connect each hazard to a specific design element. Lastly, implementing the PtD concept requires that the design be revised to eliminate the hazards. Tools and resources are still being developed that can assist A/Es with these steps. A lack of readily available and easy-to-use tools has been identified as an inhibitor to the PtD concept (Gambatese 2008; Hecker et al. 2005; Gambatese et al. 2005; Hinze and Wiegand 1992; Toole 2005).

*Designer Capabilities*

The limited education and training that A/Es receive related to construction site safety has been identified as a barrier to PtD as mentioned above. Part of this limitation is the difficulty that designers have in assessing safety and health risks during construction because of not only their traditional education and training, but also their position and role on the project team. Assessing the risk requires knowledge of the frequency and severity of the anticipated injury along with the worker exposure. This knowledge (frequency, severity, and expected exposure) resides primarily with the constructor. Without this knowledge, it is difficult for A/Es to accurately assess the associated risk. However, this situation may not be the case with all architects and engineers as some do have construction experience. No literature was found to confirm whether or not this issue is a formal barrier to PtD.

Additionally, when an assessment of the risk is made, alternatives to mitigating the risk are weighed. Determining what action to take will be impacted by a person’s risk tolerance. Those who have a high tolerance for risk may do nothing at all or implement a control that is lower on the hierarchy of controls. Those who have a low tolerance would most likely design to eliminate all hazards and/or provide multiple, redundant risk mitigation measures. A person’s risk tolerance or threshold is dependent in part on whether they personally are at risk. Typically A/Es do not participate in the construction efforts. As non-participants in the construction process, A/Es may have a different (higher) tolerance to safety risk than the constructors who experience the risk firsthand (assuming limited “get it done” or “macho” perspective of the constructors). As a result, A/Es may feel that there is less of a pressing need to incorporate safety measures into their designs. Confirmation that this issue is truly a barrier to PtD was not found in the literature.
Financial Constraints

Implementing a formal PtD program impacts both the direct and indirect costs of design. Direct costs (e.g., A/E salary, draftsperson salary) may increase as a result of additional time required to research the safety implications of their design decisions, modify the design, and alter the design documents accordingly. Indirect/overhead costs may increase in two ways. First, designers may need safety training to understand how to implement PtD. Time spent in this additional training is time that could otherwise be billable. Some firms may elect to hire a staff employee or design manager with safety expertise whose (non-billable) responsibilities would include reviewing or training for safety. This role would be similar to the CDM coordinator in the UK as described below. Another source of increased indirect costs might be insurance premiums. Insurance carriers providing designers with general liability and errors and omissions insurance may increase their premiums to cover anticipated costs associated with defending potential additional lawsuits.

Increased design time may lead designers performing PtD to increase their professional fees. Such increased fees make the firms uncompetitive with firms who continue to ignore safety aspects of their designs. As a result, those who incorporate PtD may be viewed as uncompetitive if there is no recognition of the benefits of implementing PtD. With limited design budgets and already compressed design schedules, the additional costs and time are viewed as barriers to designers implementing PtD without recognition and additional compensation from the owner/client (Toole 2005). Consideration of the commercial practicability of implementing identified safe designs may lead some project teams to forego designing for safety.

Motivations for PtD in Construction

In deciding to implement PtD on a project or throughout an industry, the barriers to PtD are weighed against the motivations and potential outcomes. Past research has identified motivators for implementing PtD in the construction industry. The most obvious are fewer construction site hazards associated with the design and improved construction site safety.

Studies of construction accidents and injuries suggest that a significant proportion of such events have their origins upstream from the building process itself and are connected to such processes as planning, scheduling, and design (Whittington et al. 1992; Suraji et al. 2001). Jeffrey and Douglas (1994), following a review of the UK construction industry safety performance, concluded that there is a definite link between design decisions and safe construction. Based on their study of the safety performance of the UK’s construction industry, the researchers determined that 35% of the site fatalities reviewed were caused by falls and could have been prevented through design decisions. Trethewy and Atkinson (2003) maintain that design professionals influence construction worker safety and health outcomes both directly and indirectly. Similarly, Hecker et al. (2001) found that decisions made during design, planning, scheduling, and material selection were likely contributors to working conditions that
pose risks of injuries during actual construction. Other researchers have attempted to quantify the connection between the design and construction worker injuries and fatalities:

- An initial attempt at determining the extent to which the design and the design process are linked to construction accidents was reported by the European Foundation for the Improvement of Living and Working Conditions (Lorent 1987). Lorent reviewed construction fatalities and concluded that approximately 60% of fatal accidents arise from decisions made upstream from the construction site. The researcher purports that these fatal accidents are due to shortcomings in design and organization of the work.
- Gibb et al. (2004; Haslam et al. 2003) analyzed accident data in the UK to determine the possible contribution of design in each incident. A total of 100 construction accidents were selected and reviewed by industry experts to determine what designers could have done to reduce risk. By studying the experts’ responses, the researchers found that in 47 of the 100 incidents (47%), changes in the permanent design would have reduced the likelihood of the accidents.
- Behm attempted to link the design for construction safety concept to construction injuries and fatalities through a review of OSHA and NIOSH reports. The design was linked to the fatal injury incident in 92 (42%) of the 224 NIOSH FACE reports from 1990-2003 reviewed (Behm 2005a). An effort to validate Behm’s findings using an expert panel confirmed the results that there is a link between the design and jobsite safety (Gambatese et al. 2008). Additionally, Behm reviewed 226 OSHA injury reports in California, Oregon, and Washington from 2000-2002. In 49 (22%) of the reports a connection to the PtD concept could be made (Behm 2004b).
- In a survey of general contractors in South Africa, approximately 50% of the 71 contractors interviewed identified the design as an aspect or factor that negatively affects health and safety on the construction site (Smallwood 1996). In comparisons with other project components, the design was ranked the highest with regard to impact on safety. To improve safety through design, almost 90% of the contractors suggested that architects and engineers should be exposed to construction site safety as part of their education in a university or technical college.
- Churcher and Alwani-Starr (1996) report that 63% of all fatalities and injuries investigated in the UK could be attributed to design decisions or lack of planning.
- Driscoll et al. (2004) investigated the role of design issues in work-related injuries in Australia between 2000 and 2002, and found that in 27 of the 43 construction cases reviewed (63%), there was either a definite or possible connection to the design.

The ideal situation is for construction worker safety to be a prime consideration of planners and designers during the conceptual and preliminary design phases. Szymborski’s time-safety influence curve illustrates how safety can be influenced to the greatest extent in the early phases of a project (Figure 2). The planning and design phases provide an opportunity to eliminate hazards before they appear on the jobsite, and the ability to eliminate hazards diminishes as the project progresses. A considerable portion of the ability to positively and
effectively influence construction site safety is lost when safety is not considered until the construction phase.

![Diagram](https://example.com/diagram.png)

**Figure 2. Time-Safety Influence Curve (Szymberski 1997)**

The expected attitudes and actions of designers in the course of their work are contained within their professional codes of ethics. The codes of ethics of national engineering associations include content that is relevant to the PtD concept. For example, the National Society of Professional Engineers (NSPE) states in its code of ethics that, “Engineers shall hold paramount the safety, health, and welfare of the public.”

NSPE has examined the implementation of PtD in regards to its code of ethics. A National Society of Professional Engineers (NSPE) Ethical Review Board case, NSPE 84-5, considered the ethical nature regarding safety hazards identified in the design phase. The case centered on a design engineer who warned their client about the dangerous nature of implementing the design during the construction phase. The engineer recommended that the client hire a full time on-site representative during the construction phase. NSPE’s Ethical Review Board quoted Section III, Professional Obligations, within their Code of Ethics. Section III.1.b states, “Engineers shall advise their client or employer when they believe a project will not be successful”. The Review Board defined the word ‘successful’ to include project safety. This decision connected the recognition and communication of construction hazards in the design phase to an engineers’ professional obligation under the Code of Ethics. It also determined that construction workers and their safety should be included under the umbrella of the term
“public.” However, the Board did not discuss the engineer’s obligation to go back and reevaluate their design to determine if these dangerous conditions could be minimized with a design modification or by better communication of the design as it relates to construction. The Board fell short in connecting the design for construction safety concept to an engineer’s professional obligations. This case was reviewed over 20 years ago. Since that time, the design for construction safety concept has evolved and much research on the concept and its implementation has been completed. Perhaps the Ethical Review Board would evaluate this case differently today in light of this new knowledge.

The American Society of Civil Engineers’ (ASCE) Code of Ethics has a statement that is similar to that established by NSPE:

“Engineers shall recognize that the lives, safety, health and welfare of the general public are dependent upon engineering judgments, decisions and practices incorporated into structures, machines, products, processes and devices.”

If construction workers are considered part of “the public,” the Civil Engineers’ code of ethics mandates designing for safety. However, as practiced, engineers traditionally do not include construction workers in their definition of “the public.” In addition to their Code of Ethics, ASCE also maintains Policy Statement 350 which explicitly addresses site safety (ASCE 2012). Two excerpts from this policy are directly relevant to the PtD concept:

“The American Society of Civil Engineers (ASCE) believes improving construction site safety requires attention and commitment from all parties involved. Effective improvements in construction site safety can be achieved through a committed, cooperative relationship between owners, contractors, subcontractors, construction managers, safety professionals, construction workers, labor unions, designers, regulatory agencies, associations, institutes, academia, and legal and insurance professionals.”

“Engineers have responsibility for: Recognizing that safety and constructability are important considerations when preparing construction plans and specifications....”

The American Institute of Architects (AIA) Canon Number 2 describes an architect’s broad principle of conduct in regards to their obligation to the public. Rule 2.105 requires that architects take action when their employer or their client makes decisions that will adversely affect the safety to the public of the finished product. However, the Commentary to Rule 2.105 deflects any motivation an architect would have towards accepting PtD as a standard practice by stating:

“This rule extends only to violations of the building laws that threaten the public safety. The obligation under this rule applies only to the safety of the finished project, an obligation coextensive with the usual undertaking of an architect.”
This language limits the architect’s focus to the final occupant and public users of the finished product. Recently, however, many architects and engineers have increased their responsibilities to other parts of the project lifecycle, including the construction phase. One example is in the area of sustainability. In order to meet green building design requirements, architects are concerned with how the finished product is designed, built, and maintained. As architects expand their role to include aspects beyond the exclusive scope of the finished product, the inclusion of designing for construction in their practice appears to not conflict with their ethical code of conduct.

The drive to create sustainable buildings is another motivator for PtD. In addition to community, diversity, human rights, governance, quality of life, and equity, the social component of sustainability includes safety and health (SCSH 2012), of which construction worker safety and health is a focus. Like the protection and conservation of environmental resources, sustainability includes the stewardship of human resources. As the concept of sustainability continues to expand and develop within the construction industry, motivation to incorporate construction safety and health will grow. It should be noted that the importance of sustainability is recognized by ASCE in its Code of Ethics. The first fundamental canon of the ASCE Code of Ethics, which incorporates both safety and sustainability, is as follows:

“Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.”

PtD is but one mechanism for injury prevention. Other safety and health program elements are commonly implemented during construction, such as drug and alcohol testing, flex and stretch programs, pre-task planning, and safety orientations. Each of these elements adds a layer of protection against hazards, as illustrated by Reason’s “Swiss cheese” model of accident trajectory (Figure 3). Reason describes each safeguard as a filter with holes. The filters are safety and health program elements put in place at different points during project development to prevent hazards from becoming losses. The holes are present because it is recognized that program elements cannot eliminate all of the risk. If the holes “line up”, a hazard can lead to a worker injury or fatality. One way to reduce the chance that a hazard does not result in an injury or fatality is to add a filter. In the present case, PtD is another filter added to the project to prevent losses.
Enablers of PtD in Construction

Research studies have been conducted to identify potential enablers of PtD implementation. Enablers are those tools, resources, processes, etc. which promote and assist in the implementation of PtD. Case studies of PtD implementation reveal factors that allow it to occur and facilitate its continued growth and effectiveness. The majority of current literature on PtD enablers is based on observational evaluations due to the difficulties associated with experimental research in construction and the limited number of studies on PtD to date.

Hinze (2000) identifies a holistic approach to design as an enabler of PtD. Focusing narrowly on just the performance of the facility during the operations and maintenance phase of its lifecycle disregards the impacts of the design during construction. When designers possess a mindset that design should consider more than just the end-user, opportunities and acceptance for PtD are revealed. A design for the entire lifecycle approach provides the foundational mindset for PtD to occur.

Providing the motivation to design for the entire lifecycle can come from the facility owner. An owner/client who is committed to safety and health throughout the project’s lifecycle will instigate the designers into action. Designers need clarity about what they are expected to achieve and guidance about how to reach those goals (Anderson, 2000). A lack of guidance and supporting resources has resulted in slow acceptance and fulfillment of designer responsibilities related to PtD (Baxendale and Jones, 2000). When owners provide the guidance and resources,
designers respond with an interest in PtD and actions on the project (Behm 2005a; Toole et al. 2012). Owners provide the motivation, which can be demonstrated through active involvement in PtD during design, the A/E selection process, contractual obligations to incorporate PtD, financial incentive, and providing sufficient resources. Leadership is required on the owner’s part to set a high expectation for worker safety and health, to ensure that safety takes priority over other project criteria and that when multiple options are available to mitigate a hazard, designing out the hazard is desired and chosen whenever practicable. It is essential as well that the owner communicates to A/E$s that the A/E$s can play a role in improving construction worker safety and that their role is important and needed (Toole et al. 2012).

The integration of construction knowledge within the design services and during the design phase has been identified as an enabler of PtD (Weinstein et al. 2005; Toole et al. 2012; Atkinson and Westall 2010). This integration can take place in different forms. One means is through designer education and training related to safety, construction means and methods, and PtD (Toole 2005). Another means is to incorporate other personnel during the design phase who have the requisite construction knowledge. Ash (2000) contends that success is often found when designers and constructors already work together more closely, such as in design-build and construction management firms. Integrated project delivery (IPD) methods provide a means to overlap design and construction, and are project delivery methods that are gaining interest. IPD supports identifying and implementing PtD opportunities (Toole et al. 2012). A key element is the relationship between the designer, contractor, and subcontractors. Working in an integrated fashion makes this relationship closer, more positive, and constructive. As a result, the relationship allows designers to design more proactively for safety (Atkinson and Westfall 2010).

Design-build, for example, is a project delivery method in which one entity develops a contract with the owner/client to provide both design and construction services. This method is seen as a good fit for the PtD concept because the design-build firm has financial incentive to design the facility to be as safe to erect as possible given that there will be fewer injuries to its own employees on site. Furthermore, design professionals and constructors are employed in the same firm, creating an environment where the communication between designer and builder is less confrontational compared to the traditional design-bid-build method of project delivery.

Another effective means for capturing construction knowledge during design is to have a construction manager, general contractor, and/or trade contractors participate in the design review process throughout the design phase (Toole et al. 2012). The constructor(s) can be hired under a separate contract during the design phase to provide the needed input. By doing so, owners establish interaction between A/E$s and constructors, which in turn provides the needed construction safety input. It is especially helpful if the project team members are co-located to facilitate their interaction. While this level of constructor involvement may not be available on publicly-funded projects, it has been found to be highly beneficial to the PtD process when implemented (Hecker et al. 2005; Weinstein et al. 2005). Coble and Haupt (2000) contend that optimizing the PtD concept must include the coordination of designers and construction forepersons, particularly those with excellent safety records. They conclude that construction
foremen can make significant contributions to the design for safety effort, provided that designers recognize and harness their skills, site experience, and knowledge base.

In addition to integrating design and construction, the presence of an explicit PtD process has been identified as facilitating its implementation (Toole et al. 2012). A formal process informs employees of the PtD concept, provides an objective and efficient process for its implementation, and provides a means for monitoring and enforcing its implementation. This process is enhanced by the use of supporting tools and resources that provide the ability to foresee the construction process and hazards, identify design-for-safety opportunities, and compare alternatives based on safety and health risk. Examples of enabling technologies are 4-D CAD systems, building information modeling (BIM), and virtual reality. Hazard identification checklists and design-for-safety databases support PtD implementation as well. The goal is to provide sufficient resources (tools, time, funding, knowledge, etc.) during the design phase to support the needs of addressing safety and health in the design.

Starting early is also a key part of the PtD process. Christensen (2011) recommends that the PtD process should be started almost as soon as the project is conceptualized. Commencing the PtD process at this time includes selecting a project team that is knowledgeable about safety, deciding on the design objectives, and agreeing that as hazards are identified, the associated risk will be assessed and mitigation techniques determined to reach an acceptable level of risk (Christensen 2011). It is important to include safety expertise within the project team from the start. Engaging safety personnel once the design is complete or is nearing completion is too late. This generally results in retrofitting for safety (Christensen 2011). That is, the initial design is insufficient and needs to be revised/retrofitted in order to provide for the safety and health of the construction workers. Putting a work process into place, then changing it to reduce risk, places workers at risk. Such strategies increase risk of injury and liability, plus introduce considerable waste into the design process (Main 2008).

The fear of undeserved liability for construction worker injuries is recognized as a barrier to PtD as mentioned above. Protection against any additional liability can be provided through liability insurance policies. The availability of insurance policies that provide design firms protection against third-party lawsuits if they participate in PtD will give AEs comfort in implementing PtD (Toole 2005). Such insurance policies would need to be developed and be financially acceptable. The cost of such additional policies would be borne by the design firms, and passed on to the owner through the professional design fees.

**Examples of PtD in Construction**

While barriers to PtD in construction are present, it is being implemented in some instances throughout the industry. Examples of PtD exist in a variety of forms in different sectors of the industry. Literature provides examples of PtD processes, design-for-safety suggestions, as well as tools and resources that have been developed to implement the PtD process.
PtD Processes

As described above, implementing a formal PtD process will facilitate its application on a project. Processes may be designed for application at the project level and/or at the organization level. Some may incorporate a variety of tools and resources, and also include designer education and training. While several methods exist to implement PtD on a project, the commonality between them is early intervention, a deliberate consideration of construction safety and health, and the utilization of construction knowledge in the conceptual and design phases. Tools are available to implement PtD; they just need to be used. The following are representative examples that come from previous case study research and reviews of published literature.

- Hecker et al. (2005) described the Life Cycle Safety (LCS) process developed by the Intel Corporation. In the LCS process, construction worker safety is considered along with safety in operability, maintainability, and re-tooling in the conceptual and design phases of a newly constructed manufacturing facility. Trade contractors familiar with similar facilities are hired during design to provide construction safety input during the conceptual and design phases of a project. Ad-hoc meetings with trade contractors are held to focus on specific options for evaluating implications for constructability, value engineering, and safety. A Safety in Design checklist, which evolved from previous projects, is used and provides a foundation for the LCS group. LCS reviews are conducted of every design package prepared by the design team. Figure 4 illustrates the design review process and targeted reviews for each design package along with the timing of the reviews for fast-track projects.
Several tools are used as part of a total evaluation plan to assist workgroups in systematically addressing each project goal and provide a graphical representation of their findings. Each tool was developed to address a specific part of the evaluation. The Change Evaluation Checklist and supporting Project Goal Evaluation Worksheet provide a comprehensive view of each work group’s assessment against each of the project goals. The Option Evaluation Sheet and Option Summary provide each workgroup with a way to quantify the pros and cons of each option against the project goals. This tool also allows multiple options to be compared against each other. The Risk Comparison and a Mitigation Plan was developed to assist in specifically evaluating hazards for options under consideration and proposing mitigation strategies for phases of the building lifecycle. These phases are Construction, Tool Install/Retrofit, and Facilities and Manufacturing Operations & Maintenance. A report on the evaluations is included in the weekly Project Team Review.

Research to study the LCS process revealed that it was successful in minimizing construction safety and health hazards when a dedicated evaluation of construction safety was considered early in the life of a project (Hecker et al. 2005).
• Bovis Lend Lease (BLL), an international design and construction company, has established and implemented a similar program that it calls ROAD – Risk and Opportunity at Design (Zou et al. 2008). Similar to Intel’s LCS process, ROAD aims to eliminate or minimize the risks of injury throughout the life of the product being designed by involving all decision makers that will be involved in the lifecycle of the product (ASCC 2006). ROAD incorporates the following key principal elements and considerations: person with control, product lifecycle, systematic risk management, safe design knowledge and capability, and information transfer. BLL implements the ROAD process through the following nine steps (BLL 2004, Zou et al. 2008):

  o Building element assessment at pre-construction phase
  o Trade package assessment at construction stage
  o Recording ROAD document and uploading into the project management plan
  o Including a ROAD agenda item on design program meetings
  o Establish action and status lists
  o Update and report status at each design review
  o Actions from ROAD issues considered prior to approval for construction
  o Environment, health, safety, and quality monthly management meetings review the reporting of projects including the ROAD status
  o Monthly update of the ROAD document as part of the project review

In their research of the effectiveness and impacts of ROAD at BLL on case study projects, Zou et al. (2008) indicate that architects and clients can gain from many beneficial qualities that come with implementing ROAD in the earlier phases of the project lifecycle. These benefits include improved worker safety and health plus improvements in productivity, usability, cost savings, and the management and prediction of costs. The researchers also found that implementing the ROAD process made the assessment and minimization of safety risks at the design stage a key priority. In addition, BLL took advantage of additional factors resulting from ROAD such as greater teamwork, communal accountability and responsibility for safety, and stronger control and management of safety risks that could disrupt strict timetables and budgets.

• Foster and Partners, an international architecture and design firm based in London, has responded to the UK’s CDM regulations to incorporate safety and health in its programming and design activities (Istephan, 2004). The firm has developed a program that includes the following components:

  o Training to increase the competence of its employees
  o Design reviews
  o Integration of health and safety with existing quality assurance systems
  o Integration of safety into other systems, e.g. specifications
  o Production and transfer of information
  o Management of knowledge through feedback, adjustments, and lessons learned
A critical part of Foster and Partners’ program is the early start and planned timing of the design reviews (Istephan, 2004).

- The Haskell Company, a design–build firm in Florida, developed a PtD program that involves three major elements (Angelo 2004). The first element is the participation of designers in an intensive safety course based on the OSHA 10-hour course. Secondly, during design, safety-oriented design checklists are used on each project to alert designers of potential hazards and suggest design modifications. Lastly, when the design drawings are prepared, warning symbols are added to project plans to alert the constructor of potential hazards that could result in electrocution, asphyxiation, falls, etc.

- The Southern Company, a power provider within the southeastern part of the US, has developed a Design for Safety (DfS) program to alert design personnel of construction worker safety, operations safety, constructability, lessons-learned, and code requirements (Toole et al. 2012). The DfS program is a design engineering effort that supports Southern’s “Target Zero” company-wide safety program. Within the DfS program, a meeting is conducted between the key design personnel and construction personnel on the project no later than 25% completion of the design. Prior to the meeting the design leads review a design for safety checklist that Southern created which contains prompts to query the designers regarding aspects of their design. The designers also are instructed to search a DfS/lessons-learned database for applicable suggested designs. A meeting, titled the Hazard Identification and Constructability Considerations meeting, is then conducted during which the design plans and specifications are reviewed for safety and the applicable checklist and database items are discussed. Modifications to the design are made accordingly following the meeting. A web page describing the DfS program was set up on the firm’s intranet which describes the program and provides assistance to those involved. In addition, an internal DfS team was established to implement and monitor the DfS program, maintain and update the checklist and database, and provide assistance to project personnel.

- In Australia, WorkCover, the occupational safety and health regulatory authority of the State of New South Wales, has developed a safety in design tool titled “Construction Hazard Assessment Implication Review” (CHAIR). CHAIR’s goal is to identify risks in a design as soon as possible in the life of a project and considers construction, operations, and maintenance activities (WorkCover 2001). CHAIR provides a framework for a facilitated discussion that is stimulated by guidewords or prompts such as size, height, and energy. The CHAIR process specifies that all stakeholders review the design in a prescribed and facilitated method to ensure that the occupational safety and health issues of the stakeholders are considered in the design phase of the project. It includes a conceptual design review (CHAIR - 1) and detailed design reviews for construction (CHAIR - 2) and maintenance activities (CHAIR - 3). Figure 5 illustrates the nature and timing of the CHAIR reviews.
During the course of project planning and design, review efforts commonly take place at several milestones. For example, it is common to update the cost estimate and conduct constructability reviews at the 30%, 60%, and 90% completion of the design. Staying with this pattern, Toole and Gambatese (2011) have developed a suggested PtD process for project development and design (see Figure 6). The process incorporates key PtD activities in the conceptual phase of the design and at the 30%, 60%, and 90% points in design completion.

Figure 5. CHAIR process (WorkCover 2001, modified)
Figure 6. PtD in Project Conceptual and Detailed Design Phases

Design-for-Safety Examples

There are many examples of how a project might be designed to eliminate construction site hazards. PtD may be implemented in a variety of ways, including: (1) modifications to the permanent features of the construction project in such a way that the facility is inherently safer to construct; (2) giving attention during the preparation of plans and specifications for construction in such a way that construction site safety is considered; and (3) communicating to downstream stakeholders the risks inherent in the design and the work to be performed to mitigate those risks. Many PtD examples are linked with structural work and have the potential to minimize and eliminate fall hazards. Of the over 400 design suggestions developed by Gambatese et al. (1997), approximately one-third are associated with structural work (see Table 1).
Table 1. Design suggestions based on design discipline affected (Gambatese et al. 1997, modified)

<table>
<thead>
<tr>
<th>No.</th>
<th>Design Discipline</th>
<th>Number of times addressed</th>
<th>% of Recorded suggestions*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Structural</td>
<td>141</td>
<td>32.8</td>
</tr>
<tr>
<td>2</td>
<td>Architectural</td>
<td>127</td>
<td>29.5</td>
</tr>
<tr>
<td>3</td>
<td>Piping/plumbing</td>
<td>84</td>
<td>19.5</td>
</tr>
<tr>
<td>4</td>
<td>Electrical/instrumentation</td>
<td>69</td>
<td>16.0</td>
</tr>
<tr>
<td>5</td>
<td>Mechanical/HVAC</td>
<td>69</td>
<td>16.0</td>
</tr>
<tr>
<td>6</td>
<td>Construction management</td>
<td>62</td>
<td>14.4</td>
</tr>
<tr>
<td>7</td>
<td>Civil</td>
<td>48</td>
<td>11.2</td>
</tr>
<tr>
<td>8</td>
<td>Tanks/vessels</td>
<td>17</td>
<td>4.0</td>
</tr>
<tr>
<td>9</td>
<td>Traffic/transportation</td>
<td>16</td>
<td>3.7</td>
</tr>
<tr>
<td>10</td>
<td>Geotechnical</td>
<td>5</td>
<td>1.2</td>
</tr>
<tr>
<td>11</td>
<td>Coatings/insulation</td>
<td>3</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>641</td>
<td>--</td>
</tr>
</tbody>
</table>

* Since suggestions may address more than one design discipline, the sum of these numbers (expressed as a % of the 430 recorded suggestions) exceeds 100.

Toole et al. (2006) provide guidance for structural steel detailers to positively enhance construction site safety through design. The suggested designs include:

- Specify holes for tie lines 21” and 42” above each floor slab, safety seats for beam connections, markings for orientation, and secure connections and anchoring systems.
- Establish a clear and consistent beam marking system to help workers orient themselves to hazards in certain sections of the structure and increase erection speed.
- Where possible, specify shop welded connections instead of bolts or field welds to avoid dangerous or awkward positions for the welder or connector.
- For bolted beam connections, provide an extra “dummy” hole in which a spud wrench or other object can be inserted to provide continual support for the beam during installation of the bolts.
- Use a minimum of four (and in many cases much more than four) anchor rods to secure columns in order to prevent movement and eliminate the need for temporary bracing during placement.
- Locate plates and bolts to provide more accessible designs. In small (short-webbed) columns, flanges can inhibit access to connections for construction purposes.
- Avoid hanging connections—design to bear on columns instead.
- Familiarity with realistic dimensions can help the detailer specify connections with improved constructability to prevent pinches or awkward assemblies.
- Avoid connections or protrusions above floor framing members.
The use of prefabricated components reduces the number of activities that must be performed on the work site and above the ground, and therefore reduces the risk of fall-related injuries. For example, prefabricated steel stairs and panelized joist assemblies are common on building projects and prefabricated bridge segments are possible on infrastructure projects. Prefabrication can occur on the site by site workers or off-site by specialty vendors. Because prefabricated components are typically lifted into place by cranes, designers must consider horizontal and vertical space needs when making site layout decisions.

Facilitating safe crane operation should be part of the PtD process regardless of whether prefabricated elements are used. Cranes are used to erect structural steel, place large HVAC components, stage materials within the building, and perform many other tasks. While crane safety is the responsibility of the operator, design professionals can facilitate safe operations by considering whether the site design provides the necessary bearing capacities, sufficient proximity to the building to prevent excessively long load radii, and vertical space that is clear of power lines and other obstructions.

Another area where structural designers can influence the safety of the project is to consider the placement of openings in the roof or floor slabs. Openings for roof skylights may be located away from frequently accessed areas on the construction site to prevent falls or to prevent drop hazards from elevated work spaces. Specific additional suggestions for skylights include designing permanent guardrails to be installed around skylights or designing the skylight to be installed on a raised curb.

One common PtD example is to include a parapet on buildings that is 42” tall to meet OSHA guardrail standards. The International Building Code (IBC) may only require parapets to be at least 30” high, which is not sufficient for construction or maintenance worker fall protection. If only a 30” tall parapet is provided, a 12” high temporary guardrail is required during construction to meet OSHA guardrail requirements. Figure 7 shows a comparison between parapet heights during construction. Taller parapets serve to eliminate the need for additional guardrails during roofing and rooftop HVAC appliance installation and prevent the need for fall protection during future maintenance. A similar example is to design upper story window sills to be 42” above the floor level. Having the window sill at this height allows it to function as a guardrail during construction.
Another broad-level principle is maintaining a consistent floor layout throughout the building. Such a design not only promotes efficient production but also gives workers the opportunity to have thorough knowledge of the hazards present on each floor. It is acknowledged, however, that architectural concerns, room layout needs, and mechanical systems often limit the extent to which this principle can be applied.

Gambatese et al. (1997) demonstrated that the architectural discipline can positively affect construction worker safety. Behm (2005a) found that architects were likely to have a more significant impact on construction worker safety compared with other disciplines. Many complex architectural features are difficult to build; subsequently they become arduous to maintain in a safe manner. When safety is ignored during design, safely constructing and maintaining the facility can be costly. Consider, for example, the atria used to provide additional lighting in buildings. While such atria provide occupants with a pleasant, environmentally-friendly entrance to a building, constructing and maintaining atria have been the source of numerous preventable injuries and fatalities. If construction safety were considered in the design phase, built-in anchorage points or other forms of fall protection devices could be designed into the building to provide the construction and maintenance workers an opportunity to work safer.

Another building feature that can pose a construction hazard is roof openings. Employees can fall through roof openings if the openings are not adequately protected with standard guardrails or covers. To reduce the hazard, the number and size of floor openings could be minimized. If that is not feasible, then the design review process could specify that the hazard

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**Figure 7. Roof Parapet: (a) Lower than OSHA Guardrail Height; (b) Designed for Safety**

(Gambatese et al. 1997, modified)
be communicated to the constructors and standard guardrails or other form of protection be specified in the construction documents.

The most compelling PtD examples are those that are inherently safer without changing the design process or the quality of the end product. Gambatese et al. (1997) and Toole and Marshall (2006) identify several practical examples from site and geotechnical work. Changing technical specifications is one example, such as not requiring the bottoms of drilled shafts to be inspected manually. While close manual inspection can be performed safely, there are other less risky inspection methods that yield a satisfactory result, such as inspecting cuttings from drill tool flights, video inspection of the completed drilled shaft, and probing the shaft location with a small diameter drill bit prior to the shaft being excavated or after the shaft has been excavated to determine sound bearing material.

The following are additional examples of safe designs along with how they reduce the risk of injury (Gambatese et al. 1997):

- Design components to facilitate pre-fabrication in the shop or on the ground so that they may be erected in place as complete assemblies. Reduce worker exposure to falls from elevation and being struck by falling objects.
- Design beam-to-column double-connections to have continual support for the beams during the connection process by adding a beam seat, extra bolt hole, or other redundant connection point. Continual support for beams during erection will eliminate falls due to unexpected vibrations, mis-alignment, and unexpected construction loads.
- Minimize the number of offsets in a building plan, and make the offsets a consistent size and as large as possible. Prevent fall hazards by simplifying the work area for construction workers.
- Design underground utilities to be placed using trenchless technologies. Eliminate the safety hazards associated with trenching, especially around roads and pedestrian traffic surfaces.
- Design roadway edges and shoulders to support the weight of construction equipment. Prevent heavy construction equipment from crushing the edge of the roadway and overturning.
- Position mechanical, piping, and electrical controls away from passageways and work areas, but still within reach for easy operation. Controls which protrude into passageways and work areas, or are hard to operate, hidden, or inaccessible, create safety hazards for construction and maintenance workers.
- Allow adequate clearance between the structure and overhead power lines. Bury, disconnect, or re-route existing power lines around the project before construction begins. Overhead power lines which are in service during construction are hazardous when operating cranes and other tall equipment.
- Route piping lines which carry liquids below electrical cable trays. Prevent the chance of electrical shock due to leaking pipes.
• Do not allow schedules with sustained overtime. Workers will not be alert if overtime is maintained over a sustained period.

PtD Tools and Resources

In addition to the application of 4-D CAD, BIM, virtual reality, and other tools developed for all aspects of the construction industry, tools and resources are publicly available that have been specifically developed for PtD. Below is a brief description of a representative sample of the types of tools and resources that are available:

• The Prevention through Design (Design for Construction Safety) website, developed and maintained by Dr. Michael Toole at Bucknell University, provides a comprehensive look at PtD in research and practice, and provides educational and training resources for those in academia and industry (http://www.designforconstructionsafety.org/).

• The Design Best Practice website (http://www.dbp.org.uk/welcome.htm) provides a long list of example cases of specific design features that are particularly beneficial to construction safety. The site is especially relevant as the examples are provided by construction industry professionals who have firsthand knowledge and exposure to the design elements.

• As mentioned above, the Southern Company, with the assistance of several other national engineering and construction firms, has developed a simple checklist of good design practices that benefit construction safety. Design-for-safety checklists are practical and easy-to-use tools that prompt designers to consider different elements of their designs and suggest alternative “safe” designs.

• The Construction Industry Institute (CII) has developed an electronic database of design-for-safety suggestions titled “Design for Construction Safety Toolbox” (https://www.construction-institute.org/scriptcontent/index.cfm). The software contains over 400 design suggestions that will help to eliminate hazards and reduce risk when implemented. In addition, as part of the effort to educate designers, the software alerts designers to the safety and health hazards related to their designs (Gambatese et al. 1997).

• In their study of the LCS process implemented by Intel, Hecker et al. (2005) describe several forms that were developed as part of the LCS process to review and evaluate design options. The Option Evaluation Sheet was developed to allow for objectively and quantitatively evaluating a design option relative to stated project goals. When two or more design alternatives are being compared, the Risk Comparison Form facilitates a side-by-side comparison to evaluate the risk associated with each alternative. Lastly, the Risk Mitigation Form is used to identify how to mitigate risks identified during the design process.

• Another category of tools is in the area of design risk evaluation and assessment. Researchers in Australia have developed a tool to assess the risk of falls during maintenance on roofs due to the design of the roof (Cooke et al. 2008). The on-line tool, titled ToolSHeD, utilized the physical characteristics of the roof design (area, angle,
loads, etc.) to provide a risk rating (low, medium, high). In the Netherlands, Frijters and Swuste (2008) devised a risk assessment model that assesses the risk of hazard events during the construction of various design features. The model can be used by designers to compare building systems during the design phase. In another example, Gangolells (2010) used risk events to evaluate the safety risk of constructing residential design features. The risks factors can be used to evaluate and compare residential design features in practice.

Impacts of PtD in Construction

When PtD practices are implemented on a project, the construction industry has recognized beneficial impacts. The primary objective of PtD is to prevent construction worker injuries and fatalities. Identifying the connection between design and an improvement in worker safety and health is a difficult endeavor. Construction sites are complex environments, both physically and organizationally, with many factors contributing to the site conditions and work practices. In addition to PtD, other safety mitigation measures are commonly implemented by constructors. Separating out the impacts that PtD has on safety performance is difficult due to the many confounding factors. As a result, much of the research and literature focuses on case study research and observational findings.

In their investigation of the LCS process as mentioned above, Weinstein et al. (2005) investigated whether the LCS program improved safety during the project. To evaluate the impact, the study relied on exit interviews of trade contractors and an evaluation of the extent to which key design changes likely led to reduced risk exposure for construction workers. The researchers found that, in 14 of the 26 (54%) changes made to the design that were studied, the trade contractors specifically mentioned that they improved safety. The researchers’ own review of other specific design changes (e.g., raising the story height to allow more headroom in the basement; creating a walkable ceiling in the interstitial space; and prefabrication of welded truss connections) similarly reduced construction site risks on the project.

In addition to reduced hazards during construction, PtD is expected to benefit worker safety and health during operations and maintenance of the facilities (Gambatese et al. 2005). The parapet design described above, for example, provides protection from falling not only during construction, but also during future roof maintenance. Anchorage points for lanyards that are designed into a structure can be used during construction and also as part of the facility’s use and maintenance. The benefit of PtD in construction to operations and maintenance safety is one of the highlights of PtD compared to other temporary safety measures. Safety measures that are only present during construction have no value to the facility later in its lifecycle.

PtD is identified with improvements in other project attributes in addition to worker safety and health. Levitt and Samelson (1993) and Hinze (2006) contend that improvement in health and safety positively influences productivity, quality, time, and activity costs (see also Toole et al. 2006). Therefore, by addressing construction worker safety, PtD is indirectly playing a part in improving these project characteristics. PtD also increases the buildability and constructability
of a project (Lam et al. 2006). Better designs, reduced workers’ compensation premiums, and reduced environmental damages are some other outcomes of PtD (ISTD 2003, as cited in Gambatese et al. 2005). In addition to better designs, a reduction of the time from project conception to completion is expected because there is less retrofit required (Christensen 2011).

Perhaps one of the biggest impacts comes from the efforts within PtD programs to provide construction knowledge and expertise early on in the project timeline. Activities to engage constructors during design promote the uncovering of safety hazards associated with the design and the development of designs to minimize or eliminate the associated hazards. This engagement facilitates collaboration between the design and construction personnel and the optimization of their combined expertise. The greater collaboration can enhance other aspects of the project (e.g., cost, schedule, quality) as well. Greater focus on designer-constructor collaboration is included later in this report.

**Summary and Need for Further Research**

Prevention through design provides an opportunity to implement hazard mitigation measures that are at the top of the hierarchy of controls for occupational safety and health. PtD addresses safety and health early in a project when the greatest impact can occur, and provides a layer of protection to augment constructor-implemented safety program elements. PtD also enables architects and engineers to enhance the sustainability of their projects by being good stewards of our human resources.

Examples of PtD application in practice exist. Leading PtD companies have developed and implemented PtD programs that incorporate checklists, risk mitigation tools, designer training, and formal PtD project management procedures. Databases of example safe designs are available for reference by the industry. When implemented, PtD has resulted in fewer jobsite hazards. Project personnel cite secondary benefits as improved quality and productivity, and lower overall cost. Efforts to insert construction knowledge during design also result in increased collaboration and communication between the constructor and designer early on in the project.

PtD is integrated within architectural and engineering design processes and practices when considering end-user safety and health. However, traditional design practice in the construction industry does not include formal PtD implementation in regards to the design of the permanent structure and construction worker safety and health. Barriers to PtD in construction include: designer education and training, professional liability exposure, regulatory requirements, industry culture and structure, resource/tool availability, designer capabilities, and financial constraints.

As the PtD concept is diffused throughout the construction industry, it is expected that the industry will react and change. Toole (2001) showed how the characteristics of a construction task, process, and industry have caused innovative building products to follow one or more trajectories. The concept of trajectories can also be applied to the implementation of PtD in the
industry. Toole and Gambatese (2007) identified four specific trajectories that PtD is likely to follow: (1) increased prefabrication; (2) increased use of less hazardous materials and systems; (3) increased application of construction engineering; and (4) increased spatial investigation and consideration.

Even though the construction industry is aware of PtD, and PtD is identified as a promising OSH tool, its diffusion throughout the industry has not occurred. Research has identified reasons for the minimal diffusion. Questions remain, however, about how to overcome the barriers to diffusion. Further research is needed to identify a path forward for the US that will be acceptable to industry and lead to the diffusion of PtD.

One means to determine how to diffuse PtD is to look at other countries where PtD has taken hold. The actions and experiences of other countries can provide the US with useful knowledge on how to proceed. In addition, the resulting outcomes when diffused in other countries, gives the US an idea of what to expect when PtD becomes part of standard practice here in the US. What will the industry look like if PtD becomes a formal practice? Are there new resources that will or should be developed to facilitate PtD? While regulations mandating PtD in construction are not expected here in the US at this time, studying other countries also provides an opportunity to determine the impacts that PtD regulations can have on the US construction industry. Utilizing the knowledge gained from other countries provides examples that the US can reflect on when developing its strategy for PtD diffusion.
III. STUDY GOALS AND OBJECTIVES

As part of NIOSH’s comprehensive NORA research study of PtD, the current study was identified and designed to contribute to the promotion of the PtD concept and highlight its importance in the construction industry. The overall goal of the current study is to develop guidance for the US on how to diffuse PtD in the construction industry. To meet this goal, the study looks outside the US to the UK where PtD has become commonplace under the Construction (Design and Management) Regulations. By examining the experiences and impacts in the UK construction industry, further insights on how to implement PtD here in the US are gained. With this knowledge, the US construction industry can move forward to implementation of PtD with greater confidence and realistic expectations. The specific aims of the study are to:

1. Identify expected organizational and industry impacts related to safety and health perceptions, roles, and culture that result from implementation of the PtD concept.
2. Identify innovative processes and products that evolve from the implementation of the PtD concept within an organization and which could be disseminated for widespread use.
3. Develop guidance for effective implementation of the PtD concept within the US construction industry.
4. Disseminate the research findings to the US construction industry for application in practice.

The present study comprises part of NIOSH’s overall NORA study “Prevention through Design (PtD): Four Component Projects within the Framework of a PtD National Initiative”. Project 1 within the NORA study is titled “Research: Benchmarking Management Practices related to PtD in the US and UK”. This project investigates the PtD concept as it is currently applied by companies in the US and UK. There are two activities within Project 1. Activity 1 is a survey of Fortune 500 corporations in the US soliciting information about their existing practices and policies regarding PtD to determine the extent to which they have embraced these principles as well as any long term results that have occurred due to their implementation of these principles. Activity 2 comprises the present study. Both activities are designed to integrate with the other three projects within the overall NORA study which focus on education, practice, and policy.

PtD in the UK and the CDM Regulations

The selection of the UK as the focus of the study is based on the UK’s experience with PtD in the construction industry. Efforts to mandate that designers consider the safety of those who construct or manufacture their designs goes back to the UK’s Health and Safety at Work Act of 1974 (Legislation 2011a). Section 6 of the Act, titled “General Duties of Manufacturers etc. as regards to Articles and Substances for Use at Work”, states:

(1) It shall be the duty of any person who designs, manufactures, imports or supplies any article for use at work or any article of fairground equipment:
(a) to ensure, so far as is reasonably practicable, that the article is so designed and constructed that it will be safe and without risks to health at all times when it is being set, used, cleaned or maintained by a person at work;
(b) to carry out or arrange for the carrying out of such testing and examination as may be necessary for the performance of the duty imposed on him by the preceding paragraph;
(c) to take such steps as are necessary to secure that persons supplied by that person with the article are provided with adequate information about the use for which the article is designed or has been tested and about any conditions necessary to ensure that it will be safe and without risks to health at all such times as are mentioned in paragraph (a) above and when it is being dismantled or disposed of; and
(d) to take such steps as are necessary to secure, so far as is reasonably practicable, that persons so supplied are provided with all such revisions of information provided to them by virtue of the preceding paragraph as are necessary by reason of its becoming known that anything gives rise to a serious risk to health or safety.

Similarly, Section 6(2) states:

(2) It shall be the duty of any person who undertakes the design or manufacture of any article for use at work or of any article of fairground equipment to carry out or arrange for the carrying out of any necessary research with a view to the discovery and, so far as is reasonably practicable, the elimination or minimisation of any risks to health or safety to which the design or article may give rise.

As indicated above, the H&S at Work Act obligates designers to ensure that their designs will be safe and without risks to health at all times when the design is being set (installed and/or constructed), used, cleaned, and maintained. In addition, the designer is obligated to take action to investigate how to eliminate or minimize any risks to health or safety which the design may create.

A similar requirement of designers does not exist in the Occupational Safety and Health Act (OSH Act) in the US. The OSH Act focuses more broadly on the employer without specifically highlighting the designer, as indicated in its general duty clause presented in Section 5 of the Act (29 USC 654) (USDOL 2011):

(a) Each employer:
   (1) shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees;
   (2) shall comply with occupational safety and health standards promulgated under this Act.
(b) Each employee shall comply with occupational safety and health standards and all rules, regulations, and orders issued pursuant to this Act which are applicable to his own actions and conduct.

The UK’s Health and Safety at Work Act contains a similar employer-responsibility statement as well. The Act places a duty on employers and other persons who are in any way in control of a work activity, whether they are engineers, architects, consultants, or other professionals. The extent to which design professionals must act under this legislation has been tested in UK legislation (for example, see Cansington Dam case in which four workers died in a confined space). In regards to the Cansington case, Baker (1986) explains that, just as on a construction site where the work is divided amongst different companies, so too are health and safety responsibilities divided.

Further obligation of UK designers to address the safety and health risks associated with their designs was instigated by the European Union (EU). The EU Temporary or Mobile Construction Sites Directive of 1992 required EU member states to place duties on designers regarding the safety and health risks associated with their designs (Anderson 2000). Aires et al. (2010) provides the following summary of the Directive:

“This Directive aims to promote better working conditions in this sector of activity which expose workers to particularly high risks. It requires safety and health considerations to be made during the design and organization of projects. It also provides for the establishment of a chain of responsibility, linking all the players involved, in order to prevent risks. These ideas are further developed in 15 important articles and 4 annexes.

Appointment of coordinators - safety and health plan - prior notice
The client or project supervisor shall appoint one or more coordinators for safety and health matters for any construction site on which more than one contractor is present. He shall ensure that, prior to the setting up of a site, a safety and health plan is drawn up. For construction sites where work is scheduled to last longer than 30 working days and on which more than 20 workers are occupied simultaneously, or on which the volume of work is scheduled to exceed 500 person-days, the client or the project supervisor shall communicate a prior notice.

Project preparation stage
During the project preparation stage, when deciding upon architectural and/or organizational aspects and when estimating the period required for completing the various items or stages of work, the project supervisor (or where appropriate the client) shall take account of the general principles of prevention concerning safety and health referred to in the Directive (89/391EEC) and of any safety plans. The coordinators shall coordinate implementation of the general principles of prevention, draw up a safety and health plan and prepare a file containing relevant safety and health information to be taken into account during any subsequent works.
**Project execution stage**
During the project execution stage, the coordinators on the site shall:

- ensure that employers and self-employed persons apply the principles of prevention and follow the safety and health plan where required;
- organise cooperation between employers in respect of safety and health matters;
- coordinate arrangements to check that working procedures are being implemented correctly; and
- take steps necessary to ensure that only authorized persons are allowed onto the site.

**Responsibilities of clients, project supervisors and employers**
Even where a coordinator has been appointed, this does not relieve the client or project supervisor of responsibilities in respect of safety and health matters.

**Obligations of employers**
Employers are obliged to comply with the minimum safety and health requirements applicable to construction sites. These cover such aspects as energy distribution installations, emergency routes and exits, ventilation, temperature, traffic routes - danger areas, sanitary equipment, etc. They must also take into account directions from the coordinator for safety and health matters.

**Obligations of self-employed persons**
All self-employed persons shall comply, *mutatis mutandis*, with the principles and certain provisions of the Directives concerning the use of work equipment and personal protective equipment, in order to preserve the safety and health of all persons present on the site.

**Provision of information to workers, worker consultation, worker participation**
Workers and/or their representatives shall be informed of all the measures to be taken concerning their safety and health on the construction site. The information must be comprehensible to the workers concerned. Consultation and participation of workers and/or of their representatives shall take place, ensuring, whenever necessary proper coordination between workers and/or workers' representatives, having regard to the degree of risk and the size of the work site.”

All EU countries are required to comply with the EU Directive; however each has responded in its own way. Some countries take a more prescriptive approach while others allow for a wider range of practice (Aires et al. 2010). In their evaluation of the safety performance in each EU country, Aires et al. (2010) found that 10 countries experienced a more than 10% lower workplace accident rate after the Directive was enacted. Two countries had significantly worse rates, although the level of confidence in the data was low.
In response to this Directive, in 1994 the UK passed into law the Construction (Design and Management) Regulations (CDM), which became effective on March 31, 1995 (Legislation 2011b). Other EU countries have since followed with similar regulations, and different results (Gibb 2004; Aires et al. 2010). The CDM regulations implemented the EU TMCS directive in the UK, placing requirements for considering construction worker safety and health on design professionals. The objective of the CDM Regulations is to reduce the total amount of risk which is introduced into the construction process by effective management of health and safety upstream of the construction activity. The Regulations aim to ensure that all those who can contribute to the improvement of site health and safety do so, thus overcoming the effects of fragmentation of the industry (Hetherington 1995). The crux of the CDM Regulations affecting the design profession is that the regulations place a duty on the designer to ensure that any design which they create avoids unnecessary risk to construction workers (MacKenzie et al. 2000).

After the CDM Regulations were adopted, concerns were raised that the regulations were failing to promote effective health and safety management while creating wasteful bureaucracy and related burdens on business. Baxendale and Jones (2000) reported that the design profession in the UK was slow in meeting their responsibilities under CDM. Anderson (2000) recommended that designers need clarity about what they are expected to achieve and guidance on how to complete those goals. Moreover, the success of the CDM Regulations in reducing construction fatalities has been difficult to establish (Gibb 2004; Maloney and Cameron 2004). Designers’ lack of knowledge (Gibb 2004) and their disregard for the legislation (Cosman 2004) have been identified as barriers to a successful legislative process. As an example, in a study of the application of the CDM Regulations to small building works, the researchers found that the Regulations left ambiguities, primarily through specified exclusions to application, through which the health and safety responsibilities may be downplayed or even simply disregarded (Griffith and Phillips 2001). MacKenzie et al. (2000) highlighted the following four key issues impacting designer involvement and success within CDM:

- Many designers do not comply with the regulations, which place a duty to ensure that any design prepared avoids foreseeable risk.
- Designers’ knowledge of health and safety is limited and many are not interested.
- Designers use off-the-shelf materials which causes implementation problems. They should do more to question what specifically causes construction fatalities and disabling injuries.
- The Health and Safety Executive must do more to encourage effective communication between designers and constructors at an early stage.

Subsequently, the CDM regulations were revised in 2007 to reduce paperwork burdens and streamline the process. The revision was designed to: (1) make it easier for the duty holders to know what is expected of them; (2) tailor the Regulations to the vast range of contractual arrangements; (3) emphasize active management and effective risk control; (4) encourage better integration of design and construction prior to the start of construction; and (5) improve the competence of those involved. The CDM Coordinator, one of the prescribed project
participants under the 2007 Regulations, is the owner/client’s advisor on health and safety issues during the design and planning phase of the project. However, it is important to note that the Regulations are about “coordination” of the project team around health and safety, not the appointment of a “coordinator”. The 2007 CDM Regulations apply to all types of construction work, however there are several triggers which make appointment of the required dutyholders mandatory on some projects but not on others.

In regards to specifically designers, the HSE ([www.hse.gov.uk/construction/cdm/summary.htm](http://www.hse.gov.uk/construction/cdm/summary.htm)) indicates that on all construction projects, designers must eliminate hazards and reduce risks during design, and provide information about remaining risks. Additionally, on “notifiable” projects, designers must verify that the owner/client is aware of its duties and appoints a CDM Coordinator, and provide any information needed for the health and safety file. Section 11 of the 2007 version of the UK’s CDM regulations pertains specifically to designers. Section 11 states (Legislation 2011b):

(1) No designer shall commence work in relation to a project unless any client for the project is aware of his duties under these Regulations.
(2) The duties in paragraphs (3) and (4) shall be performed so far as is reasonably practicable, taking due account of other relevant design considerations.
(3) Every designer shall in preparing or modifying a design which may be used in construction work in Great Britain avoid foreseeable risks to the health and safety of any person—
   (a) carrying out construction work;
   (b) liable to be affected by such construction work;
   (c) cleaning any window or any transparent or translucent wall, ceiling or roof in or on a structure;
   (d) maintaining the permanent fixtures and fittings of a structure; or
   (e) using a structure designed as a workplace.
(4) In discharging the duty in paragraph (3), the designer shall—
   (a) eliminate hazards which may give rise to risks; and
   (b) reduce risks from any remaining hazards,
   and in so doing shall give collective measures priority over individual measures.
(5) In designing any structure for use as a workplace the designer shall take account of the provisions of the Workplace (Health, Safety and Welfare) Regulations 1992 which relate to the design of, and materials used in, the structure.
(6) The designer shall take all reasonable steps to provide with his design sufficient information about aspects of the design of the structure or its construction or maintenance as will adequately assist—
   (a) clients;
   (b) other designers; and
   (c) contractors,
to comply with their duties under these Regulations.
The Health and Safety Executive and other organizations in the UK have developed documents that help design professionals comply with the requirements of the CDM Regulations. For example, the following documents are available:

- Legal guidance is available at: [http://www.hse.gov.uk/construction/cdm.htm](http://www.hse.gov.uk/construction/cdm.htm).
- General practical guidance for design professionals in fulfillment of the Regulations can be found at: [http://www.cskills.org/healthsafety/cdmaregulations/guidance/designers.asp](http://www.cskills.org/healthsafety/cdmaregulations/guidance/designers.asp).

In May 2012, the Health and Safety Executive announced that the CDM Regulations will be re-drafted for reissue in 2014. HSE indicated that the new CDM Regulations will be based more closely on the requirements of the European Union Temporary Mobile Construction Sites Directive. Suggestions for modifying the CDM Regulations will come from the Association for Project Safety (APS), which is made up of UK architectural, engineering, surveying, project management, and health and safety professionals.

The drafters of health and safety legislation pertaining to the design, whether in the EU or other parts of the world, have attempted to develop both comprehensive and focused regulations that are acceptable, efficient, and impactful. This is a difficult, and perhaps impossible, task. Common difficulties have been experienced by designers, regardless of the legislative efforts that exist in the country. Anderson (2009) provides an insightful summary of the common difficulties experienced as pertaining to the following six issues:

- The diversity of the outputs of the construction industry – from a set of houses on a greenfield site to an entire functioning nuclear power station;
- The diversity of construction site work activities;
- The diversity of construction materials;
- The diversity of the means by which construction work is procured by both the public and private sectors;
- The diversity of people within the industry, with differing levels of both technical and health and safety skills and knowledge, plus the baffling array of job titles and job descriptions; and
- The huge diversity in what one might call “health and safety stakeholders”. This world includes not only health and safety professionals but also…all employers, the self-employed, clients, all manner of designers, contractors… and the special UK-only CDM coordinators.
The experiences that countries have had with PtD regulations have led to mixed results. Some feel that legislation requiring the implementation of safety in design efforts is the only way to ensure that PtD is implemented consistently and effectively throughout the construction industry. Others believe that a focus on compliance stifles safety and ultimately leads to resentment and minimal compliance. Main (2008) provides an insightful description of the different experiences and opinions.
IV. RESEARCH METHODS

The strategy chosen for conducting the research study was to gather and analyze experiences and perspectives within the UK construction industry that have been gained from the regulatory mandated application of the CDM Regulations. Such a strategy was selected in order to meet the proposed research objectives within the complicated natures of the construction industry and the design process, and to address the limitations associated with conducting construction safety research. The research utilized both focus group interviews and structured electronic surveys as mechanisms to collect data. The interviews and surveys were directed at those in the UK who have been impacted by the CDM regulations including architects, design engineers, facility owners/developers, constructors (general contractors and trade contractors), manufacturers/suppliers, and health and safety (H&S) consultants. The chosen research strategy allows for collecting contemporary data and for increasing reliability. Assistance with access to the study populations and with collecting the targeted data was provided by researchers at Loughborough University in Loughborough, England.

During the course of the study, two additional research activities were undertaken. A site visit and interviews were conducted on a nuclear facility in Sellafield, England where new construction and renovations are taking place. In addition, interviews of design and construction personnel in Australia were conducted to solicit their experiences and perspectives of the PtD regulations that exist in Australia. Both of these added activities were opportunistic, providing the researchers additional insights into PtD in practice.

Detailed descriptions of the focus group interviews, on-line survey, Sellafield site visit, and Australia interviews are provided below.

Focus Group Interviews

Focus group interviews of personnel involved in the UK construction industry were conducted to explore the following questions:

- How has the EU and CDM legislation affected the design, construction, and safety of a construction project?
- How has involvement in PtD affected perceptions of safety, roles on the project, and organizational and professional culture?
- To what extent have innovative processes and products been developed in response to the directive to address safety in design?
- What is done differently now compared to practice prior to the CDM regulations?
- How has management of projects changed under the CDM regulations?
- What can the US learn from the UK’s experience?

The targeted participants of the focus group interviews were representatives of six different professional “communities” within the UK construction industry: (1) architects, (2) design
engineers, (3) facility owners/developers, (4) constructors (general contractors and trade contractors), (5) manufacturers/suppliers, and (6) health and safety consultants. These communities represent the primary participants involved in the development, implementation, and control of the planning, design, construction, and safety and health aspects of construction projects, and are the key implementers of the requirements set forth in the CDM Regulations. A total of 12 focus group interviews were targeted (two for each professional community). This number of focus group interviews was selected to provide multiple data collection opportunities for each community within the amount of time and funding allotted for the study.

The sample of focus group participants was taken from individuals who are members of, or whose employers are members of, one or more of the following construction industry professional organizations in the UK:

- Chartered Institute of Building (www.ciob.org.uk; 42,000 members)
- Royal Institute of British Architects (www.riba.org; 30,000 members)
- Institution of Civil Engineers (www.ice.org.uk; 77,350 members)
- British Safety Council (www.britishsafetycouncil.co.uk; 10,000 member companies and subscribers)
- Association for Project Safety (www.associationforprojectsafety.co.uk)

These organizations are comprised of individuals within all of the targeted professional communities who are currently active in their professions. There may be some overlap in membership across the organizations.

Potential focus group participants were selected from the memberships of the organizations listed above who are located in London and the surrounding area. Convenience samples were used to ensure diversity within each professional community. The focus group participants were restricted geographically to London and the surrounding area to minimize travel times to the focus group sites. In addition, this geographic region was targeted because it includes a large number and wide range of construction industry firms and encompasses a significant amount of the construction work in the UK. Each potential focus group participant was contacted via e-mail and/or telephone to solicit their voluntary participation. Interested participants joined a scheduled focus group. The targeted size of each focus group was 6–9 participants. Focus groups of this size were desired to allow all participants to be involved in collaborative discussions and consensus building, provide sufficient numbers to gain a well-rounded perspective, and efficiently conduct the research study.

The researchers developed a series of questions exploring the PtD concept and its application and impact for use as a guide in the focus group interviews. In addition to general demographic information about the participants (position, years and type of experience, education, employer type and size, experience with CDM Regulations, etc.), the focus group questions addressed the research questions posed above. A copy of the questions asked is provided in Appendix A. Prior to conducting the focus group interviews, the questions were pilot tested in a focus group to
ensure their applicability and clarity. The pilot test was conducted at Loughborough University using a subset of six of the selected sample participants. Modifications to the focus group questions were made based on the input of the pilot test participants.

The focus group interviews were scheduled over several weekly periods when the US researchers were able to travel to the UK to participate in the interviews. The interviews were scheduled for approximately two hours per focus group in the morning or afternoon at times that were convenient for the participants. Planning and scheduling of the focus groups was done by the collaborating researchers at Loughborough University in the UK.

The focus group interview responses were recorded for later analysis (hand-written and tape-recorded). Data analysis consisted of basic descriptive statistics and text analysis to understand the participants’ collective perspectives. Content analyses were used to extract key themes supported by the participants that are related to the research questions posed above.

**On-line Survey**

The second data collection effort within Activity 2 was an on-line survey of the UK construction industry. The intent of the survey was to gather industry-wide data on common PtD practices and project performance in the construction industry. The results of the focus group interviews were used to inform the selection of questions and responses for the survey questionnaire. The intent of the survey was to target responses to the following questions:

- What resources and how many are typically devoted to, and required for, PtD efforts?
- When are PtD efforts typically undertaken?
- What PtD practices and tools are commonly employed?
- What enablers and barriers to the implementation of PtD efforts commonly exist?
- What are the impacts of implementation of PtD efforts on safety and other project properties?
- What other safety and health interventions and program elements are commonly employed?

The target population for the survey was the same set of six professional communities identified above for the focus group interviews. Similarly, the study sample was selected from those individuals who are members of, or whose employers are members of, one or more of the industry associations identified above for the focus group interviews. The target sample was 200 members randomly selected from each of the five industry associations to create a total study sample of 1,000 individuals (ignoring multiple membership possibilities). No attempts were made to include or exclude participants beyond being members of the identified associations. The contact names and e-mail addresses for each survey recipient were obtained through membership and/or association directories.
An on-line questionnaire was developed for use as the data collection instrument. A copy of the questionnaire is provided in Appendix B. The questionnaire asked for general demographic information similar to that gathered in the focus group interviews. In addition, the questionnaire solicited responses to the research questions listed above. Questions were formatted for statistical analyses (e.g., Yes/No and Likert scale). A pre-test of the survey questionnaire was conducted using five randomly selected participants (one from each industry association). The pre-test was conducted via e-mail with the goal of verifying the clarity and applicability of each question and the procedures to be used to collect the data. Modifications to the questionnaire and survey procedures were made based on the input received from the pilot test. OMB approval of the survey was acquired prior to distribution of the questionnaire.

After development and approval of the survey, the survey was administered through personalized e-mails to the study sample. The questionnaire was distributed as an attachment to an e-mail sent to the study sample asking for their voluntary participation and providing instructions for submitting a response. All individuals who did not respond within two weeks to the initial e-mail were sent follow-up e-mails as needed to obtain a participation rate of at least 20% (200 responses). The survey responses were recorded in an electronic database for analysis. A statistical analysis software program was used to conduct frequency comparisons and simple Chi-squared inference tests regarding the common PtD practices and related project performance in the construction industry. The majority of the analyses were univariate, although multivariate analyses were utilized where sufficient data points were available. The outcomes of the analyses were used to draw conclusions about how PtD is currently practiced in the UK.

**Added Research Activities**

The researchers voluntarily augmented the original scope of the study to include the following two supporting opportunistic activities.

**Sellafield Case Study**

The Sellafield nuclear facility in Sellafield, England has been in operation since the 1940’s. It was first used as an ordinance factory to support the British effort in World War II. In 1956, a nuclear power plant opened at Sellafield, which was the world’s first commercial nuclear power station. Currently, the site comprises a wide range of nuclear facilities and activities. The facility is now primarily used to produce nuclear fuel and reprocess nuclear waste for disposal, for both national (UK) and international clients.

Nuclear Management Partners (NMP), which recently took over ownership of the facility from Sellafield, Ltd., oversees operations on the site on behalf of the Nuclear Decommissioning Authority in the UK. NMP is a joint venture of three companies: URS Group (USA), Areva (France), and AMEC (UK). Sellafield, Ltd. remains involved in design and construction activities on the site, while NMP acts as manager of the site. Since taking over ownership, NMP has
revised some design and construction processes to streamline and optimize the capital improvement process.

The Sellafield site was selected as a case study for several reasons. In addition to being convenient to the researchers for travel from the London/Loughborough area, Sellafield involves firms from different countries undertaking extensive design and construction operations. The involvement of URS, which is headquartered in the US, provides a unique opportunity to evaluate how a firm from the US reacts to and accommodates the PtD requirements in the UK. URS also has its own design for safety program which it implements on projects in the US. Hence, using the Sellafield site as a case study also allows for investigating whether the PtD practices and processes that URS institutes on the site are accepted and used by UK counterparts. The Sellafield site was also selected due to its extensive involvement with PtD. Activities that take place at Sellafield are highly controlled by the nuclear regulatory agency in the UK, especially with respect to operational safety and health. The design and construction processes within Sellafield projects contain a high degree of PtD. Similar to nuclear facilities in the US, owner/client involvement in Sellafield construction projects is extensive. Intimate involvement by the owner/client is characteristic of the nuclear and power industry and likely a benefit to PtD on Sellafield projects.

Visit to the Sellafield site was initiated and planned through the principal investigator’s contacts at URS, and through the Loughborough researcher’s contacts at Sellafield, Ltd. The site visit consisted of two parts: a focus group interview at the engineering design office in Risley, England, and a visit to the Sellafield nuclear facility. The focus group interview was set up to gain the perspective of those from the joint venture companies who participate in the design of projects on the site. The subsequent site visit allowed for examining the construction efforts and specifically the design for safety measures integrated into the projects.

Prior to the focus group interview, the researchers developed a list of questions to ask during the interview. The researchers started with the set of questions used for the industry focus group interviews, tailoring the questions to apply specifically to the Sellafield site. The list of questions followed during the Sellafield focus group interview are provided in Appendix C.

PtD in Australia

In Australia, “eliminating hazards at the design stage” is listed as one of five national priorities in the country’s National Occupational Health and Safety Strategy 2002-2012 (Safe Work Australia 2002). Australian occupational health and safety legislative frameworks continue to be developed (both nationally and at the state/territory level) to include design as an integral component of safety in the workplace (Breslin 2009). Recent amendments to legislation in Queensland, South Australia, Tasmania, Victoria, and Western Australia have been made that require designers to design buildings and structures that are safe and without risks (Breslin 2007; 2009).
While all jurisdictions place responsibilities on designers, the statutory obligations vary across the jurisdictions. The New South Wales State government, for example, requires that a management strategy exist for the design process which includes consideration, evaluation, and control of occupational safety and health during construction (NSW 2000). Since 1998, this requirement has been mandatory for all State government construction projects having a value of AU$3 million or greater or on lesser-valued projects where the government agency determines there is a high safety risk. According to Breslin (2009), in Queensland, the statutory obligations of designers and those that commission the design are only addressed. The Western Australia legislation places a statutory obligation on designers in relation to safety during the construction process and on building completion, whereas the Southern Australia legislation places responsibilities on designers only in relation to safety on building completion. For example, the Western Australia Occupational Safety and Health Act 1984 specifies the following duties of designers of buildings and structures:

“A person that designs or constructs any building or structure, including a temporary structure, for use at a workplace shall, so far as is practicable ensure that the design and construction of the building or structure is such that:
   a) persons who properly construct, maintain, repair or service the building or structure; and
   b) persons who properly use the building or structure, are not, in doing so, exposed to hazards.”

In 2007 the Western Australia Regulations were amended to assist duty holders by stating specific safe design duties. In regards to designers, the Regulations state that designers must provide a hazard report to the client/owner.

Designers in Victoria have a duty of care under the Victorian Occupational Health and Safety Act 2004 to design buildings or structures that are to be used as workplaces without risk to the health and safety of those using the facilities. However, the designer’s duty in Victoria does not include:

- the design of the construction and demolition phases of a building or the structure’s life cycle;
- the design of residential dwellings that are not intended as workplaces; and
- the design of roads and footpaths (Breslin 2009).

Researchers investigating the impacts of the Western Australia Regulations found that the Regulations have made a “positive impact on design engineers’ thinking and actions towards positively affecting the safety and health of construction workers” (Behm and Culvenor 2011). The Regulations have spurred innovation and prompted creative thinking amongst designers. Overall the researchers found the designers supportive of the PtD concept. In addition, the research findings indicate that, in general, designers show integrated creative thinking rather than simply a “check-the-box” attitude.
In 2009, Working Commission 099 on Construction Safety of the International Council for Research and Innovation in Building and Construction (CIB) held a conference in Melbourne, Australia. The researchers involved in the present study attended and participated in the conference. Taking advantage of the visit to Australia, the researchers conducted focus group interviews of design and construction industry personnel in Australia. Similar to the focus groups in the UK, the goal of the PtD focus groups in Australia was to assess the effects of the PtD regulations on the Australia construction industry and augment the results of the UK focus groups to determine how to best implement the PtD concept in the US. The Australia focus group interviews explored:

- How has the Australian legislation affected the design, construction, and safety of a construction project?
- How has involvement in PtD affected perceptions of safety, roles on the project, and organizational and professional culture?
- To what extent have innovative processes and products been developed in response to the directive to address safety in design?
- What is done differently now compared to practice prior to the regulations?
- How has management of projects changed under the regulations?
- What can the US learn from Australia’s experience?

The targeted participants were: architects, design engineers, facility owners/developers, constructors (general contractors and trade contractors), manufacturers/suppliers, and H&S consultants. The interviews were to be conducted either before, during, or after the CIB conference, and utilize a modified list of the questions asked during the focus groups in the UK. The research plan included conducting a total of three focus groups, one for each of the following groups: (1) architects, engineers, and facility owners/developers, (2) constructors and manufacturers/suppliers, and (3) H&S consultants. A similar number of participants per focus group (6-9) was targeted. The actual number of focus groups and participants in each focus group was dependent on the availability and interest of the targeted participants. The conference attendees were targeted for participation along with other professionals in the Melbourne and surrounding areas. To set up the focus groups, the conference organizers were contacted to ask for their assistance. The specific tasks were as follows:

1. Contact the conference organizers to ask them to help set up focus group interviews.
2. Modify the list of focus group questions if needed for the Australian construction industry.
3. Schedule the focus group interviews.
4. Travel to Melbourne to conduct the interviews.
5. Conduct the focus group interviews and record the responses.
6. Incorporate the results into the on-going NIOSH PtD study of the UK industry.

A copy of the Australian focus group interview questions is provided in Appendix D.
V. RESULTS

Focus Group Interviews

The researchers developed a list of questions to structure the focus group interviews and ensure consistency between focus groups. The questions solicited demographic information about the participants along with their experience and perspectives of PtD. A copy of the questionnaire is provided in Appendix A. The questions were tested in a pilot focus group and sent out to industry professionals for feedback. Revisions to the questions were made using the feedback, and the revised questions were then used in the scheduled focus group interviews.

In order to recruit the focus group participants, a brief information sheet describing the research and announcing the planned focus group sessions was produced and distributed through industry contacts and construction organizations. From the responses received, a schedule of focus groups was drawn up so that the disciplines required for the focus groups as planned in the research study design could be identified. The number of participants varied between focus groups. Participants self-selected the group in which to participate. However, in some cases those participants who initially planned to join a focus group did not attend, primarily due to unforeseen work conflicts. In other cases, some participants decided to join other focus group sessions at the last minute. Due to some focus group sessions containing only a few participants, additional focus group sessions were set up to ensure participation by members of all of the targeted communities. The researchers conducted a total of 14 focus groups which involved a total of 110 participants. Table 2 provides a summary of each focus group and the participants.
Table 2. Focus Group Interviews

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<th>No.</th>
<th>Location/Setting</th>
<th>Participants</th>
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<tr>
<td>1</td>
<td>Loughborough University</td>
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</tr>
<tr>
<td>2</td>
<td>Institute of Occupational Safety and Health (IOSH)</td>
<td>H&amp;S manager (2), architect (1)</td>
</tr>
<tr>
<td></td>
<td>headquarters, Leicester</td>
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</tr>
<tr>
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<td>H&amp;S manager (2), architect (1), engineer (1)</td>
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<td>4</td>
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<td>5</td>
<td>Construction Federation office, London</td>
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<tr>
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<td>Midlands Construction Safety Association, bi-monthly</td>
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<td></td>
<td>meeting</td>
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<td>European Construction Institute, Loughborough</td>
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<td></td>
<td>University</td>
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<td>Architect (4)</td>
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<td>9</td>
<td>ISE, at ISE headquarters, London</td>
<td>Engineer (4)</td>
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<td>H&amp;S manager (25), QPA research team member (3), UK HSE (1)</td>
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<td>Architects</td>
<td>Architect (5)</td>
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</tbody>
</table>

Each focus group began with self-introductions of the researchers and participants followed by an opening description of the research and focus group objectives by the researchers. The researchers also passed out a brief written description of the research and form for participants to provide demographic information (see Appendix A). The participants were alerted that the conversations were being audio-recorded, and that the information would be kept confidential. The participants were asked to provide candid remarks, and to ask questions whenever needed. The researchers led the discussion, asking questions from the list of questions developed. The
discussion was allowed to flow freely from one topic to another to promote one participant building upon the statements of another. The researchers took the time to explore points of interest in detail by asking additional questions. Each focus group lasted approximately 3-4 hours, including breaks.

At the conclusion of each session, the researchers asked the participants to submit the completed demographic forms. In some cases, demographic forms were not completed and submitted by participants. No demographic forms were received from the participants in Focus Groups #9 and #10.

A total of 62 demographic forms were received (56% of participants). The following statistics provide a summary description of the participants:

- The types of firms which the focus group participants work in, and percentage of all participants who responded, are as follows (multiple selections allowed): H&S consultant (25%), design (19.3%), architect (18.2%), contractor (9.1%), facility owner (8.0%), subcontractor (6.8%), manufacturer (4.5%), and other (9.1%).
- The services provided by the firms for those participants who submitted demographic forms are (multiple selections allowed): H&S consultant (25.6%), project management (21.6%), construction (19.9%), engineering (17.0%), and architecture (15.9%).
- The firms in which the participants work ranged widely in terms of size. The majority of participants work in firms with greater than 1,000 employees (42.6% of participants). The distribution based on size of firm for the remaining participants is as follows: 500-1,000 (11.5%), 250-499 (6.6%), 100-249 (13.1%), 50-99 (1.6%), 10-49 (8.2%), and 1-9 (16.4%).
- The participants have an average of 23.0 years of experience working in the industry, and 11.3 years working with the CDM Regulations.

Each of the demographic forms also asked the participants to provide their opinion of the impact of PtD on project cost, schedule, productivity, quality, and safety. Specifically, the question asked: “How has each of the following changed as a result of implementing PtD on projects?” The possible responses were limited to: Decrease, No Change, Increase, and I don’t Know. Additionally, if the participant indicated an increase or decrease, they were asked to estimate the approximate percent change. Table 2 below summarizes the responses. Of the 62 participants who provided demographic information, the number of participants who responded to some or all of the questions about the impacts of PtD is shown in Table 3.
Table 3. Perceived Impact of PtD on Project Criteria – Focus Group Participants  
(% of responses; n varies)

<table>
<thead>
<tr>
<th>Project Criteria</th>
<th>Decrease</th>
<th>No Change</th>
<th>Increase</th>
<th>Approximate % Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design (n = 38)</td>
<td>5%</td>
<td>45%</td>
<td>50%</td>
<td>0.5% - 10%</td>
</tr>
<tr>
<td>Construction (n = 41)</td>
<td>32%</td>
<td>22%</td>
<td>46%</td>
<td>3% - 20%</td>
</tr>
<tr>
<td>Duration:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design (n = 40)</td>
<td>8%</td>
<td>55%</td>
<td>38%</td>
<td>1% - 20%</td>
</tr>
<tr>
<td>Construction (n = 41)</td>
<td>37%</td>
<td>41%</td>
<td>22%</td>
<td>2% - 10%</td>
</tr>
<tr>
<td>Construction quality (n = 41)</td>
<td>7%</td>
<td>29%</td>
<td>63%</td>
<td>2% - 15%</td>
</tr>
<tr>
<td>Construction worker productivity (n = 32)</td>
<td>19%</td>
<td>31%</td>
<td>50%</td>
<td>2% - 15%</td>
</tr>
<tr>
<td>Construction worker health and safety (n = 48)</td>
<td>4%</td>
<td>8%</td>
<td>88%</td>
<td>5% - 25%</td>
</tr>
<tr>
<td>End-user health and safety (n = 45)</td>
<td>4%</td>
<td>9%</td>
<td>87%</td>
<td>5% - 50%</td>
</tr>
</tbody>
</table>

Each of the focus group sessions was audio-recorded and then transcribed. From these files, the participant responses were organized according to each question. Provided below are a content analysis and summary of the participant responses to each research question. Where possible, specific examples of responses are provided to characterize the overall nature of all of the responses received. The examples are identified with the focus group number (N1-N14) and the interview question (Q1-Q17).

**Question 1: Can you briefly tell us about your involvement in PtD under the CDM regulations, as an individual? (How does PtD fit into your work?)**

The varied sample of participants targeted for the focus groups resulted in a wide range of responses to this question. The participants include designers (architects and engineers), owners/clients, H&S consultants, principle contractors, trade contractors, and regulatory agency representatives. Some of the participants fill the role of CDM Coordinator on projects and are therefore intimately and directly involved in PtD as part of their daily work lives. One of the most knowledgeable participants was asked to review and help develop the current version of the CDM Regulations. Other participants interact infrequently with CDM Coordinators and PtD, and are more indirectly involved. In some cases the level of involvement in PtD and CDM was extensive, while in others it was minimal. Some firms have a CDM advisor on staff who takes care of all obligations under the Regulations. It is clear that the participants perceived a difference in involvement in CDM activities based on size of the firm. Smaller-sized firms had little or no involvement, while larger firms were involved to a greater extent.

Except for CDM Coordinators, the nature and extent to which PtD fits into their work also varied widely. In some cases the participants participated in safety design reviews
as part of a PtD process established within their firm. Other participants, primarily on the construction side but also designers, had little or no involvement in PtD and CDM activities.

It was recognized that the CDM Regulations create a significant amount of work around documenting hazards and assessing risks. As a result, involvement in PtD was associated with this type of documentation effort. This perception was a common theme in many of the focus groups. The separation of CDM from PtD did not always readily occur and, consequently, the researchers occasionally had to re-focus the discussion to PtD.

There was some recognition amongst the participants that CDM and PtD fit into and affected their work scope in other ways besides just providing the necessary documentation and conducting risk assessments. One participant indicated that during design, there is a need to focus on how the design is going to be built. The participant recognized that “the CDM Regulations are almost guiding us down the path of looking at how we erect structures, looking at site restrictions, and the problems on site” (N11, Q1). Another participant remarked that CDM really involves day-to-day cooperation and coordination (N6, Q2). The recognition that the CDM Regulations affected their work activities beyond just safety and health was evident, and valued as a benefit to the overall project.

**Question 2: How does your company approach the PtD concept on projects? (What processes and resources are used?)**

The participant firms have implemented tools and resources to comply with the CDM Regulations and improve H&S of their projects. The commonly-used tools are: safety checklists, design checklists, periodic constructability (buildability) reviews, and hazard register/log. Hazard identification reviews and a hazard register are used to identify and document the hazards associated with the design, indicate how the risk associated with the hazards has been mitigated, and record the residual risk that subsequent users (e.g., constructors) need to be aware of. The hazard register, which is implemented to partially fulfill their obligations under the CDM Regulations, is used to record the design measures or design changes that have been applied in order to either eliminate or reduce the hazard (N3, Q2).

Some firms have taken further steps in their approach to PtD. The following are some examples:

- Placing symbols on drawings that alert constructors of hazards associated with the design.
- Identifying a CDM champion for each project to oversee the PtD and CDM efforts. In some cases the firm hires a consultant to provide PtD input and also act as the CDM Coordinator on projects.
• Establishing a team of staff members who act as a CDM coordination team for the company to ensure that its CDM obligations are met and to address PtD on its projects.

One architectural firm has gone further in order to affect the companies it subcontracts with. At the start of some projects the firm conducted a series of workshops with potential subcontractors/consultants where they determined the subcontractor/consultant level of competency. The firm was able to use this information to select partners who they felt were sufficiently competent in PtD and CDM oversight. The focus group participant remarked, “And like with any company, whenever they’re going to be put to those sort of tests, the best people within their company come and carry them out” (N13, Q2).

The participants recognized that the mindset of the project participants and project culture make a difference in how PtD is approached. The client setting the tone, and especially passing it down through the supply chain, was identified as important for project culture. A tone that is positive toward PtD, and CDM, leads to acceptance of the concept and action towards improving safety and health through design. One company has gone further and adopted a motto that being safe is not a skill, but an attitude (N13, Q2).

Question 3: Is it a struggle to prioritize health and safety ahead of other project objectives, such as cost and schedule? (Examples from projects.)

The focus on construction safety and health on a project, while commonly identified as the main concern, is not the only project priority. Project team members often have goals and performance criteria related to cost, schedule, quality, productivity, and other project attributes. During the process of selecting a design alternative, all of the targeted goals are weighed. In some cases it may be difficult to prioritize H&S ahead of other project objectives. Some of the focus group participants affirmed this difficulty while others indicated no struggle. However, the question of cheaper versus safer always comes up in project discussions.

The focus group participants generally indicated that separating safety from other project objectives is not always easy to do. Safety is part of the culture, both at the project level and the organizational level. Health and safety are part of buildability along with other design objectives such as cost and schedule. The tendency to put safety and health first when designing the facility varies depending on the firm and on the project. Projects in the petro-chemical, power generation, and pharmaceutical sectors of the construction industry typically maintain a culture in which all design changes are made if they improve safety. Additionally, as safety and health become more prominent, their value relative to other project objectives has changed. One comment from a focus group participant illustrated this difference:
“One of the problems going back probably 15-20 years was, whichever client you happened to work for, they looked at the tender prices coming back and they picked the cheapest. Irrespective of the quality, they picked the cheapest. Now I think they’re much more switched on that actually the cheapest is probably not going to be the best quality. Most confrontational and people will cut corners and therefore safety and all the rest of it” (N3, Q3).

On the other hand, those projects in other sectors might forego the design change if the cost, schedule, and/or quality are compromised in favor of a hazard mitigation measure that is lower on the hierarchy of controls. This latter perspective and direction is consistent with the CDM Regulations which allow for performing what is “commercially practicable”. A viewpoint existed in the focus groups that only requiring what is commercially practicable is the appropriate path to take and that anything that is more prescriptive would be viewed negatively. The following are focus group participant comments that illustrate this point:

- “Well not a problem but I think it gives you a tool to discuss all aspects of health and safety against. So if it’s.......if you can achieve that health and safety aspect at a reasonable cost and inconvenience then you know it’s quite easy to move on and close issues. But if it’s going to be ridiculously expensive and very, very, complicated, and delay the project, I think quite quickly you will say right well that this is a risk we’re going to have to manage some other way” (N3, Q3).
- “And an example I can give you for the US, we have a dive team that does underwater investigations. We have a range of clients. If we go to the petrochemical industry, they set the standard probably four or five notches above where we normally work because they insist on cover, cover, cover, and cover and they will pay for it. If you go to the opposite extreme where we've got a port authority, they want the work done, they want it done efficiently, they want results now, and they are not interested in how you do it. They generally just want to know what the outcome is” (N5, Q3).
- “The architect will always be more interested in how a building looks and another contractor is going to be more interested in price because that always wins when people work. However, one thing I've noticed is that if you've got a better managed site which is a clean site, your costs are going - the costs are going down because there's less wastage. But if it's a well-managed site, health and safety is well managed as well. So they all come together” (N13, Q3).

Several examples were given in which safety was compared to other project objectives. Two examples are provided below:

- “So we had to culminate that 11 meter boom with a cradle or a small cherry picker that goes down, allowed you to clean the windows, get to this gutter and that light fitting and maintain that roof. That was £120,000 to put that in, so big jump in the cost plan. The client says, can’t possibly do that. Then we said, look
we’ve got no option here, we can’t not have access to it. So I then talked to the
guys who do vertical access, vertical technology, we had a presentation at the
APS, these guys actually maintain the London Eye. They had to grease the wheel
or whatever, so they climb up. It’s the only way they can do it. Someone was
suggesting it could have been a self-lubricating grease or something, fine, if you
can do that, but it wasn’t designed in. Perhaps the designer missed it, couldn’t
afford it. If you like, I’m trying to paint a picture of mild optimism in terms of first
off you’ve got to recognize the problem and it’s taken 14 years to do that. But at
least having recognized the problem there are some people who are trying to do
something about it. Whether we’re going to get successful outcomes, we don’t
know” (N8, Q3).

• And we did a job last year where we were in an alley adjacent the building
because we were looking at some housing we were doing. It’s a three-story block
of apartments and they got a connection on this at the end of the building and it
took us four days to make one connection. We could have done it in two hours if
it had been designed in the first place to take the load, whatever, or even if
they’d put it into a certain point, and we looked at it and went: Gee, who’s
designed this? Straight away we’re thinking why are we doing that? Four days at
risk at height when we could have done it in two hours” (N11, Q3).

A number of comments came out in regards to incorporating H&S into business risk
assessments. By doing so, the firm is strategically placing safety next to other project
objectives to objectively determine and assess the potential design alternatives. Below
are focus group member comments that address this issue:

• “Most of the big companies that I deal with are concerned about health and
safety purely from the point of view of business risk” (N9, Q3).

• “Safety is important to them [upper management]. Safety is a priority but it has
a financial element to it of which is easily struck off when they don’t like the
value of the building in terms of cost” (N12, Q3).

In a couple focus group sessions, discussion centered on the inability to bring safety into
the decision process along with other project objectives because of the timing in which
safety is considered and when the CDM Coordinator is involved. Two focus group
comments that illustrate this point are:

• “There are still difficulties with it because again, as I say, we are not appointed
until the 11th hour still in most cases. And, I think that appointment is then too
late and unfortunately you’ve missed all the opportunities” (N12, Q3).

• “I think they always think that it’s something that’s just tagged on at the end.
You know, when the design has all been done, and then just before it goes out to
tender, somebody sort of casts their eye over it for safety” (N14, Q3).
Question 4: Think back to practice before CDM – What is done differently now in your work [as an architect, etc.]? Have the 2007 CDM regulations had a greater impact on your work?

The focus group participants recognize that change has occurred as a result of the CDM Regulations. The change has occurred in a variety of ways. One is that now the topic of PtD is incorporated into design and construction education and training. Additionally, H&S is now part of the examination for design professional registration. The following are additional impacts to their work environment and practices:

- **Work processes and procedures:**
  - Under the CDM Regulations there is now more paperwork to comply with the Regulations and create a H&S file.
  - The construction perspective is now brought into the project earlier in the lifecycle. As a result, buildability used to be a lower priority and now it is considered regularly. Consideration of buildability earlier was also recognized as benefiting other areas besides safety.
  - There is an expanded effort in the area of risk analysis. “With HAZCOM [hazard communication], because HAZCOM is sort of -- it's built up momentum over the last 10 or 15 years, whereas everybody talks about it now. But if you went back 15 years ago, it wasn't really a tool in the basket at all. So did CDM change that? CDM has changed that, yes” (N6, Q4).
  - Designers are now seeing the benefits of more design and planning discussions, pre-planning efforts, working as teams, and a closer relationship between the constructor and owner. “From the benefit of what I've seen, working from a contractor’s point of view right through the Reg’s, the benefit we’ve seen is that we've forged close relationships with the client’s side of the team and that brings its own benefits because you discuss the problems early on and you resolve them and therefore that has without doubt a cost saving, which the client...” (N2, Q4).

- **Work culture:**
  - There is more accountability than before.
  - H&S is now throughout the project team, not just an add-on provided by the H&S professional.
  - Owner/client knowledge of safety and involvement has increased, along with increased corporate responsibility. “The difference that’s now come out of the new regulations is that designers are seeing the benefits in some respect and the teaching that I give is not saying, 'The law says you must', it actually says what are the benefits of the buildability angle and there are, if we really boil it down, some great significant savings by following the CDM principles” (N2, Q4).
“There’s no doubt that culturally there is a big difference out there” (N5, Q4).
“It’s not universal, but there are a lot of people, a lot of clients, who insist on talking about safety on their projects who wouldn’t have done it before. A lot of designers talk about safety in their design process that wouldn’t have been doing it before.” (N5, Q4).
“I think it’s helped me personally do my job better than before, where before it was always the commercial edge such as, ‘Oh, I’ll just get them to this contractor’s risk, let the contractor do it.’ You step away. And you can’t do that anymore” (N13, Q4).

- Facility design:
  - More prefabrication; more notes on the drawings; and more rationale for the design placed on the drawings.
    - “A number of clients commented to us that this is a breath of fresh air to see this sort of information being put on drawings” (N6, Q7).
  - “I’d say the drawings probably aren’t much different, but the embedded knowledge in them is hopefully better” (N2, Q9).
  - “10 years ago the idea of putting in safety nets, hooks for holding safety nets at the top of steel expansions, I think you would have got the same response: ‘You can’t do this’. But is it common practice now? If it hadn’t been for these changes, nothing would have happened” (N5, Q4).
  - “I’ve learned an awful lot over the last 14 years. All sorts of things on design which I wouldn’t have even thought about 14 years ago. So in terms of design, there’s a lot of things I do now which I wouldn’t have done 14 years ago. I wouldn’t have even considered putting up guardrails on roofs or things 14 years ago” (N8, Q4).
  - “Most of the pump sets and fans and everything will be sat on concrete bases on the floor previously. So if we need to maintain the equipment, it involves bending down to it as well as it all being someone inside. What we do now is have all the pump sets, everything is assembled in a metal frame offsite and they crane into the job so it’s off-site assembled, put in place, and it’s all built. So it lands in place, it’s all about waist/chest height which makes everything, all the valves accessible, much easier for the manual handling if you’ve got to lift small motors off. So yes, it has made a difference” (N13, Q4).
  - “I agree with that as well. Some of the things we’ve done in terms of module M&E systems coming in, it’s just reduced a lot of manual handling. It’s been brought in – manufactured offsite and brought in, where prior to that that would never have happened, I don’t think. And again, the access” (N13, Q4).
  - “Typical example is the roofing on factories. You’ve got the felt roofs where hot working, felts, I mean even the old performance felts still have
problems, you're going up there with gas bottles and torches, hot torches to repair. Now we just do cladding, steel cladding which is 20-year performance guarantee on materials, no hot working, it's all fixed. If you see any leaks in it, that's a big plus. That's probably doubled by insurance, to be quite honest, but it was – the CDM made you look, well, let's look at another system” (N13, Q4).

- Project team:
  - The CDM Regulations created the CDM Coordinator position (previously the Planning Supervisor) on the project team. The change to the CDM Coordinator title and responsibilities was intended to optimize the input that the CDM Coordinator provides.
    “All they [Planning Supervisor] tended to be was people with a big stick saying this is criminal law, you’ll go to prison if you don’t do it, which turned everybody against them. The PS didn’t sit in the middle, between the contractor and the client, he sat on that side of the table, and now we’ve seen with the change from the new Reg’s, CDM-C actually sits right in the middle, got to get involved with everybody” (N2, Q4).

- Construction:
  - “The other thing that’s happened, and I’m not sure whether this ties in with CDM or not, is that there’s also the move away from scaffolding construction at all, and now doing things from [the slab] so there’s all sorts of new fancy cranes and suction devices from the inside” (N4, Q4).
  - “Construction plant design actually over the last 50 years has leapt forward in leaps and bounds. You know you’ve got the double articulated yoke that can reach round the edge of a bridge and underneath and you’ve got the smaller one man bobcat-type things that come in to get into smaller places to minimize manual handling and issues. So I think the demand has been there for more innovative solutions and equipment that will do a better job and people can sell it” (N4, Q4).

*Question 5: How has PtD specifically changed the management of projects?*

Traditional management processes remain in place and have been modified to respond to the PtD requirements established within the CDM Regulations. The primary additions have been in assessing and managing the foreseeable H&S risk. Management practices now include efforts to identify and assess the risk during the design phase, manage the risk through the design if possible or desired, and communicate the residual risk to the constructor.

Early on the risk assessments were static. The assessments were created and then filed to meet the CDM requirements. This practice has largely changed, especially given the...
revised CDM Regulations. Now, everyone involved in the project knows that the risks will be documented (N3, Q5). Another participant stated it differently: “So for what it does, is it says, well the risk hasn’t gone away, but it’s become maybe more manageable because you know we’re going to think about it” (N2, Q5). However, as indicated in the following quote, use of the documented risk has changed: “The main thing I’ve taken out of the new Regulations is that, okay we’ve done away with risk assessments because they’re static; they’re done once and filed. But, what we have got is active management of risk. So somebody identifies a hazard and they take ownership of it and they take certain actions to try and eliminate it or reduce it. And then they at some point pass it on” (N8, Q5).

The presence of constructability (buildability) reviews is now prevalent. Constructability reviews are conducted during the design stage to identify impacts of the design during construction. The focus now includes safety whereas prior to CDM, safety may not have come up at all in the review discussions which focused largely on productivity, cost, and quality. The incidence and nature of constructability reviews were summarized as follows:

“What we do on every project is that we have a constructability review of the design. So the architect or the mechanical designer, depending whose design it was, will come along to the meeting and present the design and look through it” (N13, Q5).

Interjecting safety into project management discussions also extends beyond constructability reviews. Recognition of safety impacts comes up when considering project feasibility. The need and ability to address safety and health risks is a consideration along with the need for projects. This has resulted in innovative designs and construction processes. An example is the Terminal 5 expansion at Heathrow airport. When describing the expansion project, one participant described the following exchange in a meeting:

“And the guy from the HSE chatting away to us, hang on a minute, he says according to all those stats you’re going to kill about nine people on this project. And, the [airport executive] said right, we won’t build the airport then. Of course, all these bankers’ jaws dropped because we’re not building the airport. And this is where we’re going to have to do something different. And this is when we talked about how we should build the roof on the ground and jack it up, and we engaged the designers every month, walking round the project, looking at what they’d done” (N13, Q5).

**Question 6: Have any project team roles changed significantly because of PtD?**

The role of the CDM Coordinator or “CDMC” (previously titled Planning Supervisor under the prior version of the CDM Regulations) is central to PtD implementation in the
UK. The CDMC oversees adherence to the CDM Regulations. Involvement beyond this limited role is dependent on the industry, the project, the owner/client, and the CDMC. In some cases the CDMC participates at the level of the architect and design engineer, providing design input to eliminate safety hazards. Participation in this regard is viewed by the participants as beneficial to the project.

The CDMC is appointed by the owner/client. In some cases the role is fulfilled by the architect. In others, a safety consultant or other professional organization is hired. This has created a new profession in the industry. The history of its development was described as follows:

“And when the CDM Regulations were introduced they didn’t envisage that they had this personal planning supervisor, I suppose now CDM Coordinator, that wasn’t supposed to be a new person, a new profession, that was one of the design team, preferably the lead person, the architect, taking responsibility for coordinating health and safety on that project. Architects didn’t want it, didn’t want to get involved. We’re designers. So they shed that and a new profession was created. All of a sudden a new part of the industry will spring up in response to it that they [the architects] didn’t want” (N8, Q6).

The CDM Regulations have also provided an additional confirmation of the roles and responsibilities of the different project participants. Rather than solely outlined in the contracts, and created through standard practice, the CDM Regulations solidified the roles of the parties with respect to worker safety and health. For the owner/client, one participant remarked: “Clients tend to realize that actually......they were always culpable but now it says in black and white the client is responsible and there is very much a desire to comply with that which was very obvious, very visible, and that’s a big difference” (N3, Q6). Another participant remarked about the positive benefits of more confirmation of roles: “But now the onus is more on the client and the designer and they’re more culpable and I think that’s having an effect in the short-term” (N6, Q6).

In terms of expanding roles and perceptions of importance, the traditional roles are changing. With the requirement to assess risk, project team members other than architects and design engineers play a significant role. As a result, constructors, construction managers, and safety professionals are garnering greater support and involvement in project leadership. This has become pronounced for quantity surveyors (QS). Decisions related to designing for safety often are made with consideration of cost and availability of materials and equipment. The QS is coming to the forefront in regards to PtD opportunities during purchasing and subcontracts. Their increased role, and the subsequent reduced role of the design professional, is summarized by one participant as:
“The QS has taken more contract stuff on board. So, the industry as a whole has devolved. It is almost like the architect used to be a very respected person, like a doctor, and it tends to not happen now” (N14, Q6).

Understanding and recognition of the unique roles and contributions that each project team member can provide has been positively impacted as well. One participant remarked: “What I think there is now is a far better recognition......of how decisions I make as an architect will affect like the hazard profile and structure an engineer has” (N3, Q6). This recognition leads to designs that accommodate the needs and priorities of the other project team members to a greater extent. In addition, there is more consideration of the interfaces between design disciplines. Where previously one design discipline’s scope of work ended and interfaced with another design discipline’s scope of work, transitions between the designs were not always smooth. Now, the greater consideration of other disciplines leads to improved interfaces between design features and systems. Ultimately, it is recognized that it is now a much more thorough design approach (N11, Q6). This change is significant for the US, as it is can be created through not necessarily legislation, but just better professional practice.

**Question 7: Has the biggest assistance with the implementation of PtD come from within or outside your company? (External: training, funding, cross-industry relationships. Does CDM legislation help or hinder your application of PtD? Which is more powerful, internal or external?)**

Participant responses to other questions during the focus group sessions underscore the importance of the CDM Regulations. Change has been instigated by the CDM Regulations, and is manifested in how the project team has responded. The response has been, in many areas, with significant changes in how the team works together, communicates, and collaborates. The impetus came from an external source (the CDM Regulations); however actual practice is driven internally and to a great extent by the owner/client expectations and resources on the project. The Regulations place a responsibility on the owner/client – a key aspect of the Regulation’s success – who in turn drives the project team members to work together to eliminate and manage the risk.

The CDMC can play a significant role in implementing PtD. CDMCs who have knowledge of the construction process, construction safety and health, and design impacts, can significantly benefit PtD implementation. One participant stated: “Within all these [practices] we’ve got what we call a CDM Advisor who is basically a CDM champion who can help the group or the practice when you have issues relating to health and safety risks during design” (N3, Q7). Lacking this expert knowledge, improving design practice is difficult and other resources are needed. Helpful assistance is provided by both technological resources and project team members. The most prominent sources of assistance are described in the following participant responses:
• Internet resources: “The HSE are a very important part of that because their website has got some great information on it for designers. They have the red/amber/green lists. When everybody turns on their Internet at [company name], this is the page they get and you know there’s a lot of links there, I appreciate that, but health and safety is on the front page” (N3, Q7).

• Upper management: “But the CDM Regulation going back to where I came from, I think, many have had an effect on companies where they are involved with a much broader range of clients, to actually focus the Board, not the designer, the Board, to say well we need to really do something about this because this could have an effect on the company and more recently as legislation in the UK has changed, or the emphasis has been much more, too many people in the boardroom feel they’re more vulnerable, on me personally. And that does really change the attitude that pushes down” (N5, Q6).

• End users: “So I’m seeing facilities management involvement in projects being a driver to when we start banging on about do you know how you’re going to clean a façade, get to the roof, and all the rest of it; the bells going in my mind saying oh yes, he's right” (N12, Q7).

• Facility maintenance: “The work at height regulation has probably been one of the most driving factors of the issues they’ve got. But the work at height from a maintenance point of view, from the client’s point, has been the biggest driver” (N12, Q7).

Question 8: What do you feel are the barriers to implementing PtD on projects?

Archival literature describing previous work identifies a wide variety of barriers to PtD in both the UK and US, as described in Section II of this report. These include barriers associated with: a lack of relevant education and training, fear of professional liability exposure, roles and responsibilities created by regulatory requirements, industry culture and structure, a lack of resource availability, designer capabilities in regards to identifying construction safety and health risks, and financial constraints. Some of these barriers, and additional barriers, were identified in the focus group interviews. Below are barriers that were identified and supported throughout the focus group interviews:

• **PtD coordinator**: The role and authority of the individual tasked with overseeing PtD efforts, in this case the CDM Coordinator, needs to be clearly defined and observed. In addition, sufficient weight needs to be placed on the coordinator’s input such that PtD is taken seriously (N2, Q8). Lacking such authority, other project objectives take precedence.
  o “I don’t think I’ve ever spoken to a CDMC directly, we may have one or two e-mails with them but they are seen very much as this distinct character who doesn’t really input to the sort of day-to-day, weekly, or even monthly decisions that happen on site. There’s been one job where a CDMC has been very heavily involved and that’s been very much the exception. When the CDMC sort of became aware of the issue all of a
sudden it moved to the front of the agenda and then commissioned for [us to actually do the work]” (N4, Q1).
  o “For the most part, they simply do train you. It’s more about what your responsibility is, and who you need to tell, who you need to tell what, and when. It’s more a CDM thing than a health and safety thing” (N14, Q2).

- **Timing of PtD input**: Input regarding the nature and extent of safety and health risks related to the design can come at any time. Ideally, the input would be provided as early as possible before the design is finalized and changes can be made more easily. Safety constructability input at the end of design, and also during construction, is often ignored in favor of other priorities such as cost and time. The focus group participants indicated that PtD input provided late in the design is an obstacle to implementing PtD in practice. Some of the participant comments which express this barrier are:
  o “Also it’s the timing of the appointment of the Senior Coordinator. If they come in as the tender doc’s are being produced, well even if you’ve got all the resources in the world there’s nothing you can do” (N5, Q7).
  o “They pick a design solution and at the end of the design process they write up their design risk assessment, at which point they have no choice, you can’t alter the design” (N5, Q8).
  o “But the age old problem is when do you engage a contractor, and that's the problem” (N7, Q8).
  o “I think one of the big problems perhaps so is that the architects perhaps don’t involve engineers early enough for the design process. They’re not in a position where they’ve agreed with their design, their outline design with the client, or with the local authority or whatever in terms of planning. And therefore things are cast in stone before we actually get terribly involved in it” (N9, Q8).

- **Understanding of construction process and construction safety**: The ability to recognize how and when to modify a design for safety stems to a great extent on an understanding of the construction process and the safety and health risk exposures. When designers lack construction site experience and knowledge, their ability to implement PtD practices suffers. Those who do have such experience and knowledge are more able to contribute to PtD implementation independently. When such knowledge is lacking, implementing PtD requires the involvement of others with the requisite construction background.

The focus group participants suggest that this issue is more significant in some design disciplines than others. One participant commented that, “Mechanical and electrical engineers don’t seem to understand CDM as well as civil and structural engineers” (N3, Q8). Another participant remarked, “I mean all I can do is tell you the network of people……and the people who seem to have got it
are civil and structural engineers and the people who seem to be struggling with it still are architects” (N5, Q1).

Another potential cause of this barrier is the level of complexity of projects. Projects have become quite complex with extensive mechanical and electrical systems, specialized structural systems and materials, and designs to optimize energy use. With such complex designs, it is difficult for a designer to be knowledgeable about all aspects of its construction. The following participant comment describes this barrier: “I think going back to when I first got involved in construction you would tend to find that you had a fully designed scheme, from the ground up and you could measure that, every nut, every bolt and you’d actually ... the drawings would show exactly how this thing was going to fit together. Nowadays there are so many specialist packages and packages that haven’t been regularly used, the understanding of how they work and how they fit is not laid with architects” (N3, Q8).

- **Competing priorities:** The literature indicates that one of the barriers to PtD is that construction safety and health is only one design criteria. Cost, quality, aesthetics, schedule, and long-term performance are other common project priorities. Limitations on satisfying all of the criteria together can hamper the implementation of designs that optimize construction safety and health while negatively impacting other criteria. This barrier is also exposed in the focus group transcripts. The following are examples of participant comments on this topic:
  - “Architecture is driven by aesthetics, I’m sorry, it is. CDM is the tail, not the dog...” (N2, Q8).
  - “And it’s all down to pricing and it’s all down to the cost of the project and it’s all down to one lot not telling the other lot what they’re going to do.” (N12, Q8).
  - “And for me in the projects I go on, I have these people who are extremely influential. And their only objective is time and money” (N12, Q8).
  - “Barriers, I’d say inherent speed and efficiency of working” (N14, Q8).
  - “In architecture you quite often find architects having real difficulty imagining how a building is physically put together, because they’re interested in the vision” (N3, Q8).

- **Commercially practicable:** The CDM Regulations require designers take action in their design if the action is considered commercially practicable. If not, there is no obligation for designers to take action beyond documenting and communicating the risk. A question arises as to what is “commercially practicable”—a question which continues to be discussed and argued today. This allowance may cause some new and innovative ideas for improving construction site safety from being implemented if they are identified as initially cost
inefficient. While the allowance is warranted so as not to require the designer to do everything they can think of regardless of cost, it can also hold back those designs that might ultimately reduce injuries and fatalities. Comments from the focus group participants on this barrier include the following:

- “Reasonably practical is a problem then in that sense? Well not a problem but I think it gives you a tool to discuss all aspects of health and safety against. So if it’s......if you can achieve that health and safety aspect at a reasonable cost and inconvenience then you know it’s quite easy to move on and close issues. But if it’s going to be ridiculously expensive and very, very complicated and delay the project I think quite quickly you’ll say right well this is a risk we’re going to have to manage some other way” (N3, Q8).
- “Health and safety legislation is underpinned for the most part by this concept of reasonable practicability and there is no book that’s going to give you the answer” (N4, Q8).

It should be noted that the question of commercial practicability has been addressed in the UK courts. The historical standard for reasonable practicability came from a 1949 decision (Edwards v. National Coal Board) in which it is stated: “a computation must be made by the owner in which the quantum of risk is placed on the one scale and the sacrifice involved in the measures necessary for averting the risk...is placed on the other and if there is a gross disproportion between them – the risk being insignificant in relation the sacrifice – the defendants discharge the onus on them.” From this statement comes the opinion that a particular action is reasonably practicable if the risk is not grossly disproportionate to the cost. Following this decision, the question of what is “disproportionate” and how to measure it, specifically in regards to injury incidents, has been debated and described as follows: “the test of what is reasonably practicable is not simply what is practicable as a matter of engineering but depends on consideration in light of the whole circumstances at the time of the accident, whether the time, trouble and expense of the precautions suggested are or are not disproportionate to the risks involved...” (Marshall v. Gotham, 1954). More recently, the courts have included the requirement of foreseeability in the decision of reasonable practicality. That is, determining whether reasonably practicable measures were taken must also consider the ability to foresee the associated risks. This opinion is expressed in the Court of Appeal decision in the 2011 Tangerine Confectionary and R v. Veolia cases as follows: “We note that this defence [reasonable practicability] does not impose on an employer the duty to take every feasible precaution, or even every practicable one; it imposes a duty to take every reasonably practicable one. What is reasonably practicable no doubt depends on all the circumstances of the case, including principally the degree of foreseeable risk of injury, the gravity of injury if it occurs, and the implications of suggested methods of avoiding it.” Therefore, the determination of whether it is reasonably practicable is determined in light of the many impacting factors on a case-by-case basis.
For comparison to the UK definition, New Zealand prescribes that “all practical steps” be taken to ensure worker safety. New Zealand subsequently defines “all practical steps” as (Department of Labour 2012):

“All practical steps means all steps to achieve the result that are reasonably practicable to take having regards to:

(a) The nature and severity of the harm that may be suffered if the result is not achieved;
(b) The current state of knowledge about the likelihood that harm of the nature and severity will be suffered if the result is not achieved;
(c) The current state of knowledge about harm of that nature;
(d) The current state of knowledge about the means available to achieve the result; and
(e) The availability and cost of each of these means.”

- **Design and construction industry culture**: The culture of the design and construction industry is perhaps difficult to define and describe, but plays a significant role in the acceptance and implementation of PtD. In addition, the cultures of the design community, the construction community, and the regulatory community play a role in how each regards and addresses construction safety. Similarly, the culture within each individual company, and that which gets established on a project team, affect PtD.

Two aspects of the culture within the design and construction industry are commonly noted when discussing barriers to PtD. The first is the tendency of the constructor to have a “can do” attitude when it comes to performing the work and solving problems. Regardless of the perils that may exist in completing the work, the constructor often suggests that it can accomplish the work safely, on time, and under budget. The constructor is always willing to find a way to complete the task, even if it involves utilizing safety management practices that are lowest on the hierarchy of controls. As a result, constructors tend to not feel the need to design out the hazards, and the rest of the project team allows the constructor to proceed with the work without striving to eliminate the hazards first through the design. This issue was raised in the focus groups periodically, and expressed as follows:

- “There’s still a problem with the cultural issue of contractors that they still have a “can do” attitude, whatever happens they will still try and do it. That’s a cultural issue which I think it’s gradually changing, but we’ve still got a long way to go on that” (N3, Q8).

The second aspect of industry culture that is raised periodically is in regards to the separation of the fields of design and construction. Even though
architect/engineering firms come together with construction firms to design and build projects, there is often still a separation. There is often an “us and them” attitude. Such an attitude can inhibit collaboration in regards to construction safety. PtD requires construction expertise during design. If constructors are not willing to share that expertise, or designers are not willing to accommodate the constructor’s requests for safer designs, then PtD suffers. This cultural issue came up in the focus groups:
  o “The designer does the designs and when you ask him about how to build the designs he says that’s not my problem, that’s the construction company’s problem. That attitude has got to change” (N6, Q8).
  o “Still a lot of ‘Well it’s the contractor, he can deal with that’ on the site” (N12, Q8).

The focus groups also revealed a culture of apathy that can hinder exploring ways to improve safety through the design. If none of the project team members feel strongly about making improvements or changes, nothing may happen. Comments which expose this issue as a barrier were as follows:
  o “If you have a designer who may not be particularly switched on or they know that if there is an issue, it’s going to upset the client or whatever other agenda there is behind the scenes, this is where it doesn’t work” (N4, Q8).
  o “Where we note the residual risks, the only problem with that was that nobody really read it, and it was just repetitive. You end up with repetitive stuff which sometimes you would hide the really important stuff...’yes there’s a live load underneath what you’re building’” (N9, Q8).
  o “The contractor can do whatever way he or she wants provided that he considers the health and safety risks with that method and he comes up with acceptable solutions to manage these risks” (N4, Q3).

- **Education and training:** As noted previously, designer education and training is an important aspect of PtD. A lack of sufficient education and training related to understanding construction means and methods, recognizing safety hazards on construction sites, and how to design out safety hazards, prevents designers from being engaged in the PtD process. The need for architects and engineers to have education and training on these topics is recognized within the UK communities. This need is highlighted in the following comments from the focus groups:
  o “Well I can tell you what doesn’t work is when you [the designer] don’t have a construction industry background” (N4, Q8).
  o “What about just once you hire the architect, at that point saying architect, you will play this role initially until we hire the CDMC. They haven’t got the knowledge. They haven’t got the health and safety” (N13, Q1).
The problem of not having sufficient education and training is a result of perhaps different industry factors. The factors highlighted in the focus groups are as follows:

- “I think actually the HSE is not very good at inspecting designers, they [HSE] don’t really understand the design process that well” (N4, Q8).
- “The HSE who were the main body bringing in this new legislation, were very remote and very disconnected with the rest of the industry. And really up until 2000, the HSE were not engaged in any real sense with the rest of the industry” (N8, Q8).
- “Part of the problem starts in academia really. It’s the training background of architects and designers and there doesn’t seem to be enough or any emphasis on the buildability” (N6, Q8).
- “I think one of the big problems the designers face these days is that new graduates, younger engineers do not get time on the site to see the construction in practice and find out about buildability” (N6, Q8).

It should be noted that there are a variety of resources available within the UK, including some published by the HSE, which provide information about the CDM Regulations and suggested practices in regards to PtD and fulfilling the requirements described in the CDM Regulations. Also, some universities have responded by incorporating content related to the CDM Regulations, as well as construction safety in general, in their curricula.

- **Risk threshold:** Recognizing the need to act to address safety hazards is in part dependent on a person’s threshold for acceptable risk. Depending on the situation at hand, one person may be accepting of more risk than another person. If a designer, for example, has a higher tolerance for risk, they may not be inclined to see the need to design out the hazard. Similarly, a constructor with a high tolerance for risk may feel it is sufficient to utilize personal protective equipment to protect their workers as opposed to designing out the hazard. The following comments from the focus groups address this barrier to implementing PtD:
  - “You know somebody who’s been around for 30 or 40 years is going to have a very different view of what risks are when they walk into a room than somebody who’s been around for 10 years. Meanwhile they’re still expected to fill in these hazard risk registers” (N4, Q8).
  - “Comfort level well below minimum safety level required [was the reason for action]” (NS, Q1).

Creating change in an industry such that alternatives higher on the hierarchy of controls are selected perhaps requires a change in the project team’s risk threshold. This can be done through a variety of risk mitigation measures, such as education about the hazards and risk of construction, and the addition of fines/penalties if a specified level of risk is not achieved.
The issue of professional liability was identified as an issue of concern by the focus group participants. However, as long as the designers fulfilled their role and responsibilities under the Regulations, most participants felt there was minimal exposure to liability related to worker injuries and fatalities. Since the Regulation’s inception, legal proceedings have primarily centered on the failure of an owner/client to appoint a party responsible for health and safety assessment (a CDM Coordinator in the 2007 Regulations). In regards to designer liability, one case led to the prosecution of an architect who was fined following the death of a worker in January 2005. In the case, the worker died after falling during work on an air conditioning unit which was built on a platform accessed by a fixed ladder near the edge of a flat roof. As reported, the deceased worker fell from the edge of the roof while gaining access to the mechanical unit. The roof was designed with only a low parapet which did not afford suitable edge protection, and the permanent ladder access was positioned very close to the edge of the roof. The designer pled guilty to breaching Regulations 13 and 14 of the 1994 CDM Regulations by failing both as a designer and a planning supervisor. The poor design and positioning of the access arrangements in this case was a significant contributory factor to the fatality.

Question 9: What capabilities, resources, and/or training are needed by architects and engineers in order to address construction worker health and safety in a design?

As mentioned above, effective implementation of PtD requires not only designer involvement, but also designer knowledge of construction means and methods, safety hazards typically encountered on construction sites, and applicable design alternatives that lead to improved safety. “And that means that you [the designer] has to know your job as a designer well enough and how he [the constructor] erects your design” (N4, Q9). Such needs are gained through education and training, or by collaboration with construction personnel. Utilizing construction firms to support PtD efforts is a common practice. For example, one focus group participant stated, “So if I identify a risk which I can’t think of how to work it out myself as a designer, I will pull in the contractor to talk about it or a CDM Coordinator or somebody who understands the issue better” (N3, Q9).

The construction expertise must additionally be brought in early enough in the design phase such that the advice can make a difference. “The best improvements in design have been through early contractor involvement” (N6, Q9). If not received early enough, there may be limited opportunity to incorporate the design suggestions without significant re-design efforts. If involvement of a construction firm is not available, “the Senior Coordinator is the one who should be able to give you the practical buildability of the office, so that the designers can be notified if necessary to make them more buildable” (N5, Q9). Others can play a role also if they have the necessary expertise and motivation: “And those who are good site managers and have got a firm grasp of what
health and safety requirements are, are realistically excellent and run a very good site” (N12, Q9).

Part of excelling at PtD is simply an inquisitive mind and motivation to innovate or “find a better way to do it”. It involves continually questioning the design. One focus group participant described it as pausing during the design and saying, “Okay wait a moment, how am I going to build this and then the whole thinking process starts” (N4, Q9). As part of this thinking process, there needs to be an understanding of the level of risk associated with the design. “In risk assessment, actually understanding when something is really low, medium, or high, that’s one of the things when you’re looking at trying to help design risk assessment processes” (N4, Q9).

Along with training, continued awareness and updating is beneficial. This is commonly achieved through on-line resources which can provide up-to-date information and push PtD knowledge to the appropriate respondents. At one company represented in the focus groups, “when everybody turns on their Internet, the first page that they come to is the page where they know there’s a lot of links and it includes a link to health and safety” (N3, Q9).

Lastly, the focus group participants tended to highlight a need for collaboration. The ability to collaborate well enables the exposing of potential hazards and development of effective design fixes. “And you think what is going on here is our basic training – not about safety. Actually, it’s just good design. It’s good design coordination. It’s working as a team, it’s the architect talking to his M&E guys and saying ‘how much space do you need?’” (N12, Q8). The collaboration involves the project owner/client as well. Typically if the owner is involved in the PtD process and pushes PtD as part of the project development process, it will occur. “So if the contractor wants to do a good job in managing safety on site, he can do that as long as he’s prepared to put whatever resource into it. It won’t drive anything up, it won’t drive it down. If the designer wants to do it, he can build it in, but if the contractor’s not interested, nothing happens. If the client wants it right at the top, and they’re serious about it, they’ll force absolutely everybody else in the chain to do it” (N5, Q9).

**Question 10: What are you aware of that has had, for you and your company, a significant impact on health and safety performance, culture, and practice in construction since 1994?**

The implementation of the CDM Regulations in the UK is not the only new program, legislation, or change in the design and construction process that has impacted health and safety performance in the construction industry. Like in the US, the industry and companies are regularly trying new technologies and processes with the hope of improving. In some cases the change is highly positive and leads to innovation in the industry. The focus group participants recognize that the impact has come to a great extent from a change in the perspective of health and safety in the workplace amongst the industry practitioners. “I think there’s been more of a drive to reduce accidents in
the industry and it’s not just been CDM-driven. It’s been driven by the general perception of safety in the industry” (N13, Q7). It is recognized that the change has also come due to the perspective that the project team now has in regards to the integration of the project development process with safety and health interests. For example, greater project team collaboration is frequently recognized as a change that has had a significant impact. “We’ve changed from a quality assurance (QA) system into a combined management system, so it’s not just quality but it’s also health, safety, and environment” (N3, Q10). This change in collaboration has extended to the owner/client as well. “The benefit we’ve seen is that we’ve forged close relationships with the client’s side of the team that brings its own benefits because you discuss the problems early on and you resolve them” (N2, Q10).

In regards to the contractor specifically, there is recognition that one of the impacts is related to a changed perspective on responsibility. Contractors have become more aware and accepting of their responsibilities, especially in regards to managing risk for all construction site workers and subcontractors. “Prior to 1994 was how contractors were perceived and how they operated, where you had a principal contractor, he tried as much as possible to detach himself from subcontractors working for him and made it their responsibility on the construction and all the elements that go around it. CDM changed that to the fact of, you are the principal contractor, and you are therefore responsible. That gave the grounds for a change in standards and actions by the contractor” (N2, Q10).

For designers, there has been change in both design processes and designer perspective. As an example, one participant added, “In all of our design procedures that you apply to structural design or architectural design, always include the prompt for health and safety” (N3, Q10). Another participant indicated, “So health and safety immediately comes into the conversation. You know it’s one of the decision factors that will be part of resolving that problem, whatever the problem is” (N3, Q5). The following quotes summarize additional changes that have impacted health and safety, mainly as a result of the CDM Regulations:

- “I don’t know if you can quote it as a percentage but it’s certainly a big influence on everything because it does impact. It impacts on manual handling regulations and, as you say, early planning preparation. It impacts work at height regulations and PPE regulations because a lot of these on-site things can be done in the factory where PPE might not even be needed because it’s done by a machine. So I think CDM was the backbone if you like of the regulations and all the others hang off it” (N11, Q10).
- “The sheer process of CDM enforces a thought process before you get out on the site where the designers have to think through how it’s going to be built, method, means whatever, and it’s an awful lot easier to change a design when you’re still in the office on paper or on screen than when you’ve got plant up your back on site. This thought process before means that they expand......it’s
not just on health and safety, it goes into various areas and has various benefits because by thinking through this particular point here you might find it cheaper or faster or a better way of doing something on the site. And I think that’s one of the major benefits of CDM legislation itself” (N4, Q1).

**Question 11: Can you tell me about any types of innovative processes and products, both design and construction, that have been developed as a result of the PtD effort?**

Efforts to address safety in the design of a project commonly involve conducting design and constructability reviews to identify potential hazards and ways to mitigate the hazards. As a result of this process, innovative ideas may arise that will eliminate the hazard on the project and also be applicable to other projects. The positive impacts that PtD can have on innovation are recognized as one of the benefits of PtD (For example, see: Behm et al. 2011; and Behm and Culvenor 2011). Based on an insightful model connecting creative potential with effort (shown in Figure 8), Behm et al. (2011) propose that safe design can be a source for construction innovation, is highly underutilized as a driver of innovation, and “can be an intersection of invention and insight, leading to the creation of social and economic value.”

![Figure 8. Relationship between hierarchy of control use and creative potential (Culvenor 2006)](image)

The focus group respondents recognized that innovative processes and products have been developed as a result of PtD efforts. These innovations have related to the physical
design of facilities, the design process and tools, communication of safety hazards, and safety organizations. For example, in response to the CDM Regulations, most companies now utilize a risk register or other tool to record and track design risks and their mitigation. Some unique design changes are also related to the specific construction sequence planned for the project. Below are descriptions of the other innovations identified by the focus group respondents:

- **Design features:**
  - “They’ve come up with ground anchors, corkscrew anchors which now, if the ground is suitable, we just throw into the ground, we don’t dig a hole we actually leave that in-situ. It’s grouted in. We now put the structure over. That’s a lot safer” (N2, Q11).
  - “What’s the significant issue, you know the heavy blocks, it was a significant issue a few years ago, but we’ve moved on, it’s an insignificant issue now because we’ve designed them out, they’re not specified anymore, you can’t get a hold of them generally” (N2, Q11).
  - “When you are designing, consider the location of vertical ducts and try and put them not in the middle. Try and put them at the perimeter” (N8, Q11).
  - “Some of the things we’ve done in terms of module mechanical and electrical systems coming in, it’s just reduced a lot of manual handling. It’s been brought in – manufactured offsite and brought in, where prior to that, that would never have happened, I don’t think” (N13, Q11).
  - “There were roof lights on the building which we moved simply more close together. And we put a sort of parapet wall around, so it didn’t mean that people could just sort of – when they were cleaning, sort of walk into them and things like that” (N14, Q11).
  - “Instead of having bars sticking out of your wall down to the floor, have a u-bar sticking out. Because the problem with the bar sticking out and you’ve got these safety caps on, because the safety caps fall off” (N9, Q11).
  - “The other example I can think of is a lot more buildings are getting parapets round the sides so you wouldn’t go up man-bridge systems where you just go up a cable and someone will connect onto them. Now they’re saying that if you’ve got to get up to the roof for maintenance reasons they don’t want someone to have to go and clip onto a system which might fail, they want a solid parapet at the edge” (N11, Q11).
  - “There are things like building self-cleaning glass and all that sort of thing. It’s innovations that may or may not work in reality but (the builder’s gone into that) but if you make it self-cleaning you don’t need to get people up there quite so often to clean it” (N3, Q11).
• Design documents:
  o “We came up with the idea of hazard symbols on drawings, and that was something we looked at in terms of asbestos” (N8, Q11).
  o “Most structural engineers in their rebar drawings, put a little note telling the contractor how heavy rebar is. For a 25 mm bar, a length of 23 m or something is more than 20 kg” (N12, Q11).

• Design process and tools:
  o “We’ve got a fantastic intranet, health and safety site ... which is divided into three areas, which is safety in the office ... which is straightforward and there’s nothing to talk about, safety on site, and safety in design” (N3, Q11).
  o “A number of networks where our people basically exchange all topics ... you know if you have a problem in design you tap into the system and someone else from New York will help you out and stuff like that. We’ve changed from a QA system into a combined management system, so it’s not just quality but it’s also health and safety environment” (N3, Q11).
  o “Subs are brought in very early now, all the way down the line they’re brought in very, very early, sometimes a couple of months before they’re due to start to discuss it and it works very well. It’s not necessarily partnering because you’re not always partnering all the time” (N6, Q11).
  o “That’s right, here we’ve got what we call red, amber, green lists ... and that’s where the HSE has suggested ... the red you eliminate, asbestos on site, scabbling piles, minimise dust creation, hazardous sprays on site. The amber, avoid if you can, heavy blocks, repetitive leaks, as suggested in masonry you can use them whilst they’re not repetitively, heavy bar panels, chasing services, solvent use internally, unprotected roof lights. And green, they’re encouraging good practices, successful services, lifting points of heavy units, half size plasterboard as we’ve talked about, off site symmetry, there’s some and they can very easily go into specifications and just be approved or not” (N2, Q11).
  o “And the system is a tool bar system that is in the CAD build up, the systems to build and so we have the same, these are the same signs, not the same as US signs, European signs, safety signs, so that’s mandatory requires it, that’s prohibited and so forth and so on, so using those signs which are common and understood, should be understood by anybody in Europe, then whatever your discipline if you see that sign it represents something, does that make sense” (N2, Q11).

• Revised designs to accommodate construction sequence:
  o “One of the most recent things that we have done which we’ve taken really from Terminal 5 is on one of our projects we’ve done the roof at ground level and we’ve sort of jacked it up” (N13, Q11).
o “It’s an ISOH produced product but it got a health and safety award the same year we did actually. But it talks about how they have sockets in the floor as they’re building the staircase to put a temporary scaffold in until the main handrail goes in there, so they can use it during construction” (N8, Q11).

• Safety organizations:
  o “What we've put together now is a sort of retail client safety group. So I'm now - because I’ve got together now, my old counterpart in Tescos, Waitrose, so we all are now meeting. Our first meeting’s in two weeks' time. So this is something that I've developed in the last three months so we can all hopefully share each other's learning and best practice” (N13, Q10).

In some cases an innovative design intended to improve safety may negatively impact other aspects of the work. As a result, the design alternative may not be selected in favor of other project priorities. One example given by a focus group participant is wire mesh in floor openings. The mesh is cast into the floor slab as reinforcing for the slab, and continues across the floor openings to provide protection against workers falling through the openings. The mesh is then cut out when the mechanical and electrical services are installed through the openings. The focus group participant indicated that, “We identified that on a recent project and the contractor’s answer was no, we would far rather build in edge protection around this because you have got to end up cutting this wire mesh as well, it’s a damn nuisance to the services engineers, services contractors as well and it gets in the way and then it leaves jagged edges and the guys injure themselves, so there is a contrary argument to that one. In the end they didn’t put it in, they protected it, and so it’s another way of protecting it” (N2, Q11).

Question 12: As an [engineer, etc.], how has your perception of health and safety changed since the introduction of PtD?

Designer collaboration with the constructor to improve health and safety on the construction site will undoubtedly expose designers to the health and safety field. By doing so, it is expected that designers would be more understanding of the needs and difficulties related to site safety. Awareness should result in a change in perception, from separation and indifference to supportive and contributing partner. On the construction side, personnel are typically quite involved in ensuring jobsite safety and feel it is the highest priority. As a result, it is not expected that PtD will change their perception of health and safety.

Overall, the focus group participants were quite knowledgeable about the CDM Regulations and their impacts on their firms and the industry. Designer participants commonly viewed addressing construction safety as an imperative. This is especially true of those who have most recently entered the A/E/C industry (“Well you will actually
find that new graduates coming out, people into the industry, will have that awareness about health and safety and CDM Regulations” [N3, Q13]. There is recognition that health and safety are important to the overall success of the project. This viewpoint has affected the culture within the design community. The change can be summed up by one of the focus group participants as follows:

“I mean, in my opinion, what the CDM Regulations have done positively is that it caused a cultural change in the way the structural engineer thinks now, because he has to, he really does have to, or she has to, think about health and safety; it’s almost primary you know in your – the two are in hand-in-hand, you do the day job of designing connections, designing frames, but with it is your obligations to the CDM Regulations, so it’s – it is a positive thing, it really is. Not only does it save lives, it stops you from going to jail as well. It does.” (N11, Q10).

Much of the change has come in regards to the responsibility for health and safety. Designers recognize that they have a responsibility as part of the project team. Rather than being an outsider when discussing site safety, they are a participant. When evaluating an unsafe design, “the designer has to claim responsibility for that and flag it up as a problem. Have some understanding about how it’s going to get in and how it’s going to get replaced later” (N8, Q12).

Similarly, there is recognition that PtD requires responsibility for control of a design and comprehensive design. Considering safety and health in the design after the design is complete leaves safety and health as an add-on to the design. Those who understand PtD recognize that this should not be the case. “Should health and safety be designing your buildings or should you be designing buildings and getting your health and safety rationales to fit into it. If it then doesn’t fit, if you then modify your building, you don’t design your building based on health and safety. That’s what the message is” (N8, Q12).

In some regards, however, the perception of how designers should act within the PtD concept is not present. PtD aims to move hazard mitigation up the hierarchy of controls to eliminate the hazard before the start of construction. Under the CDM Regulations, the hazard may be flagged and noted to alert the constructor without the designer altering the design to mitigate the hazard. If this is perceived as the common and accepted practice, designer perception of health and safety has not changed. One of the focus group participants revealed this attitude as follows:

“To me, that’s a contractor risk really. I mean, I still put it down on my risk assessment – hazard assessments because I’m covering my backside. But every time I look at it I’m thinking, well really, what am I doing? It’s a hole in the floor and a contractor is just going to put a guard rail round it and if he doesn’t – I would turn round to a contractor, and I think it’s quite legitimate to say, right, you’ve built buildings before because otherwise you wouldn’t be on the team, you know about holes in slabs, therefore I’m not going to deal with any of this
stuff because you should be competent. You’ve signed a piece of paper to say you are” (N8, Q12).

Question 13: What are the industry attitudes to health and safety now as compared to before the introduction of the CDM Regulations? (In terms of organizational and professional culture)

Prevention through design is a hazard mitigation tool that involves all of the project team members. As such, its implementation will have an impact across the A/E/C industry. This impact is expected not only in the way projects are designed or in the design features, but also in the actions and attitudes of the industry practitioners. It is expected that organizational and professional culture will change, primarily on the design side, with comprehensive PtD implementation. In some cases, this is true. “You see now that health and safety generally people will say it should be agenda item number one in all meetings and most of the time it is. So health and safety immediately comes into the conversation. You know it’s one of the decision factors that will be part of resolving that problem whatever the problem is” (N3, Q13). In regards to whether there has been a change in attitude towards health and safety, another focus group participant affirmed the change by stating, “I would say yes because the health and safety culture is so strong now that if you can argue that you’re taking a risk away then there’s very few people who will argue with that” (N3, Q13).

“Clearly for decades people have been talking about the issues in isolated pockets perhaps but I think it’s coming more to the fore” (N4, Q13). However, it is recognized that the acceptance of PtD and the change in attitude is not all-inclusive. In some sectors of the industry, the culture remains as it was prior to the implementation of the CDM Regulations. One focus group participant summarized the sporadic acceptance as follows:

“You’ve got the people who are fully signed up to it, which I think are the people sitting in the room in front of you, and who are trying to do their best. You’ve got the people who don’t understand, arguably probably might never understand, and they’re saying, I’m a business man and I build buildings or design buildings and really what’s this got to do with me, I’m nobody. And you’ve got the people who sit in the middle and then you’ve got a few groups outside that I would characterize as I did earlier as zealots, in so far as they’re interested in health and safety for health and safety’s sake” (N8, Q13).

The change in attitude toward health and safety may truly be a result of the CDM Regulations or the health and safety “zealots”. The change may also be due to other factors, such as for financial gain. Making a business case for PtD is expected to be important in the US. The focus group participants did recognize this as a reason for change. For example, one focus group participant stated, “The difference that’s now come out of the new regulations is that designers are seeing the benefits in some respect and the teaching that I give is not saying, the law says you must, it actually says
what are the benefits of the buildability angle and there are, if we really boil it down, some great significant savings by following the CDM principles” (N2, Q10). Another focus group member concurred, indicating that more recognition of the financial benefits is needed: “This gives us more opportunity to think about cost savings for our client, better design for our client, more efficient design for our client, and oh by the way, there happens to be health prevention through design as well, as an end result. So I think there isn’t enough acceptance or awareness of that opportunity in designers, clients, contractors thinking to achieve that sort of cultural gist” (N5, Q13).

Some focus group members indicated a difference between what is done in the design office and what actually takes place in the field. For example, one focus group participant felt that, “One of the downsides of CDM has been you can go out on site and you can see a dislocation between what’s in the file and what the guys are actually doing” (N6, Q10). Designers may go to great lengths to accommodate safe construction practices through their design, but if the contractor’s attitude and culture is to neglect the safety measures, the overall result may be not be as initially intended.

*Question 14: Do you see PtD more as a fundamental ‘moral’ imperative or rather as a requirement from legislation, and why? (Or, would you still practice PtD if the CDM Regulations had never existed, and why?)*

One dimension of implementing the PtD process is that designers must have a desire to do so. This desire can be through external or internal motivation. Some examples of external motivation are legislation dictating implementation, financial return, and increased market share. Internal motivation is not as easy to quantify and includes, among other factors, a designer feeling that he/she has a duty or moral obligation to design for construction safety. The focus group interviews attempted to determine if those involved in PtD are internally motivated by a moral obligation in addition to being externally motivated through the CDM Regulations.

Overall, those participating in the focus groups recognize an obligation to put safety first, regardless of whose safety is being considered. This is commonly expressed within construction firms in which the slogan “Safety First” is often repeated. On the design side, codes of ethics commonly communicate the importance of safety by indicating that the safety, health, and welfare of the public is paramount (e.g., ASCE Code of Ethics, [http://www.asce.org/Leadership-and-Management/Ethics/Code-of-Ethics/](http://www.asce.org/Leadership-and-Management/Ethics/Code-of-Ethics/)). One focus group participant expressed this belief as follows: “Personally, me, I have a moral obligation to make sure the people from my firm and other people are safe. The CDM Regulations happen to be there enforcing that but it is ... I ought to be doing it because it’s the right thing to be doing” (N11, Q14).

The Regulations, if not fulfilled, carry a threat of prosecution. This is an external motivation that could be significant. However, if the moral obligation is present, the external motivation may not be needed, or may be inconsequential. This position was
presented by one respondent who stated, “[In] environment and safety you get those who do it morally, those who do it because it’s the way they’ve been brought up, those who do it because they’re told they’ve got to do it. It’s the same across … I don’t think that’s going to change with the legislation. The legislation and the risk of getting prosecuted are so remote” (N6, Q14).

Some of the focus group participants believe that the CDM Regulations have changed the industry’s viewpoint towards safety. That is, since the implementation of the CDM Regulation, people have changed and now feel morally obligated to consider safety in their design roles. This obligation is recognized in addition to the external motivation provided by the Regulations. For example, “Whereas now I think that the industry is much more mature in taking it on as a moral responsibility as well as a liability and a paper exercise” (N14, Q13). The benefit of implementing PtD is also recognized as going beyond just meeting the legislative requirement and fulfilling a moral obligation. “It’s interesting…in the end that this safe by design concept works for the UK because legislatively it has to, but they’ve [a UK company] actually said it makes damn good sense and they’ve just rolled it out globally” (N3, Q10).

Other focus group participants are not as convinced that the industry now feels it to be a moral obligation. This is suggested in responses that PtD is solely implemented in order to meet the CDM Regulations, abide by instructions from clients or superiors, or there is a monetary benefit. The following selected comments suggest this case:

- “I think the legislation adds some weight to it and makes us go a little bit further. Without it why would designers want to do more work for no benefit for them? Why would clients want to have the illusion of paying more?” (N6, Q10).
- “I think in the absence of a legal driver, there is always this balance that a designer would strike in between economy and time spent on design” (N4, Q14).
- “I would say that the phrase I get from clients and architects a lot of the time is what can I get away with? So if the legislation wasn’t there they would try and get away with as little as possible” (N8, Q14).
- “We've given somebody key points of guiding them. They look at those key points and say 'tick, done that, tick, done that, tick, done that'. We don't think outside the box again, we're back to another tick list which we rigorously just tick off. So they've picked it up, ticked the box, done. Why have they done it? Because somebody has told them they need to do it” (N12, Q14).
- “I think there's a degree of some would definitely adopt it, because knowing some of the people I work with, they personally, professionally, morally, would go down that route. I think if it wasn't there and there was no requirement, it wouldn't get mentioned. If there was no CDM to support it, if there were no design issues to support it, other than a select few, it wouldn't happen” (N12, Q14).
• “No. I don’t think anybody would be doing anything without the Regulations. Well sorry, we’d just sort of be going along as we always did and it’s brought – it’s needed the Regulations to force us into doing something. I mean when before CDM 94 or whatever it – I don’t think health and safety was mentioned on any of my projects. Whereas now it’s on all – every single” (N14, Q14).

Some of the focus group participants recognize that the motivation for some companies is simply to not project a negative image with regards to safety. For example, one focus group participant stated, “There is a bit of self-interest in this as well because these bigger companies don't want to be seen to be profiting on the fact that their infrastructure is built on death trap construction” (N5, Q14). Public perception, and the views of clients, is of great concern to many companies. Being viewed as positively working towards safe and healthy worksites is a benefit for marketing purposes.

Some focus group participants argued that the motivation is still based on cost and the financial impacts of implementing PtD. Competing priorities (cost, schedule, quality, safety, etc.) often carry performance targets on projects, with cost often claiming top priority for most situations in which the safety risk is minimal. This is perhaps reflected also in the CDM Regulations in regards to requiring that risk be mitigated through the design if it is commercially practicable. The overriding focus and value placed on cost was described by one focus group participant who stated, “It's not moral, it's cost. If you take petro-chem, it's purely out of the accidents in the US primarily, and Shell is a good example. They've said on-site and okay this is on-site, but 10 years ago the Project Director for a large petro chemical firm, using his terms, would be responsible for bringing the job in on budget” (N7, Q14).

**Question 15: How important is PtD to construction worker health and safety compared to other health and safety programs and processes that are implemented on projects?**

Many different types of worker health and safety programs and processes are implemented on construction projects. These include conducting job hazard analyses (JHAs), safety incentive programs, daily toolbox talks, random drug and alcohol testing, worker safety awareness campaigns, and more. PtD is another means of mitigating safety risk. The safety hierarchy of controls indicates that PtD is the most effective and reliable means to reduce or eliminate risk compared to other safety measures that are lower in the hierarchy. Therefore, it would be expected that PtD in practice might be recognized, through personal experience, injury statistics, or some other means, as being more important to worker safety and health. Distinguishing between the variety of safety and health programs in regards to impacts on safety performance is no easy task and may ultimately not be possible.

The focus groups were asked to provide their opinion regarding relative importance based on their experience. However, most of the focus group participants were not able to confidently identify a difference in how PtD compares to other health and safety
programs and processes. One focus group participant remarked that the variety of measures taken by regulatory agencies plays a big role as well. The participant stated, “I think there’s been more of a drive to reduce accidents in the industry and it’s not just been CDM-driven. It’s been driven by the general perception of safety in the industry. And that’s driving it. It’s not specific - I mean one of the things that counter - or counteracted that was at the same time as they introduced CDM and the revised CDM is that they had a big cutback in the funds that the Health and Safety Executive had. So they never had the team to police this new legislation either. And the government reduced the Health and Safety Executive workforce significantly. And if they’d have kept it at the same level, I think it would have had a bigger impact because there would have been more officers on the ground to police it” (N13, Q9).

Identifying and eliminating risks during the design phase prior to construction will result in workers being exposed to fewer hazards during construction. As a result, if the PtD impacts are significant, constructors may not have to implement as many safety measures or may be able to more easily implement safety measures during the construction phase. This is one of the objectives of the PtD concept. When considering this point during focus group discussions, the participants agreed. For example, one focus group participant concurred, stating that, “I suppose it’s a bit of a sliding scale, isn’t it, if you put more into the prevention through design at the beginning … you do less on site” (N11, Q9). However, none of the focus group participants were able to identify if this were truly the case based on their experiences.

It should be noted that one focus group member brought up the point that the need to fulfill the documentation requirements of the CDM Regulations can be a negative. “Part of me worries the Regulations have absorbed valuable resource within designers to do the process and you think that could only have taken time and money from focusing on the design itself” (N12, Q15). Assuming that available design time is fixed or limited, the time and effort taken to prepare the necessary documentation could instead be put into making a better, safer design.

**Question 16: How would you suggest PtD should be further developed in the future?**

The experience that industry practitioners in the UK have with implementing the CDM Regulations provides them with an exposure to PtD that is not present in the US. This exposure can provide a valuable perspective on developing and augmenting the practice of PtD. A variety of suggestions for improving the process, and comments about what makes the process work well, were received in response to this question. A summary of those applicable to the US are provided below:

- Design and construction coordination and integration:
  - “And you think what is going on here in our basic training - not about safety actually, it’s just good design. It's good design coordination. It's
working as a team, it’s the Architect talking to his M&E guys and saying, how much space do you need?” (N12, Q3).
  o “Getting all the different interested parties, understanding each other’s viewpoint and it’s the first time I’ve actually had a chance, opportunity, to actually talk to IOSH and it’s to get that joined-up thinking” (N2, Q16).

- Owner/client involvement:
  o “To me it’s at least 10 years late. If it had started off from OK let’s start with the client and then look at the process, we might have had a better, more comprehensive take up, and then the issue of cost would have also been better understood” (N7, Q12).
  o “One of the things you might do and put more emphasis on, if you were re-launching CDM, is the client responsibility” (N7, Q16).
  o “I feel that the client can do more. Within the organization I’m in now, that’s called a VAF - Value Added Framework. And I think the clients can be doing more at that level and I think they would have far better success in CDM further down the line” (N7, Q16).

- Designer education:
  o “Well I think it’s got to be education, education. Going more and more into the colleges and good examples of how it can work. I think also showing the two ways of how it could work and even if that’s retrospective, because if we don’t look back, they say, you can’t look forward” (N2, Q16).
  o “Having sat here to me it comes across as an education issue really. And it’s all about quality as well. It’s an education issue and it’s a quality issue” (N5, Q16).
  o “I believe there needs to still be some hard and fast rules for designers to get them through education and through continual and professional development to a level that they ought to be at. Education and awareness has got to be fundamental to how we go forward. Because if the message is not put out there in the first place, nobody knows what’s expected of them” (N12, Q16).

- Constructability and contractor involvement:
  o “What is important is that designers stop and think how they are going to build this. And this is something that is important that sort of the younger generation start to have that is built into their training” (N3, Q16)
  o “The best improvements in design have been through early contractor involvement. We’ve found by early contractual involvement and actually helping us design the structure it’s gone much better” (N6, Q16).

- Design risk assessment:
  o “In risk assessment, actually understanding when something is really low, medium, or high. That’s one of the things when you’re looking at trying to help design risk assessment processes” (N4, Q16).

- Supporting tools and information:
Question 17: How would you change your specific role in PtD in order to enhance its effectiveness?

PtD in practice often integrates multiple areas of expertise (design and construction), in different roles, and at various times during the planning and design process. The practices may be effective for some projects, but not others. An efficient PtD process is desired in order to not weigh down the overall planning and design process and not significantly increase cost and time. The focus group participants provided some input on desired roles of each party to efficiently implement PtD.

In some cases, architectural designers feel that the health and safety demands placed on them by the CDM Regulations do not coincide with their area of expertise. They feel that the Regulations are overly burdensome at times, and often not relevant to architectural decision-making processes. This perspective is sometimes reflected in their attempt to persuade owners/clients and contractors to adopt the same viewpoint and therefore allow the designers to abdicate their responsibilities. If such a perspective is expressed, blame is placed on the designers for being negative about health and safety and possibly ignoring their role and responsibilities under the Regulations.

The knowledge and involvement of owner/clients in the design and construction process can vary tremendously. Some owners/clients participate in this role only one
time, while others are actively involved in construction on a regular basis. If the owner/client is very informed on the process, they tend to be very involved in the PtD process and do well in managing the risk. This level of involvement, however, is rare given the demographics of owners/clients. Those owners/clients who are not informed tend to transfer the role and responsibility to others, often to health and safety practitioners.

Contractors have a substantial role in and bear significant responsibility for construction site safety. It is sometimes the case that contractors see the CDM Regulations as a way to offset some of this responsibility. That is, contractors may try to put some of the burden on designers, whether appropriate or not, in order to limit the extent of work that they need to do to keep the construction site free of risks.

A summary of the related responses is provided below:

- **Role of Designers:**
  - “I think they also need to talk to contractors more as well, have actually a sort of dialogue between them so that they understand construction methodology which often, they get a general idea of how a thing will be constructed” (N4, Q17).
  - “I think there is definitely a need for more practicing designers to have a role in undergraduate education” (N9, Q17).
  - “I don’t think from a practical point of view in terms of what we do as designers, we would probably not change anything to be honest” (N9, Q17).
  - “I think that the designers and the architects should have some onsite training” (N13, Q17).

- **Role of CDM Coordinator (or similar participant):**
  - “So you - again we’ve come across this before, if everything was done right, by all competent people there shouldn’t be a CDMC” (N12, Q6).
  - If you want to extremely critical, and again we could talk here for ages, ideally when a proper health and safety culture is established within the design community, you won’t need a CDM Coordinator anyway” (N3, Q17).
  - “And there is no reason in my book why you can’t have the role [CDM Coordinator] being passed between the key professionals as the scheme progresses” (N8, Q17).
  - Eliminating CDM Coordinator role: “I think the big benefit we would see is we wouldn’t have CDM Coordinators asking us to produce extensive risk assessments” (N9, Q17).

- **Project team make-up and integration:**
  - “They’ve got to get the structure right, right from the start. Get the right people in right at the start, with the right training through the courses with health and safety as part of design” (N13, Q17).
o “I also now do that with local authorities and say that yes, you can be the local authority and you’ll get the checking fee but you need to come to our meetings. And our meetings are held here, we need to design it with you as opposed to designing it all the way and handing it in at the end of the period. So that could happen with HSE, to get them in early as this safety consultant or whatever, in fact it would help, so” (N12, Q17).

Additional Focus Group Comments and Themes

The focus group meetings allowed for open-ended discussion related to the questions presented above. In addition, the focus group participants brought up, or the conversations led to, other issues important to the PtD concept and process. Below are some additional issues and experiences that came out of the focus group interviews which are of interest to the implementation of the PtD concept.

• A focus on safety later in the life-cycle.
During the focus group sessions, the participants frequently mentioned process safety and process operations safety, and the researchers tried to steer them towards construction and maintenance safety with their responses as indicated in the transcripts. Similarly, when implementing PtD within the CDM Regulations, there is a tendency to drift more towards designing out hazards that occur during use/operation and maintenance of the facility and less on construction safety. This emphasis is consistent with the traditional focus of designers which is on the safety of the end-user rather than the constructor. Construction safety is still more often left up to the contractor to take care of through actions that are lower on the hierarchy of controls. When deciding between multiple alternatives to reduce safety risk, those alternatives that are higher on the hierarchy of controls are not always selected. There needs to be a mindset of designing safety in rather than engineering hazards out after the design is complete. Designing for safety needs to be inculcated into the architect/engineer discipline and mindset. The following are comments that address these issues:

 o “It wasn’t really construction safety that they were thinking about. It was really operational safety – yes, but our own people were going to be operating the plants” (N7, Q2).
 o Health and safety, I don’t think has changed how a building is put up. Personally I don’t think it’s changing what a building ends up as. [What about the maintenance aspects?] Apart from the maintenance aspect. It’s the aesthetics on the outside basically that are working at height has to be incorporated within that, whether you can still get the nettings up or getting up to the light bulbs or whatever else” (N11, Q4).
• **The benefit of working together and communicating.**
The focus group responses indicate that problems with PtD implementation predominantly relate to the separation of the roles of design and construction. The CDM Regulations require communication of risk assessments amongst project team members. Additionally, to conduct risk assessments, designers may need to consult with the contractor to understand the expected hazards. These required actions lead to benefits in terms of reduced safety hazards plus improvements in the overall design and construction process. Integrated project delivery methods (IPD) aim to reap the benefits of such integration of the project team. The focus group participants recognized that the CDM Regulations were simply the catalyst to create communication and integration on projects. The real benefits came from the other subsequent changes as a result of complying with the Regulations. This recognition is reflected in the following focus group participant response:

  o “How they design and pass it onto another department who’s going to build it and then talk to them about what’s good and what’s bad and what needs changing - that’s CDM in a nutshell. Finished. End of story – draw the line. That’s what they’re after, communication between the people who design it and the people who are going to have to put it together” (N11, Q13).

As a result of the integration and communication, safety and health are now spread throughout the project team, not just an add-on provided by the health and safety coordinator. In addition, there is a change in perspective towards construction safety. All of the project team members have construction safety on their mind.

• **A need for changing the designer culture.**
The recognition that more project team integration and communication is perhaps a reflection of the cultures within the design and construction communities. The need to reform the design culture was a periodic topic of discussion in the focus group sessions. A tendency to mediocrity in design was exposed in the focus group responses. Focus group participants generally believed that the designers could play a larger role in working together on safety. The following focus group comments present these issues:

  o “It’s very easy sort of to allow mediocrity of design to take over (N14, Q5).
  o “I suppose as a designer and design manager in my early life, I would find it really difficult to make that measure of what a Planning Supervisor/CDM Coordinator can add because essentially all we’re doing, we are only promoting good design. My mind boggles that we actually need almost legislation to tell us to do it” (N12, Q1).
However, there is also recognition that the burden should not solely be placed on the designer and design culture, and placing blame in such a way is not beneficial to the industry and to worker health and safety. The Designers’ Initiative on Health and Safety (DIOHAS), based on its Habilllis Report and statistics, concluded that “the weight of evidence, to support such assumptions, is less than definitive. Furthermore these conclusions have led to a ‘blame the designer’ culture within the construction industry which has tended to alienate designers rather than engage them. There needs to be a new mutual respect and understanding of CDM issues in construction which puts aside the blame culture and develops integrated cooperative working to the commercial and safety benefit of all.”

Focus group participants recognized that in order to effectively implement PtD, the designers need to be engaged. Just telling the designers to participate, however, is not always the best option. Getting the designers engaged may best be accomplished by showing designers where and how they can participate through their unique role as designers. This involves identifying and providing a framework around what it is that designers can effectively provide in their role.

- **Unclear extent of responsibility for mitigating safety risks.**
  For given hazards present on construction sites there may be multiple ways to mitigate the risk. For example, the design could be revised, or the constructor could revise the construction means and methods. Each of these may require additional resources and time, and additional cost. An understanding of what the expected or preferred limit of PtD is when mitigating risk was not clear amongst the focus group members. That is, how far should a designer go to design out hazards? In some cases, there were discussions about the architect’s perception of the gray area of what is their role and responsibility and what should be the contractor’s role and responsibility. Standard practice in this area has not been universally established while attempts to do so have taken place” (e.g., “Managing Health and Safety in Construction: Construction (Design and Management) Regulations 2007, Approved Code of Practice”).

- **Unclear understanding of ability for designers to impact construction safety.**
  Construction projects and construction sites are often complex by nature. Many factors impact the health and safety of construction workers. As indicated above, the design can have a significant impact on site hazards. Construction practices are extremely important to ensuring worker safety as well. The focus groups exposed a feeling of helplessness amongst the design community when it comes to improving safety on the site, i.e., a “Whatever I do won’t help” feeling. This is based on the belief, and in some cases experience, that regardless of how the project is designed, the constructor will perform the work in an unsafe manner and accidents will occur. Therefore, designers may not be motivated to take
extra steps to change the design if accidents will occur anyway. It is unquestionably clear that in order to improve the safety performance of the construction industry, all project team members must contribute through their role on the project. A team-oriented approach of designer, owner, and constructor is necessary for PtD to be meaningful and successful.

- **Focus on CDM instead of PtD.**
  The focus group conversations often drifted towards the CDM Regulations as opposed to the PtD concept in general. It is evident that many in the industry have difficulty separating PtD from CDM. By implementing the CDM Regulations, there is a tendency to focus on the Regulations, not PtD. In many ways they are inextricably linked. Given the additional paperwork required to meet the CDM documentation requirements, many comments received during the focus group interviews concerned the significant amount of paperwork required by the CDM Regulations and the desire to streamline and reduce the paperwork.

- **Expanding the PtD message beyond the main project team members.**
  The construction industry has changed over the years from primarily site-built structures to prefabrication and modularization where construction involves the installation of assemblies. In addition, much of the design of project components is done by manufacturers of the materials and equipment. As a result, the PtD process needs to filter down through the project supply chain to fabricators and manufacturers of products that will be installed on the site. In addition, to effectively address expected hazards on the site, the PtD message needs to filter down to the field staff.

**On-Line Survey**

The target population for the survey consisted of the following six professional communities within the UK construction industry: architects, design engineers, facility owners/developers (clients), constructors (principal contractors and trade contractors), manufacturers and suppliers, and health and safety consultants. To obtain the desired number of survey participants from the communities (200 participants), the research plan developed for the study targeted the memberships of the following industry associations: Chartered Institute of Building (CIOB), Royal Institute of British Architects (RIBA), Institution of Civil Engineers (ICE), British Safety Council, and Association for Project Safety (APS). In the UK there are other industry associations that a design or construction professional might be affiliated with, depending on the specialization of the individual. Therefore, in order to fully represent the UK design and construction community and to increase the response rate, the following industry associations were added to the study sample: The Institution of Structural Engineers (IStructE), The Institution of Mechanical Engineers (IMechE), Chartered Institution of Building Services Engineers (CIBSE), and Royal Institution of Chartered Surveyors (RICS).
The research plan for contacting the potential participants was to randomly select participants from the association membership directories. Due to data protection and confidentiality requirements, e-mail addresses and contact information are not available from association directories. Therefore, the researchers chose to request participation and disseminate the survey through the association newsletters, on industry association websites, via organizations involved in design and construction, and at in-person forums/events. As a result, it is not possible to determine the exact response rate for the survey as some of the sizes of the populations that received the request for participation are unknown.

To obtain a participation rate of at least 20%, the research plan included sending follow-up e-mails two weeks after the initial participation request. In order to comply with the ethical research requirements and maintain a sufficient response rate, the survey questionnaire is anonymous unless the participant chooses to document his/her personal details. It was not possible to track each individual respondent, unless they provided their personal information (name and e-mail address), and to follow up only with non-respondents. Therefore, general follow-up/reminder e-mails and requests were sent periodically to all possible participants and to all associations.

In addition to engaging the industry associations noted above in the research, requests for participation in the survey were made at the following forums/events:

1. Midlands Construction Forum
2. European Construction Institute
3. Constructing Excellence
4. Construction Confederation
5. Working Well Together
6. Clients’ Construction Group (CCG)
7. Specialist Engineering Contractors’ (SEC) Group
8. National Specialist Contractors’ Council (NSCC)
9. Construction Industry Council (CIC)
10. UK Contractors’ Group (UKCG)
11. Contractors Health and Safety Assessment Scheme (CHAS)
12. National House-Building Council (NHBC)
13. Constructionline
14. IOSH Connect Bulletin
15. CIB Conference

Lastly, personnel contacts of the researchers within each of the following companies were asked to disseminate invitations to participate amongst the personnel within the organization:

1. Scott Wilson Ltd.
2. Loughborough University
3. ClancyDocwra
4. Arup
A survey questionnaire was prepared and placed on-line using the SurveyMonkey tool (see Appendix B for questionnaire). It should be noted that in the survey questions, the term “design for safety” was used instead of “prevention through design” because “design for safety” was felt to be more universally understood in the UK. The link to the survey was included in the request to participate in the survey. Responses to the survey questionnaire were downloaded from the SurveyMonkey website for review and analysis.

A total of 258 responses were received of which 228 contained complete information and were usable for the study. Below is a summary of the responses to each survey question.

**Professional Affiliation:** Almost 90% of the 228 respondents reported that they are affiliated with at least one professional institute. Thirty-six percent of respondents are members of the Institution of Civil Engineers. The next most common affiliations were the Institute of Occupational Safety and Health (30%), Association of Project Safety (11%), Chartered Institute of Building (10%), and Institution of Structural Engineers (8%). Five percent of respondents are members of the Royal Institute of British Architects.

**Respondent Demographics:**

- Employer organization: The majority of respondents work in construction (37.4%) and engineering (30.3%) organizations. The percent of respondents who work in other types
of organizations are as follows: 5.6% in architecture, 5.1% in project management, and 4.5% in health and safety consultation.

- Role on projects: Most of the respondents (24%) classified their current role as a design engineer. Principal contractors and CDM coordinators comprised 21% and 15% of the respondents, respectively. The percent of respondents who participate in other roles on projects as follows: 4.1% as architects, 3.1% as facility owner/developer, 3.1% as subcontractor, and 2.0% as manufacturer/supplier.

- Capabilities of respondent organization: In regards to the capabilities and services provided by the respondent’s organization, the results are as follows:
  - Design engineering (82%)
  - Health and safety consultation (82%)
  - CDM coordination (70%)
  - Architectural design (60%)
  - Principal contractor (56%)
  - Facility owner/developer (41%)
  - Manufacturer/supplier (21%)
  - Subcontractor (31%)

- Size of organization: The pool of respondents work for companies that range significantly in terms of size (number of employees) with the majority working for larger companies. Just over half of the individuals responding work for large organizations (> 1,000 employees). The distribution of respondents based on organization size is as follows: >5,000 employees (32.3%), 1,001-5,000 employees (21.7%), 500-1,000 employees (11.1%), 250-499 employees (8.6%), 100-249 employees (8.6%), 50-99 employees (6.1%), 10-49 employees (7.6%), and 0-9 employees (4.0%).

- Project types: Many different types of projects are designed and constructed by the construction industry. The most common types of projects conducted by the respondents’ organizations are: infrastructure/heavy rail (42%), industrial (28%), and commercial buildings (27%). Approximately 14% of the respondents’ organizations work on residential projects.

- Years of experience: The pool of respondents have a significant amount of experience in design and construction, with individuals having a mean of 15 years of experience in design engineer roles, 11 years of experience in health and safety consultant roles, and 10 years of experience in architect roles. The mean number of years of experience in other roles is as follows: 10 years for principal contractor, 9 years for project manager, 5 years for subcontractor, 4 years for facility owner/developer, and 3 years for manufacturer/supplier.

- Years of experience working with CDM Regulations: Just over half of the respondents (55%) stated that they have more than 11 years of experience working with the CDM Regulations. Approximately one-third of the respondents reported that they have worked with the Regulations since their original introduction in 1994.

Involvement in PtD: Involvement in PtD can include many activities including providing safety hazard information, designing to address safety, and coordinating PtD efforts. Almost one-third
of the respondents reported that their involvement in PtD entailed overseeing and/or coordinating design professionals who implement PtD in their designs. Those whose involvement is as an architect/engineer incorporating safe designs amounted to 23% of the respondents. Approximately 20% of the respondents provide PtD input through design and/or constructability reviews. Interestingly, a reasonable proportion of respondents (14%) reported that they are not regularly involved in PtD efforts on projects.

In regards to the extent to which PtD is part of their everyday activities, a majority of respondents (60%) reported that PtD is integrated throughout their role, but not a specific part of their role. Other individuals stated that PtD is either tagged onto a small part of their role (17%) or that their entire role is specific to PtD (13%).

**PtD resources, tools, and processes:** The tool most commonly reported to be used to address safety in a design on projects is risk assessment pro forma (used by 81% of respondents). Periodic design reviews (65%) and constructability reviews (53%) are also popular. The percent of respondents who use other tools is as follows: 54% use design checklists, 51% use a risk matrix, and 48% use in-house design guides. The least-used tools are: computer program to visualize the design (32%) and on-line design resources (23%).

PtD input comes from a variety of resources. Approximately 57% of the respondents indicate that in-house staff provides PtD input, and 56% indicated that input is provided by constructors. Input from external design consultants is also utilized (35% of respondent organizations).

In regards to publicly available references on PtD, the top three references used are: British Standards (76% of respondents), HSE Guidance – Health and Safety in Construction (74%), and Approved Code of Practice (72%). Guidance from professional institutions is used by 52% of respondents. The references used the least are: Reducing Risks Protecting People, Construction Hazards Assessment Implication Review (CHAIR), and the CONIAC Green Book, each used by less than 15% of the respondents.

Just over half (58%) of the respondents indicated that their company has a formal PtD process that is used on projects. Almost 20% of the respondents did not know if their company has a PtD process in place. The significant percentage of people who do not know if their company has a PtD process suggests that there is a need for more promotion within organizations about such enabling processes. Of those respondents who indicated that their company has a formal PtD process, the types of processes varied from strictly adhered to methods such as risk assessments, design reviews, and hazard and operability studies (HAZOPS) through training for designers.

**Input to PtD:** The survey examined the typical level of input to PtD by the different project team members. The survey found that most respondents see the greatest amount of input coming from the principal contractors, design engineers, and CDM coordinators. The lowest amount of input comes from manufacturers/suppliers, subcontractors, and facility owners, which is not surprising since these parties typically have little to no design input. It was noted in the
responses that the level of input can vary significantly within companies due to different individuals’ attitudes, and that the actual level of input can differ from the ideal level of input. Below are some of the comments provided by the survey respondents in regards to this question:

- CDM is a wonderful concept but is still largely misunderstood or ignored by the building sector and the construction sector to a smaller degree.
- Contractors are the main drivers of PtD as they have to find solutions resulting from the inadequacies of other parties (in particular the designers and CDM coordinators).
- PtD input is dependent upon the experience and attitude of the client to ensure competent and capable persons with adequate resources are involved early as possible.
- Too many design consultants operate a checklist or tick-box option which limits imaginative identification of real hazards and tends to produce misguided mitigation of risk which can be of little real use to the contractor. Many architects are focused on concept and little on buildability.
- Input varies greatly between projects, e.g., if client (i.e., owner/developer) is not significantly involved then the process is usually less thorough and less effective.

**Impact of PtD:** The respondents were asked to provide their opinion of the impact of PtD implementation on various project performance criteria: cost, duration, quality, productivity, and safety. Table 4 provides a summary of the responses. A large number of participants reported that PtD leads to increases in quality, productivity, construction safety and health, and end-user safety and health. About half of the participants reported that PtD leads to less desirable increases in other project characteristics (design cost, total project cost, construction cost), although high numbers of participants also argued that there is no change to these characteristics as a consequence of PtD. The respondents also suggested that no change or an increase occurs in total project cost, construction duration, and design duration as a result of implementing PtD.
Table 4. Perceived Impact of PtD on Project Criteria – On-Line Survey Responses
(% of responses; n = 228)

<table>
<thead>
<tr>
<th>Project Criteria</th>
<th>Decrease</th>
<th>No Change</th>
<th>Increase</th>
<th>I Don’t Know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>3%</td>
<td>43%</td>
<td>48%</td>
<td>6%</td>
</tr>
<tr>
<td>Construction</td>
<td>14%</td>
<td>33%</td>
<td>46%</td>
<td>6%</td>
</tr>
<tr>
<td>Total project</td>
<td>14%</td>
<td>32%</td>
<td>47%</td>
<td>6%</td>
</tr>
<tr>
<td>Duration:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>3%</td>
<td>54%</td>
<td>36%</td>
<td>7%</td>
</tr>
<tr>
<td>Construction</td>
<td>17%</td>
<td>57%</td>
<td>22%</td>
<td>4%</td>
</tr>
<tr>
<td>Total project</td>
<td>11%</td>
<td>59%</td>
<td>25%</td>
<td>5%</td>
</tr>
<tr>
<td>Construction quality</td>
<td>0%</td>
<td>32%</td>
<td>64%</td>
<td>4%</td>
</tr>
<tr>
<td>Construction worker productivity</td>
<td>6%</td>
<td>36%</td>
<td>50%</td>
<td>7%</td>
</tr>
<tr>
<td>Construction worker health and safety</td>
<td>0%</td>
<td>9%</td>
<td>87%</td>
<td>4%</td>
</tr>
<tr>
<td>End-user health and safety</td>
<td>0%</td>
<td>8%</td>
<td>87%</td>
<td>5%</td>
</tr>
<tr>
<td>Personal view of importance of H&amp;S</td>
<td>0%</td>
<td>15%</td>
<td>82%</td>
<td>2%</td>
</tr>
</tbody>
</table>

**Impact of PtD on project team members:** The general consensus of the respondents was that PtD efforts have had a positive or very positive impact on the roles of the different team members on a project, with 66%-88% of respondents indicating a positive impact. The greatest positive impact was to principal contractors (88% of the respondents agreed that PtD efforts have had a very positive or some positive impact on this role). Similarly, 87% of the respondents believe that the design engineer’s role has been impacted, and 85% of the respondents believe that the CDM coordinator’s role has been impacted. Lastly, the survey results reveal that one-third (33%) of the respondents feel that the role of the manufacturer/supplier has been affected.

**Impact of PtD on design and construction of projects:** One survey question asked the respondents to indicate the extent to which PtD efforts have affected the design and the construction of projects (e.g., different design features, modified construction methods, etc.). The overwhelming perception was that PtD efforts have had a positive impact on both design and construction (see Figure 9). Comments received (n=4) suggested that the positive effect is only achieved if the proper effort is put in without “corner-cutting”. Respondents acknowledged that “it has been very difficult to implement change” and that “there is still some way to go” in positively impacting projects through PtD efforts.

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New products and processes developed: When asked to provide examples of innovative processes and products for both design and construction that have been developed to assist with implementing PtD on projects, a wide range of examples were described. Some of the most common included: changes and improvements in tools and construction products, changes in working practices (e.g., behavioral training/safety, better working relationships and communication between designers and constructors), and the use of offsite manufacture and assembly. Below is a categorized list of the other responses:

- Over-riding PtD principle:
  - We work hard on each project to make the construction safer. This involves challenging each element of the project to see if there is a better way of constructing.
  - Design 4 LIFE philosophy throughout the company
- Design risk reduction:
  - Design risk reduction processes that reduce the amount of paperwork and ineffective communication historically produced by designers, and others.
- Hazard and risk registers
- Hazard and risk workshops
- Offsite fabrication
- Specific construction equipment designed:
  - Developed lifting devices/containers to reduce spillages occurring during crane lifts
- Change to safer plant & equipment such as dual lock quick hitches
- Developed hitch pins for dumper truck buckets to reduce human error in use of equipment
- Prefabricated shutters
- Standardization of tank construction – means workers know what to expect
- Use of couplers to provide formed "rebar doorways" in starter reinforcement
- Lifting techniques and equipment as a result of changes in practices leading to redesign of temporary site accommodation

**Integrated design and construction:**
- As a design organization within a construction company, we are constantly in close collaboration with our sister companies in providing design improvements and processes that result in the delivery of safe projects.
- Ensuring the designer and contractor work more closely together from an early stage is essential.
- More alliancing/partnering-type working relationships.
- The use of collaborative workshops between members of the design team and the construction team.

**Integrated management system**

**Communication of residual risks**

**Designer and CDM Coordinator competency training**

**Design processes and procedures:**
- Design Means and Methods document which is a visual guide of how to comply with our Global Minimum Requirements and improve the safety of both construction and operations in the asset (design guides)
- In house Continuous Improvement (CI) events
- Building Information Modeling (BIM)
- Safety, Health, and Environment (SHE) box placed on key drawings to clarify what is being achieved through reviews and design development
- Design option evaluation chart
- Interface matrices on drawings showing who does what
- Changes in the design of timber frames to allow for safer erection
- Careful rebar detailing to reduce sharp ends protruding from cages
- Bent ends of rebar starters to eliminate the need for end caps

**Minimize manual handling:**
- Vacuum lifter to lift and place units
- Use of stick down tactile paving
- Pre-bent rebar
- Rollmats for reinforcement

**Avoid/reduce working at height:**
- Lifting frames to enable lifting steel from the back of vehicles without the use of workers
- Rebar panels formed at ground level and lifted into position
- Column head remote position surveying prisms
o Design of handrail on cranes to prevent drivers from falling from height when carrying out the maintenance of the crane
o Proprietary edge protection systems
o Structural hooks and tubes positioned in the structural steel to facilitate safety nets and edge protection in the initial erection of the building frame

**Barriers to PtD:** When asked to identify the barriers to implementing PtD on projects, the most commonly-reported barriers were:

- Architects/engineers lacking the requisite knowledge and skills to design for construction worker health and safety (identify by almost two-thirds of the respondents)
- Other project objectives being given higher priority by *project owners/clients* (60%)
- Construction means and methods are not known when designs are created (54%)
- Other project objectives being given higher priority by *architects/engineers* (52%)

Table 5 provides a summary of the responses to different barriers. Interestingly, only 15% of the respondents suggested that the effort required to address construction worker health and safety in designs is too great and therefore is a barrier. Based on the barriers cited, there appears to be a need for improvement in the training of designers regarding PtD, earlier planning and communication regarding the construction means and methods, and a change in the culture amongst the project owners/clients as well as the designers to give PtD higher priority on a project.

**Table 5. Barriers to Implementing PtD – On-Line Survey Responses**

<table>
<thead>
<tr>
<th>Barrier</th>
<th>% of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architects/engineers lack the requisite knowledge and skills to design for construction worker health and safety</td>
<td>64.8%</td>
</tr>
<tr>
<td>Other project objectives are given higher priority by <em>project owners/clients</em></td>
<td>60.0%</td>
</tr>
<tr>
<td>Construction means and methods are not known when designs are created</td>
<td>54.3%</td>
</tr>
<tr>
<td>Other project objectives are given higher priority by <em>architects/engineers</em></td>
<td>52.4%</td>
</tr>
<tr>
<td>A lack of time available for architects/engineers to consider construction worker health and safety in their designs</td>
<td>41.4%</td>
</tr>
<tr>
<td>Architects/engineers lack sufficient resources (tools, guidelines, etc.) to address construction worker health and safety in their designs</td>
<td>33.8%</td>
</tr>
<tr>
<td>A lack of financial compensation for architects/engineers to consider construction worker health and safety in their designs</td>
<td>31.9%</td>
</tr>
<tr>
<td>The effort required to address construction worker health and safety in designs is great</td>
<td>15.7%</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>10.5%</td>
</tr>
</tbody>
</table>
Enablers of PtD: The respondents were also asked to describe the factors that facilitate implementing PtD on projects. The factors that were reported to most assist with implementing PtD were:

- Architects/engineers having the required knowledge and skills to design for construction worker health and safety (68% of respondents)
- Adequate time being available for architects/engineers to consider construction worker health and safety in their designs (61%)
- Design for safety being a high priority against other project objectives by project owners/clients (58%) and architects/engineers (57%)
- Construction means and methods being known when designs are created (55%)

Table 6 shows the list of enablers listed along with the percent of respondents who identified the enabler.

<table>
<thead>
<tr>
<th>Enabler</th>
<th>% of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architects/engineers have the required knowledge and skills to design for construction worker health and safety</td>
<td>67.6%</td>
</tr>
<tr>
<td>Adequate time is available for architects/engineers to consider construction worker health and safety in their designs</td>
<td>61.4%</td>
</tr>
<tr>
<td>Design for safety is a high priority against other project objectives by project owners/clients</td>
<td>58.1%</td>
</tr>
<tr>
<td>Design for safety is a high priority against other project objectives by architects/engineers</td>
<td>57.1%</td>
</tr>
<tr>
<td>Construction means and methods are known when designs are created</td>
<td>55.2%</td>
</tr>
<tr>
<td>Architects/engineers are provided with sufficient resources (tools, guidelines, etc.) to address construction worker health and safety in their designs</td>
<td>51.9%</td>
</tr>
<tr>
<td>The effort required to address construction worker health and safety in designs is minimal</td>
<td>24.3%</td>
</tr>
<tr>
<td>There is financial compensation for architects/engineers to consider construction worker health and safety in their designs</td>
<td>23.8%</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>11.0%</td>
</tr>
</tbody>
</table>

Motivation to implement PtD: Motivation for implementing PtD is already provided in the UK in the form of the CDM Regulations. The survey looked for other motivating factors and motivations for improving the implementation of PtD. The main motivating factors for improving the implementation of PtD included: enhanced firm reputation (93% of
respondents), improved construction worker health and safety (92%), improved facility occupant health and safety (85%), and recognition from the owner/client (84%). Motivating factors that were identified, but to the least extent, were: shorter project schedules (47%) and reduced project costs (53%), suggesting that half of the study sample do not consider that PtD significantly affects these performance criteria in a positive way.

**Assistance provided by CDM Regulations:** The survey asked the participants about their feeling regarding whether the CDM Regulations help or hinder the implementation of PtD. Amongst the survey participants, a large majority (85%) reported that the current CDM legislation significantly or at least moderately helps their application of PtD. The main advantage of CDM was perceived to be that it places obligations and responsibility on the owner/client. From a negative perspective, it was suggested that CDM legislation is a minimum standard for contractors and may actually hamper innovation in safety as well as ensure safety of site workers. It was also suggested that designers are still somewhat reluctant to take responsibility/do not fully appreciate CDM, and that regulations are “largely unenforceable” or there is a lack of “policing”. Comments received about the CDM Regulations themselves hindering progress were that they are too ambiguous, subjective in application, and “diluted”.

**Attitude towards CDM Regulations and PtD Concept:** The survey questionnaire requested the participants to indicate they would practice PtD if the CDM Regulations never existed. Most of the study sample (95%) stated that they would still practice PtD if the Regulations had never existed, either in its current form (51%) or in a different way (44%). The following comment illustrates that there were several indications of ongoing professional learning and appreciation for PtD:

> “Having had 5 years of experience working on construction sites I have realized firsthand the importance of incorporating safety or risk mitigating design features as they can significantly reduce risks to workers on site. I found that these features are very frequently overlooked at the design stage, leading to things like, having to dig trenches near the toe of an unstable earth slope, or having buildings designed in irregular often circular shapes which hinder the repetition factor and make it more difficult to construct.”

Overall attitude towards PtD was also addressed in a survey question which asked, “Would you still practice Design for Safety if the CDM Regulations were now abolished?” As might be anticipated given the response to the continuity of practice of PtD, the large majority of respondents (97%) reported that they would still practice PtD if the Regulations were now abolished, with most stating that they would practice PtD as currently practiced (67%) and others suggesting they would practice PtD but modify their current practice (30%).

When asked specifically about their attitude towards the PtD concept, over half of the participants (60%) indicated that PtD is an important aspect of construction health and safety and it should be given greater importance on projects. Approximately one quarter of the study sample (27%) stated that the expected benefits of PtD are worth the effort to implement it.
Less than 10% of the sample suggested that the benefits of PtD are promising but that there are too many barriers for it to be effective.

**Priority of project criteria:** Ensuring construction worker health and safety is one of many priorities on projects. Other project priorities include cost, schedule, quality, productivity, etc. When asked about the priority that their company places on various criteria with respect to their importance on construction projects, construction worker health and safety was consistently rated as the highest priority factor, with 72% of respondents rating it as high priority within their company’s construction projects. Although other criteria were rated highly, none were given the priority of construction worker health and safety:

- Quality of work (rated as high priority within their company’s construction projects by 63% of respondents)
- Project cost (62%)
- Project schedule (55%)
- Facility occupant health and safety (48%)
- Aesthetics (23%)

While construction worker health and safety was rated the highest priority, it should be noted that the focus of the survey on construction health and safety likely influences the participants’ responses to this question. In addition, the competitive nature of the industry means that all of the priorities now have to be considered as high priority, although it was reported that delivery of such aspirations remains variable, and dependent on the knowledge and/or commitment of individuals involved in the project.

**Importance of PtD compared to other health and safety programs:** Design and construction firms may implement a variety of programs and processes to improve construction worker health and safety. Some programs and processes may have greater positive impact than others. While it may be difficult or even impossible to distinguish the relative difference in impact of each program/process, the participants were asked to provide their perception of the importance of PtD relative to other health and safety programs/processes. Based on the responses, the general feeling (53% of responses) was that PtD has about the same importance to ensuring worker health and safety as other programs and processes. However, 20% of the study sample suggested that PtD is more important, and 11% feel that it is significantly more important, to construction worker health and safety compared to other health and safety programs and processes. On-site activities such as workforce participation, appropriately designed/used risk assessments, method statements and audits, site inductions, and awareness raising (of potentially dangerous situations and practices) were noted as being particularly important health and safety initiatives. Behavioral safety initiatives and client driven health and safety initiatives were also deemed important, presumably to push the message from the top and to cascade good practice throughout the supply chain.

**Motivation to implement PtD:** The survey questionnaire asked the participants about their personal motivation and perspective of PtD. When asked, “What is your perspective of Design
for Safety?”, 94% of the study sample agreed that PtD is a fundamental, “moral” imperative and not just a requirement of legislation. It is clear that the design and construction community within the UK has gained appreciation for the benefits of PtD. The actual percent of participants who feel this way, however, may be impacted by the focus of the study on PtD and the ability of respondents to self-select participation in the study (i.e., those who elect to participate in the study may have a greater interest and appreciation for PtD than those who elect not to participate).

Advice for implementing PtD in the US: Much advice and guidance with regards to implementing PtD in the US was received from the respondents. It was repeatedly emphasized that involving the contractor as a key team member as early as possible in the design process (e.g., to identify construction methods/options and safety issues) has a major positive influence in the success of PtD and safety generally. For example, one respondent noted:

“The key is to get the whole design/ construction/client team to come together at an early stage to evaluate and set out joint aspirations and objectives. Risks should be debated openly and where they can’t be eliminated risk registers should be created, reviewed and updated regularly. A clear process should be established to ensure that the risk register is communicated to all subcontractors and ultimately to the operatives work processes.”

The study sample suggested that owners/clients should lead health and safety initiatives (including PtD) as a core business activity as they have an important role as do much of the ‘driving’ of good practice and behavior change. Enforcement measures were reported to be useful in helping to drive implementation and compliance across all stakeholder groups, and it was suggested that enforcement is required to demonstrate intent amongst regulators.

The initial and continuing professional development of members of the design community was another area of advice suggested by the respondents to support the successful implementation of PtD, with equal emphasis given to theoretical, classroom-based education as well as to the need for the design community to gain practical, hands-on experience in the industry. Examples of comments on this topic are as follows:

- “Designers need to understand that they have a pivotal role in producing safe design solutions that aid construction, rather than leaving it to the contractor to sort out. This is often missing from the training consultants are given.”
- “... it is important to ensure that those implementing design to safety have spent a suitable amount of time working in the environment they are trying to design as safe. Those lacking experience on the ground are in my view in danger of being less effective at designing for safety despite having good intentions and having got suitable "theoretical" training.”
Sellafield Case Study

The focus group meeting took place at the Sellafield engineering design office in Risley, England. The focus group consisted of the researchers interviewing six Sellafield personnel: an architect designer who also participates as a CDM Coordinator, a structural engineer who oversees design quality and compliance, a health and safety engineer (non-nuclear), a nuclear safety engineer, an engineering director, and another participant whose role on the project was not recorded.

As a nuclear facility, Sellafield is subject to many safety programs and regulations. Prior to the implementation of the CDM Regulations, other risk assessment programs and processes were in place which essentially provided compliance with the Regulations. For example, under the Nuclear Installations Act, the nuclear site license prescribes site conditions which specify control and design, and the need to develop safety case assessments for construction, operations, maintenance, and deconstruction. The license requires Sellafield to maintain command and control of all nuclear materials on the site, which leads to the command and control of all designers and contractors also. Hence, changes to the way design and construction are undertaken at Sellafield in order to meet the Regulations were minimal due to the existing requirements and programs. However, the CDM Regulations helped bring the designer requirements to the forefront. As a result, it was recognized by the focus group participants that now the designers think about their designs, and the impacts of their designs, in more detail.

Recent changes in the overall management structure at the Sellafield site have also resulted in changes to help streamline the design and construction process, i.e., make it leaner. As a result, new initiatives to improve health and safety are now being implemented as part of the drive to make design and construction more efficient. In the end, safety is just “re-packaged” a bit. There have been no identified impacts to safety yet; mostly just looking deeper into what can be done to make the process leaner.

The focus group participants recognize that Sellafield is different than other construction sites. Given the history and importance of the site, and the immense implications of a leak of radioactive material, the participants feel that safety is never compromised. For example, in one part of the facility specialized piping was required. However the piping materials are more hazardous. The contract indicates that they cannot change the piping, but in order to meet the safety regulations, the piping must be changed. The end result was that the piping was changed to meet the safety regulations. It was apparent from the focus group responses that safety is the culture of the site, and the mindset is to design for safety. The CDM Regulations do not have to tell them to do it.

The design process at Sellafield contains many different risk mitigation measures. These measures include:
• Rigorous design checking and approval (plans and calculations)
• Design reviews: discipline-specific and whole design review with keyword checklist
• Audits and peer reviews (senior engineers will review a project and challenge the design)
• Hazard operation reviews at different points in the design
• Preparation of a risk register to assess the risk throughout the course of the design
• Design risk assessment by a panel to review buildability
• Development of a construction work safety plan
• Design event review team (lessons-learned review team) review of safety incidents which is then fed back into the design process
• Consultation with expert designers in the knowledge area (“reachback” – reaching back to the original knowledge base to solve a problem)

Very early on in the project they hire people with construction management expertise and engage them in the design. Engineers with operations and management experience are also engaged early in the design process. As part of the design process, engineering designers are required to design out hazards and highlight significant risks. Options for highlighting significant risks include the use of:

• Installation method statement outlines
• Design reviews
• Constructability reviews
• Hazards of construction (HAZCON) studies
• Risk assessments
• Work safety plans

The measures taken to assess risk and improve safety through the design are both formal and plentiful at Sellafield. It is recognized that while the processes are to be followed, independent thought on the designer’s part is also essential. There is an effort to try to move designers to rely less on policies and procedures and more on their own expertise. By utilizing the formal risk mitigation measures, designers can provide the most input; they know their design and the construction issues.

Design and construction at Sellafield is conducted through the collaboration of multiple companies and organizations, centered both in the UK and abroad. This consortium approach can be more difficult because of the need to blend the cultures of different companies. Working together has also led to learning. The focus group participants recognize that the issues and attitudes related to construction safety are the same amongst US and UK designers. There has been a sharing of PtD knowledge between US and UK engineers on the project. Teams of UK engineers have travelled to the US to learn (“reachback”), mostly about related US Department of Energy requirements. Similarly, US engineers travelling to Sellafield are learning the front-end engineering that is done well in the UK and bringing the knowledge back to the US. This
communication and sharing of knowledge is consistent with the CDM legislation objective of using good, competent people and communicating between the project team members.

A goal on the Sellafield project is to fully integrate the CDM requirements into their design process and approach. However, the focus group recognized that they are not yet at the point where the designers do not have to think about CDM and it is just a part of what they do. Some are skeptical and feel that they may not ever come to that point. The participants recognize that they do some things well: there is a strong, positive safety culture; the design risk assessments are well done; there is extensive knowledge of a designer’s legal requirements; and there is good design focus on the reality of installation/construction. With regards to what they need to do to improve PtD at Sellafield, the following were offered:

- Eliminate the bureaucracy and paperwork
- Focus more on significant risks
- Consider the proportionate effort in relation to the risk
- Improve the flow of information from design to construction
- Recognize the different cultures and methods in the multiple design offices
- Improve leadership of design for safety

The focus group participants also offered the following recommendations for industry regulations and standards to optimize PtD:

- Need to have a stratified PtD process based on the size and complexity of the project
- Minimize the bureaucracy and paperwork
- Recognize that the construction environment is dynamic
- Place more emphasis and trust on competence of those involved, including suppliers
- Benchmark against other high hazard industries
- Recognize and require both corporate and individual responsibilities

If the CDM Regulations were abolished, would the focus group participants still perform the same processes and procedures implemented to meet the Regulations? The sentiment of the group was that they would likely not implement the processes and procedures. However, some participants believe that, given that PtD leads to cost savings, the current activities may be continued, and especially if the owner/client wants it done.

Lastly, as far as recommendations for the US, the group offered one suggestion. Rather than focusing on regulations, the group suggested focusing on the commercial benefits of PtD and the edge it provides against competition.
Australia Interviews

Attempts to set up multiple focus group interviews in association with the CIB Conference in Melbourne were not successful. At the conference, the researchers were only able to informally meet with several local construction industry professionals. However, an additional attempt to conduct focus group interviews through an acquaintance in Western Australia was fruitful. Three focus groups were set up as follows: WorkSafe Western Australia and WA Commission for OSH personnel (n=15), design and OSH professionals at a large design and construction consulting firm in Perth (n=35), and a community forum on safe design which was advertised by WorkSafe and Engineers Australia (n=30). Participation in each focus group was self-selected based on their interest in the Code of Practice and PtD. After the CIB Conference, one of the researchers traveled to Perth, Western Australia to conduct the focus groups.

The results of the focus group interviews have been published in the *Journal of Health and Safety Research and Practice* (Behm and Culvenor 2011). Below is a summary of the conclusions and recommendations drawn from the focus group interviews by Behm and Culvenor:

- The regulations and code of practice for safe design of buildings and structures in Western Australia have made a positive impact on design engineers’ thinking and actions towards positively affecting the safety and health of construction workers.
- New innovative and creative thoughts have emerged by focusing on construction site safety and health. These design changes can sometimes impact more traditional construction business measures, such as quality, cost, and schedule in a positive way.
- The design engineers were found to be generally supportive of the concept.
- Design engineers are not simply conducting risk assessments and design reviews in a check-the-box manner.
- Innovation and creativity can sometimes be stimulated by focusing on construction site safety and health in the design.
- To diffuse PtD, the proper environment is needed to ensure a positive mood among the design community in regards to safety. The proper environment for concept adoption must be created before regulations are sought.
- The early adopters and champions of new concepts, such as construction PtD, can provide demonstration projects and case studies so that the design industry can learn about the methods that work and do not work. Incorporating the construction safety and health through design concept into large government projects would be a method to demonstrate effectiveness to the larger industry. Linking the construction safety and health through design concept to sustainable and green construction would be another method to introduce the concept to the industry.
- The relationship between the construction safety and health through design concept and construction project business measures should be researched more thoroughly.
- The approach of building support for the concepts and practices first and then underpinning these with regulatory instruments would be effective. Jurisdictions considering methods to adopt construction safety and health through design should not
rush into a regulatory approach; rather, this research demonstrates the benefits of a cooperative effort which can ultimately benefit workers and business value.

- It would be useful, especially for the practical implementation of construction safety and health through design concept, to document case studies that in turn could be used to educate and spur innovation amongst the design community.
VI. ANALYSIS AND DISCUSSION

The results of the focus group interviews and on-line survey provide an opportunity to understand PtD in practice and plan how to enhance acceptance and use of the concept here in the US construction industry. As described in Section IV above, multiple research questions were posed prior to conducting the focus groups and on-line survey. An analysis of the results with respect to each of the research questions is provided below.

The researchers conducted both quantitative and qualitative analyses of the data. For open-ended questions in which the respondents provided a narrative response, the researchers conducted detailed contextual examinations of the responses and recorded trends based on frequency of statements, perspectives, and issues identified. This was done to answer the questions posed, to identify key concepts, themes, and terms, and to develop an understanding of the similarities and dissimilarities between different parties and projects. For quantitative, closed-ended questions, the researchers performed statistical analyses based on frequency comparisons and Chi-squared tests.

Focus Group Interviews

For each of the research questions posed for the focus groups, the researchers utilized content analyses of the focus group interview responses to answer the questions. The analyses were conducted using multi-level keyword searches to target and confirm trends in the response data. The findings of these analyses are provided below for each research question.

How has the EU and CDM legislation affected the design, construction, and safety of a construction project?

Descriptions of changes to the design, construction, and construction safety came from all of the different discipline areas included in the focus groups. Those changes which were identified most often by multiple participants are listed below. It should be noted that the impacts indicated, including those related to cost and duration, are based on each participant’s personal experience and perspective. No quantitative analyses of the actual impacts were included in the research study.

- Design:
  - Increased modularization
  - Improved constructability (buildability)
  - Earlier incorporation of construction knowledge
  - Inclusion of more engineering controls in the design (e.g., designed-in anchorage points, guardrails, etc.)
  - Greater use of less hazardous materials
  - Slight increases in design cost and design duration
- Construction:
  - Increased prefabrication
- Reduced material handling
- Less use of scaffolding
- More use of specialized equipment to remove the worker from hazardous conditions and eliminate hazardous operations
- No clear trend regarding impacts on construction cost and duration

- Construction worker health and safety:
  - Reduction of jobsite hazards, which leads to improved H&S

- Other:
  - Improvements in construction quality, construction worker productivity, and end-user H&S

**How has involvement in PtD affected perceptions of safety, roles on the project, and organizational and professional culture?**

Focus group respondents generally indicated positive changes to safety perceptions, project roles, and organizational and professional culture. The improvement has to a great extent been greater collaboration and communication amongst the project team and specifically between designers and constructors. A different perspective on safety, and the role which each individual can and should play in regards to safety, have also been positively affected. The ways in which PtD has affected perceptions, roles, and culture, as indicated by the focus group participants, are listed below.

- **Perceptions of safety:**
  - H&S is now viewed as important to the overall success of a project
  - Designers now generally view construction H&S as an imperative
  - The view that H&S is an “add-on” to the project is not as prevalent; however, a perception exists that simply identifying hazards for the constructor to address during construction fulfills the PtD concept
  - Changed perspective on responsibility for H&S and on designer’s ability to affect H&S; now H&S immediately comes into conversations in all aspects of planning and design
  - Increased perception that H&S is a moral obligation rather than a regulatory requirement

- **Roles on the project:**
  - Greater designer recognition that, as part of the project team, they have a role and responsibility with regards to H&S
  - Project management efforts now include active assessments and management of H&S risks; H&S included in project feasibility assessments
  - Role of CDM Coordinator created as part of CDM Regulations; role sometimes filled by architect or construction manager
  - Other parties besides the architect/engineer, such as the quantity surveyor, are playing a bigger role in project leadership
  - Increased owner/client participation in, and knowledge of, H&S
Organizational and professional culture:

- Closer relationships between project team members; working more as a team
- Greater consideration of the needs and priorities of the other project team members
- More thorough design approach; better professional design practice
- H&S now spread to a greater extent throughout the project team

To what extent have innovative processes and products been developed in response to the directive to address safety in design?

The positive impact that PtD can have on innovation is recognized (Behm et al. 2011; and Behm and Culvenor 2011). The focus group participants gave some examples of changes to the physical features of designs, the design process and tools, communication of safety hazards, and safety organizations. Most are project-specific; the intent and application was to solve a problem on a project. Diffusion beyond the project to other projects or to other companies has been limited. Innovation includes inception and development of the idea, initial application and evaluation, and implementation to other instances to validate the benefits and confirm the industry change. Further efforts are needed to encourage dissemination of new and modified designs throughout the construction sector.

In regards to the physical features of designs, most of the changes have been revised designs to eliminate hazards and facilitate safe construction operations. That is, rather than creating some new design or product, it is more common for existing designs to be slightly revised. Examples of this type of change are: including anchorage points for fall protection in the design; modifying the size, location, shape, or materials of a design; and designing such that the systems can be prefabricated. In addition, much of the change has occurred in the structural, mechanical, and electrical systems within a facility. When new designs are created, the examples provided by the focus group participants were most often targeted at modularizing the designs and at designs of features used in the maintenance of structures (e.g., window washing systems).

What is done differently now compared to practice prior to the CDM regulations?

Much of the difference since the implementation of the CDM regulations is related to how information is developed and shared, and how communication occurs. Some designers are now placing symbols on drawings to alert constructors of potential hazards (e.g., a picture of a person tripping where a tripping hazard exists). Notes describing potential safety hazards and needed personal protection are also being added to design documents. Within design firms, on-line networks and databases have been developed to collect and share H&S knowledge. These systems are often tied to a firm’s lessons-learned resources. Lastly, many different variations of risk assessment tools have been created to facilitate meeting CDM requirements. The risk assessment
tools are typically designed to help identify, evaluate, and mitigate the risks present in a design, as well as provide a formal record of conducting a risk assessment.

The focus group responses indicate that H&S immediately becomes part of conversations about a project, whereas previously it was often an afterthought. This change is evident in project team meetings, communications, and the information included in project documents, including plans and specifications. In addition, construction worker H&S has also become one of the decision criteria. While not necessarily the only decision criterion, it is now considered to a greater extent compared to other criteria such as cost, time, quality, etc.

The focus group participants were clear in their responses that the differences and change are not consistent across all industry sectors. Some sectors, such as petro-chemical, power, high-tech, and pharmaceutical, are experiencing a high level and broad implementation of PtD. Additionally, large firms, in both design and construction, have commonly integrated PtD into their projects and processes. The focus group participants felt that the acceptance and application of PtD has been less on smaller (both in terms of cost and size) projects and in the homebuilding, light industrial, and small commercial building sectors. Extra efforts are needed to expand the PtD concept in these sectors.

**How has management of projects changed under the CDM regulations?**

Based on the focus group responses, change to project management has occurred but has been limited. Project management now includes additional efforts to fulfill the requirements set forth in the CDM Regulations. This includes the addition of a CDM Coordinator to manage project risk. Overall, the greatest change has been the additional efforts to formally manage H&S risk. This includes ensuring that the appropriate parties and roles are in place, the required documentation is created, and H&S risks are recorded and addressed. As mentioned previously, the focus group participants recognize that H&S is not part of every project conversation. Whereas construction worker H&S was previously limited to the management within the constructor’s organization, it is now expanded to the entire project team. All parties to the project are more involved in managing H&S in some aspect through their role on the project.

**What can the US learn from the UK’s experience?**

The focus group responses provide an indication of the needs, best practices, and outcomes for expanding PtD in the US in the absence of legislation similar to the CDM Regulations. Those needs, practices, and outcomes can be summarized as follows:

- Involvement of the owner/client is critical to ensuring that: (1) PtD is implemented; (2) H&S is included as a decision criterion and given high priority compared to other decision criteria; (3) authority is granted to modify the design
to improve safety rather than just mitigate risk through lower level controls; and (4) importantly, designer performance will be judged based on the extent to which PtD is included in a project.

- Designers need to be educated and trained such that they are knowledgeable about typical construction means and methods, H&S hazards commonly present on construction sites, and designs which effectively mitigate the hazards.
- Contractor involvement (or the inclusion of construction knowledge through other means) in the design phase is needed; constructability (buildability) will improve as a result.
- Supporting tools and design resources are needed to guide designers how to address H&S in their designs.
- Design and construction coordination and integration enables safer designs and safer construction. Working side-by-side with open communication promotes teamwork and assistance to eliminate H&S hazards.
- A design risk assessment process is needed to determine how best to mitigate hazards prior to the start of construction.
- Implementation of PtD will result in modified designs, additional H&S information on construction documents, modularized designs, and increased prefabrication.
- A means to motivate implementation of PtD is required. This can be through the owner/client as indicated above, or through other means (e.g., competition, regulation, etc.). Proper motivation will eliminate a tendency to mediocrity in design and a “leave it up to the contractor” attitude.
- Efforts need to engage designers to convince them that they play a key role, and to show them how and when to participate. These efforts should identify the potential positive H&S impact that designers can make, along with the associated cost and time.
- Responsibility for implementing PtD, identifying hazards, and assessing and mitigating risk must be clearly defined. This can be facilitated through the use of a responsibility matrix which shows the roles and responsibilities of each project team member.
- Involvement in PtD should be expanded beyond the main project team members to consultants, manufacturers/suppliers, subcontractors, and others involved in the project delivery process.

On-Line Survey

The on-line survey provided a wealth of data from a large segment of the UK construction industry. As described in Section IV of this report, the survey was designed to answer multiple research questions. Analyses of the survey data were conducted to both answer the research questions posed, and explore connections between various respondent characteristics and performance/perspective outcomes. Detailed descriptions of the results of the on-line survey are presented above in Section V of this report.
Analyses of the survey data based on frequency statistics (number and % of respondents) are summarized below for each research question. The frequency statistics on which the analyses are based are shown in Section V of this report.

What resources and how many are typically devoted to, and required for, PtD efforts?

Human resources are required and used to implement PtD. Project team members work together to identify, assess, and mitigate hazards through the design of the project. The number of employees required to implement PtD varies from one company to another. Sufficient staff is needed to thoroughly implement PtD concepts. The actual number depends on both the project and company characteristics; there is no set or recommended number of people who should be involved. This process does require time, the extent to which depends on the size and complexity of the design and the level of detail to which the project team reviews and optimizes the design. For those who include PtD in their job description, PtD is most commonly integrated throughout their work activities, and less likely to be an add-on to their job duties. Similarly, PtD is typically not an employee’s entire role.

Based on the survey responses, most PtD input comes from in-house staff and from constructors. External design consultants are used to a lesser extent. The use of in-house design staff is encouraging as it shows that designers are engaging in the PtD process and can play a beneficial role. In addition, including constructors is expected given the need for construction knowledge to effectively design for construction safety.

In terms of which resource provides the most input to PtD, the survey respondents pointed to principal contractors, design engineers, and CDM coordinators. The level of input can vary significantly within companies due to different individuals’ attitudes, education, and training. In addition, the actual level of input may differ from the ideal level of input. However, it is clear that some project team members are more valuable as a resource to PtD than others.

When are PtD efforts typically undertaken?

In addition to possessing the needed resources, PtD resources need to be implemented at the right time. PtD efforts may be undertaken at various points in the overall project lifecycle (planning, design, construction, operations and maintenance, recommissioning/decommissioning). As indicated above, H&S can best be addressed earlier in the project lifecycle; this is especially true for PtD which involves the design of a project.

Of those survey respondents who are either partially or fully involved in PtD, 81% conduct PtD activities in the planning (preparation) phase prior to design. Similarly, the percentages are 89% conduct PtD activities in design, and 96% in pre-construction. A
significant portion (90%) of those who are either partially or fully involved in PtD also conduct PtD activities during construction. The PtD activities during construction may indicate that re-design is taking place once the construction operations reveal potential hazards.

The survey responses reveal that those involved in PtD are involved both early in the project and during construction. The presence of PtD early in the project lifecycle is expected given the nature of the PtD concept and the CDM Regulations. The significant amount of activities that take place during construction may be evidence of the difficulties in assessing construction H&S hazards during design. Hence, addressing PtD on projects may require PtD activities not only during planning and design, but also during the pre-construction and construction phases.

What PtD practices and tools are commonly employed?

The survey respondents indicated a variety of tools and processes being used for PtD efforts. The most common tools (based on % of respondents indicating use) are used to assess risk and guide the design (e.g., risk assessment matrix, design checklists, lessons-learned databases, and design guides). These are typically developed in-house in hardcopy or electronic form. The tools are either implemented at specific milestones as part of a planned design process or used on an ad-hoc basis. When external PtD references are used, whether on-line or hardcopy, the most commonly used come from government organizations (e.g., HSE) and professional associations (e.g., Approved Code of Practice). Tools that are used less frequently are computer visualization/simulation software and on-line design resources. Their lack of use may be due to a variety of reasons such as a high cost of owning and implementing the software, and a need for further development of the resources to provide sufficient value and utility.

Formal PtD processes have been developed and are used by the majority of firms. Typically the processes incorporate risk assessments, design reviews, and hazard and operability studies (HAZOPS) through training for designers.

Based on the overall selection and usage of tools and processes, it is clear that those utilized for PtD vary in type and format. However, in order for effective PtD implementation to take place, the tools and processes must meet some fundamental needs and provide specific utility. The needs and utility to be met by the tools and processes are:

- Provide information about typical construction site operations and the related H&S hazards
- Ability to visualize the construction process during design and identify potential H&S hazards
- Ability to objectively assess the risk associated with H&S hazards
- Ability to generate ideas for alternative designs to mitigate the H&S risks
- Ability to evaluate each alternative to assess its feasibility and select the most appropriate alternative

If the available tools and processes meet the needs and provide the utility listed above, PtD can effectively be implemented. Lacking such resources will inhibit its implementation.

**What enablers and barriers to the implementation of PtD efforts commonly exist?**

Section V of this report provides a list of enablers and barriers identified by the survey respondents along with the frequency in which each was cited. The enablers of PtD reflect a need for sufficient resources, knowledge, and motivation. When sufficient time and funding are available to conduct reviews, assess risk, and develop and implement design alternatives, the level of PtD increases. It is all too often that the prescribed design phase duration limits exploring new options to enhance the design. The design duration should be established such that the designers have adequate time to consider and revise their designs for safety. Providing time to conduct thorough constructability reviews allows for construction knowledge to filter into the design.

PtD implementation is also enabled when designers are knowledgeable about safety, construction methods, and designing for safety. Lacking such knowledge makes it difficult to go beyond the lower-level jobsite safety measures. This knowledge helps to minimize the effort required to address construction worker safety in designs, which is another enabler commonly identified by the survey respondents.

Sufficient motivation must exist for those involved. This motivation can be personal, a part of the project, established by the industry, or part of standard practice. In the absence of legislation directing the implementation of PtD, the motivation typically comes from the project owner/client (in terms of firm selection, recognition, and contractual obligation), and from the potential for enhanced firm reputation. Motivation is also created by including PtD as a criterion for determining project performance and success. When H&S is included as a priority along with cost, schedule, quality, and other typical performance measures, and is given high priority relative to these measures, PtD can flourish.

In addition to enablers, the survey revealed numerous barriers to PtD. The primary barriers are: a lack of knowledge and skills to design for safety, unknown construction means and methods at the time of design; higher priority given to other project objectives; and a lack of time allotted for design to include PtD. It should be remembered that PtD is currently implemented not only in the UK but also within some firms in the US. Therefore, the barriers identified do not prevent PtD from being implemented; the barriers merely inhibit efficient and comprehensive implementation. Eliminating the barriers makes it easier to implement PtD and leads to safer designs.
What are the impacts of implementation of PtD efforts on safety and other project properties?

Understanding and quantifying the impacts of PtD is a critical step in expanding its use in the construction industry. Importantly, the survey respondents indicate that PtD has a positive impact on construction worker H&S. That result is the main goal. The benefits of its implementation also extend to end-user H&S. The survey respondents indicated that those who maintain and operate the facilities will experience better safety performance as well. Secondary impacts include improved construction quality and higher construction worker productivity, both of which have been recognized in previous research as described previously.

In addition to the impacts to the project outcomes described above, PtD is expected to also affect project inputs. The initial cost of design and construction will likely increase to account for additional design and constructability reviews, risk assessments, and modified designs. These extra efforts also require additional time. It is commonly believed, however, that there is a payback over time as the initial costs and time are offset by enhanced productivity, less re-work (better quality), lower insurance costs due to improved safety, and greater efficiencies during future operations and maintenance. While these benefits are not identified as part of this research study, they are commonly cited in previous work (see Section II).

The impacts to the project design features and construction operations are greatly project-dependent. The change is recognized as benefiting projects. Almost all of the respondents indicate either very positive or some positive impact to the design and to the construction of projects. As indicated previously from the focus group interviews, the changes to the design typically show up as increased modularization and prefabrication, the use of alternate materials, and revised size, location, and shape of design features. For construction operations, the change leads to less of a need for, or easier implementation of, PPE and engineering controls. There is also greater use of automated technologies that remove the worker from hazardous operations.

The project team members are also affected. Based on the survey responses, increased designer appreciation for construction worker H&S, and greater consideration of the needs and limitations of other project team members, are examples of change. For designers specifically, PtD has helped to increase their understanding of construction site hazards and the important role that they can play in eliminating the hazards. As a project team, there is increased collaboration and improved communication amongst the team members. The majority of survey respondents feel that overall PtD has had a positive or very positive impact on the roles of the different team members.

What other safety and health interventions and program elements are commonly employed?

On most projects, multiple efforts are undertaken to ensure construction worker H&S. PtD is one intervention that is implemented alongside others during both design and
construction. As indicated previously, the survey respondents identified the following on-site activities that are typically employed to address construction H&S: worker participation in H&S roles, construction method statements and audits, jobsite inductions, and hazard awareness training. Behavioral safety initiatives and client driven health and safety initiatives are also implemented.

The extent to which each of these interventions is implemented varies from project to project and from one contractor to another. Likewise, the importance of each to overall H&S performance depends on many factors such as the quality of implementation, type of work conducted, project and organizational culture, and worker acceptance. Research to quantify the relative importance of each intervention has yet to be conducted, and the difference in importance may be too difficult to quantitatively measure with meaningful confidence. When asked their opinion about how important PtD is compared to other interventions for improving construction worker H&S, most of the survey respondents felt that the importance is about equal. However, a significant percentage (31%) feel that PtD is either more important or significantly more important than other interventions. One aspect of overall H&S management to remember is that effective implementation of PtD should result in less of a need for other interventions. Eliminating H&S hazards from the jobsite should decrease the need to implement additional downstream (i.e., construction phase) interventions.

The survey results provide an opportunity to explore, through statistical analyses, connections between specific respondent characteristics and particular responses. Of interest is whether factors such as the amount of work experience, project team role, industry sector, and level of involvement in PtD, correlate to the respondent’s attitude towards PtD and responses regarding PtD impacts, legislation, motivation, and other aspects of PtD implementation.

To conduct the analyses, the researchers performed Chi-squared tests on the data. Chi-squared is a statistical test commonly used to compare observed data with that which would be expected based on a specific hypothesis. The results provide an indication of whether there is a significant difference between the expected and observed results. The test can be used to investigate whether distributions of categorical variables differ from one another.

Table 7 shows the analysis matrix indicating the independent and dependent variables for each Chi-squared test performed along with the survey questions used to provide the data for each variable. An “X” in the table indicates that a Chi-squared test was performed. 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, such as “involved in PtD” versus “not involved in PtD”, 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.

Table 7. Chi-Squared Tests of Survey Response Data

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<tr>
<th>Independent Variable</th>
<th>Survey Question(s)</th>
<th>Level of Influence</th>
<th>Impact of PtD on performance criteria</th>
<th>Impact of PtD on project team roles</th>
<th>Impact of PtD on design and construction</th>
<th>Impact of CDM legislation on PtD</th>
<th>Attitude toward PtD (aggregate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years of work experience</td>
<td>Q29</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Extent of involvement in PtD (aggregate)</td>
<td>Q2+Q3+Q3</td>
<td>Personal</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Timing of involvement in projects</td>
<td>Q7</td>
<td>Personal</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Role on project team</td>
<td>Q25</td>
<td>Personal</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Performance criteria priority</td>
<td>Q20</td>
<td>Personal</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Industry sector</td>
<td>Q28</td>
<td>Organization</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Type of firm</td>
<td>Q24</td>
<td>Organization</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Firm capabilities</td>
<td>Q26</td>
<td>Organization</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Size of firm (# of employees)</td>
<td>Q27</td>
<td>Organization</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

In those cases where the independent variable is quantitative (e.g., size of firm), ordered contingency Chi-squared tests were performed. This test is used to indicate whether the dependent variable varies with respect to the magnitude of the independent variable. A one-sided p-value is calculated with each test to indicate the possibility that the observed variation is due to chance.

Provided below is a summary of the results from the statistical analyses. The frequency statistics associated with each variable are provided in Section V of this report. Appendix E provides summary tables showing the statistical results for each test (odds ratio, p-value, and 95% confidence interval). Given the many possible combinations of responses for each independent variable and for each dependent variable listed in Table 7, many Chi-squared tests were performed and too many to include all of the results in this report. Only 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, are listed in the appendix tables.

**Years of Work Experience**

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, the respondent’s perception of how PtD impacts the project team member roles, design, construction, and the respondent’s perception of the impact of the CDM legislation on PtD implementation. The number of years of work experience was found to correlate to the respondent’s perception of the impact which PtD has on some project performance criteria. The results can be summarized as follows:

- Those without architectural experience are more likely to perceive PtD as leading to increases in design cost, construction duration, and total project duration.
- Those with architectural experience, and those without any design engineering experience, are more likely to indicate that construction worker productivity increases.
- 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 H&S consultant experience are more likely to indicate a decrease in construction cost.
- Those without any H&S consultant experience are more likely to indicate an increase in construction cost and duration, and total project cost and duration.
- Those with any amount of contractor experience are more likely to indicate a decrease in construction duration.
- Subcontractors who possess low or medium amounts of experience are more likely to indicate an increase in worker productivity.

**Extent of Involvement in PtD**

The extent of involvement in PtD aggregate reflects the respondent’s type of involvement in PtD, extent to which PtD is part of his/her role on a project, and the amount of time which the respondent has worked with the CDM Regulations. Greater involvement in PtD was found to lead to a more positive attitude towards PtD and a better understanding of the impacts of PtD. The following summarizes the statistical analysis results:

- The greater the level of involvement in PtD, the more likely the respondent will have an opinion that the construction duration, construction H&S, and end-user H&S will all increase.
• Those who are highly involved in PtD are more likely to recognize positive impacts to the roles of the owner/client, manufacturer/supplier, CDM coordinator, principal contractor, and subcontractor.
• Those who are highly involved in PtD are more likely to indicate positive impacts to design and to construction.
• Those who are highly involved in PtD are more likely to have a positive attitude towards PtD.

No statistically significant relationship was found between the extent of involvement in PtD and the respondent’s viewpoint of the impact of the CDM legislation on PtD implementation.

Timing of Involvement in projects

In addition to the extent of involvement with PtD, the researchers investigated whether the timing of the involvement is an indicator of PtD-related outcomes. The Chi-squared tests revealed the following:

• 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.
• If fully involved in design, respondents are more likely to indicate that PtD leads to no change in end-user H&S.
• Those who are not involved in the construction stage are more likely to indicate that PtD leads to increases in design cost, construction cost, and to no change in construction quality.
• When involved in construction, respondents are more likely to indicate an increase in construction quality, and decrease in total project cost, due to PtD implementation.
• Those who are involved in pre-construction activities are more likely to indicated that PtD leads to an increase in construction quality, and no change in end-user H&S.
• Those who are involved in planning/preparation, design, and facility use are more likely to indicate a positive impact on design.
• Those who are involved in planning/preparation and design are more likely to indicate a positive impact on construction.
• Those respondents who indicated involvement in design and pre-construction are more likely to possess a positive or very positive attitude towards PtD.

Role on Project

As described in Section II of this report, previous research suggests that the role which people take on projects impacts their perspective of PtD. The survey allowed for testing
whether a person’s role on the project affects their responses. Below is a summary list
of the statistical analysis results:

- Those who participate in the design engineer role are more likely to indicate that PtD increases construction cost, total project cost, construction duration, and total project duration.
- Those who work in the architect or engineer role are more likely to indicate that PtD leads to increases in: construction cost, total project cost, design duration, and construction duration.
- Those who have CDM Coordinator as part of their role are more likely to indicate that construction cost will decrease, that construction H&S will increase, and that the CDM legislation helps to implement PtD.
- Those who do not have architect as part of their role are more likely to indicate that PtD will lead to an increase in design duration.
- Those whose role contains that of a principal contractor are more likely to indicate that construction quality will increase as a result of implementing PtD.
- Those who participate in the architect role are more likely to have a negative or poor attitude towards PtD. Similarly, when comparing architect and engineer to the other project team member roles, those who work in the architect or engineer role are more likely to have a negative or poor attitude towards PtD.
- Those who participate in the principal contractor role are more likely to have a positive or very positive attitude towards PtD.

The analysis results show a clear difference in perception of, and attitude towards, PtD based on the survey participant’s role on projects. These results confirm previous research that those who participate in design roles are commonly less enthusiastic about the PtD concept and feel that PtD leads to additional construction cost and time. Given that design is the focus of PtD, efforts to expand PtD in the US must address the attitude of designers towards the concept.

Performance Criteria Priority

The trade-off between different project performance criteria can impact how PtD is accepted and implemented. If construction worker health and safety is lower in priority compared to other criteria, PtD may not be viewed as a valuable concept. The results of the statistical analysis reveal that those who place aesthetics lower as a priority (compared to cost, schedule, quality, safety) are more likely to have a positive or very positive attitude towards PtD. As the priority given to aesthetics decreases, the likelihood that the respondents have a positive attitude towards PtD increases. The analysis additionally found that as the priority given to construction worker H&S increases, the attitude towards PtD becomes more positive.
Organization’s Industry Sector

As described in the literature review section above, and in the results from the focus group interviews, safety performance and PtD acceptance differ amongst the industry sectors. Sectors such as power generation and petro-chemical have a heightened focus on safety during construction and throughout the lifecycle of the facility. The nature of the work and demographics of the organizations involved in other sectors have typically resulted in less of a focus on construction safety in the other sectors. The statistical analysis tested whether the industry sector in which the respondent works is an indicator of the respondent’s response to the survey questions. Listed below are a summary of the statistically significant results:

- Those working in the industrial sector are more likely to indicate that implementing PtD results in an increase in construction duration and total project duration, and also an improvement in construction quality. However, industrial sector employees are also more likely to indicate a decrease in worker productivity.
- Those involved in the commercial buildings sector are more likely to indicate that PtD leads to better construction quality.
- Those who are not involved in the infrastructure/heavy civil sector are more likely to indicate that PtD leads to a positive impact to the role of the architect and CDM Coordinator.

Type of Firm

The survey asked the respondents to indicate the type of firm in which they work (e.g., architecture, engineering, construction, etc.). The type of firm in which the respondents work is closely related to their role on projects and the timing of involvement in projects. As part of the statistical analysis, the researchers tested whether type of firm is also an indicator of their responses. The following list summarizes the statistically significant analysis results:

- Those who work for an engineering firm are more likely to indicate that PtD increases construction duration. This result was similarly found in regards to those who work as a design engineer.
- Those who work in a construction firm, and those who do not work for a design firm, are more likely to indicate that PtD positively impacts the owner’s role on a project.
- Those who work in a construction firm are more likely to possess a positive or very positive attitude towards PtD.
- Those who work in an architecture or engineering firm are more likely to have a negative or poor attitude towards PtD.
Firm Capabilities

Some firms may have a variety of capabilities related to, or not related to, the design and construction of projects. Based on previous research, it was assumed that there would be a difference in survey responses when certain capabilities are present or not. The survey respondents were asked to indicate whether their firm possesses (in-house) capabilities related to architecture, engineering, construction, safety, owner/developer, and manufacturer/supplier. In addition, the respondents were asked to indicate whether these capabilities were used on construction projects or not. The statistically significant results from the analysis are summarized below:

- Those respondents whose firms possess architecture capabilities in-house are more likely to indicate that PtD leads to an increase in construction cost and total project cost, and a positive impact on the architect’s role. In addition, with architecture capabilities, the respondents were more likely to indicate that the CDM legislation hinders PtD implementation.

- Those respondents whose firms have design engineer capabilities in-house are more likely to indicate a positive impact on the manufacturer/supplier role due to PtD.

- Those respondents whose firms have facility owner/developer capabilities in-house are more likely to indicate that PtD results in a positive impact on the facility owner/developer role.

- Those respondents whose firms have H&S consultant capabilities in-house are more likely to indicate that PtD implementation decreases construction cost and total project cost.

- When the firm does not possess H&S consultant capabilities in-house, the respondent is more likely to possess a positive or very positive attitude towards PtD.

- Those respondents whose firms do not have any principal contractor capabilities are more likely to indicate an increase in design cost. However, when the firm has principal contractor capabilities, the respondents are more likely to indicate a positive impact on the subcontractor role.

- Those respondents whose firms have CDM Coordinator capabilities in-house are more likely to indicate a decrease in total project duration. However, they are also more likely to possess a negative or poor attitude towards PtD.

- Those respondents whose firms have subcontractor capabilities in-house are more likely to indicate that PtD leads to increases in worker productivity. When the firm does not have any subcontractor capabilities in-house, the respondents are more likely to indicate positive impacts to the architect, design engineer, and manufacturer/supplier roles.

The impact of CDM Coordinator capabilities are curious in that, with such capabilities present in the firm, there is more of a likelihood that the respondent will have a
negative or poor attitude towards PtD. The reasons for this attitude are not certain, but may be due to the general feeling that there is too much paperwork associated with the CDM Regulations, or the inability for CDM Coordinators to feel accepted by and integrated within a project team. Similarly, the analysis reveals that in those firms which do not have any H&S consultant capabilities in-house, the respondents were more likely to indicate a positive or very positive attitude towards PtD. The opportunities that in-house H&S consultants can bring to promoting PtD perhaps are not occurring or are not being communicated well.

Size of Firm

The knowledge, resources, and capabilities available within larger firms can provide such firms with advantages over smaller firms and lead to different safety cultures. Smaller firms may not have sufficient resources to put into PtD while trying to meet other competing performance criteria. The difference in safety performance based on construction firm size is recognized and can be seen in safety performance statistics in the US (CPWR 2013). The statistically significant analysis results related to firm size are summarized below:

- The larger the firm size, the more likely the respondent will indicate that PtD leads to a decrease in construction duration.
- Those who work in firms with greater than 10 employees are more likely to indicate that implementing PtD leads to an increase in construction quality.
- Those who work in firms with greater than 500 employees are more likely to indicate an increase in construction H&S.
- Those who work in firms with less than 500 employees are more likely to indicate positive impacts to the architect and subcontractor roles.

As described above, the 2007 CDM Regulations do not apply to all projects. There are several triggers which make appointment of the required dutyholders mandatory on some projects but not others. Given that the types of projects on which a firm works likely depend on the size of the firm (e.g., larger firms undertake larger projects), the exposure of a firm to the CDM Regulations may vary depending on the firm size. Therefore, the analysis results indicated above may also be due in part to the requirements of the CDM Regulations as opposed to simply the nature of PtD.
VII. CONCLUSIONS

As an occupational safety and health intervention, prevention through design is an attractive concept. For OSH professionals, PtD provides an opportunity to eliminate H&S hazards from the workplace and, therefore, greatly lower OSH risk. For workers, fewer jobsite hazards means a safer place to work; there is less of a chance of getting injured. When employees feel safer on the job and are not distracted by unsafe conditions, improvements in worker morale, work quality, productivity, and organizational culture follow. Consequently, PtD is also an appealing proposition for employers, especially construction employers. PtD helps to fulfill moral and regulatory obligations in regards to employee safety, health, and welfare, and can also lead to enhanced financial gains and recognition for a firm. The potential benefits from implementing PtD processes and practices in a workplace are clearly recognized.

In the US construction industry, PtD is regularly implemented as part of standard practice when designing a facility for the H&S of the end-user of the facility, i.e., those who use and maintain a facility after it is constructed. Formal application of PtD with respect to the H&S of the construction worker, however, is commonly not a part of standard design practice in the US. The H&S of those who construct the facility has traditionally been considered and addressed by the constructor after the design is complete. As a result, the design may need to be retrofitted during construction to provide a safe workplace, or the constructor must apply less effective and reliable H&S controls, such as personal protective equipment and administrative rules, to mitigate the risk.

The desire to improve OSH here in the US has generated interest in expanding the PtD concept to include designing for construction worker safety and health. Diffusion and acceptance of PtD as part of standard design practice require knowledge and understanding of the concept, PtD practices and tools, and expected impacts. The findings of the research study reveal the expected organizational and industry impacts related to H&S perceptions, roles, and culture that result from implementation of the PtD concept. Additionally, the study exposed PtD processes and products that have been developed and which could be disseminated for widespread use.

A study of PtD in the UK could not be conducted without consideration of the CDM Regulations. However, equivalent regulations do not exist in the US. Also, the focus of the research study is on PtD, not PtD regulations. As described previously, during the focus group interviews the researchers periodically reminded the participants of the focus on PtD and steered them away from just thinking about the CDM Regulations. Similarly, when developing the conclusions to the study, the researchers distinguished those related to PtD from those related to the CDM Regulations. Only those conclusions related to PtD specifically are included herein. Research on the implementation and effectiveness of the CDM Regulations is available (for example, see: Frontline 2007; Aires et al. 2010; Anderson 2000; Ash 2000; Baxendale and Jones 2000; and Griffith and Phillips 2001). In its pilot study of the CDM Regulations, for example, Frontline (2011) found that the Regulations are largely meeting their intended purpose. However, approximately half of the participants in the research complained that the Regulations did not
minimize bureaucracy. The study findings also suggest a divided opinion as to whether the Regulations have led to greater integration of designers and constructors. Lastly, when considering the costs and benefits of the Regulations, the study participants indicated that, on average, the benefits are moderate and the costs are moderate or lower.

The results of the present study also reveal that PtD impacts the costs and benefits of construction projects. According to those involved in PtD efforts, implementing PtD in practice either does not change or increases design cost and duration. With regards to construction cost and duration, there is no clear trend; the impact is likely project and/or firm dependent. It is clear, however, that implementing PtD leads to improvements in constructability, workmanship/quality, and productivity, and less rework. And, importantly, implementing PtD results in fewer H&S hazards, for not only the construction worker, but also the end-user and maintainer. The overall impacts on the physical features of the design and the construction of a project are positive.

The benefit that the application of PtD to construction worker safety has on operations and maintenance safety is one of the highlights of PtD compared to other temporary safety measures. Safety interventions that are only present during construction have little or no value to the facility later in its lifecycle. However, the processes and practices used to implement PtD for construction safety also lead to lower safety risk during facility use and maintenance. Another desirable feature of PtD is its potential to decrease the need for implementing downstream safety measures. By eliminating or minimizing safety hazards from the jobsite, the constructor may find that additional “add-on” safety controls are not needed during construction. Such a result would lead to decreased construction costs and durations. While those who participated in the research were not able to confirm this benefit based on their experience to date, it is a logical conclusion given the nature of PtD and principles of risk management and cost engineering. Realizing such a benefit in practice would likely require optimal PtD implementation and a highly integrated project team.

When PtD is implemented, the design impacts are typically expressed in increased modularization of the design, and in modified designs to accommodate and promote safer construction methods. Often the new designs result from simply problem-solving on projects during design reviews. When a safety hazard is identified, and alternative construction methods are desired to more safely conduct the work, the design is changed to accommodate the alternative methods. The alternative methods may be implemented on the jobsite, although much emphasis is put on prefabrication. PtD promotes and leads to prefabrication away from the jobsite to eliminate safety hazards on the jobsite. The prefabrication also results in better quality and lower costs.

To implement PtD, project team members have developed design process tools. Design for safety checklists are now commonly used by design firms along with risk assessment pro forma. These tools are applied as part of PtD processes which commonly consist of multiple design and constructability reviews throughout the project planning and design stages. Utilizing constructor, H&S consultant, and end-user input, “safety constructability” reviews are
conducted to identify hazards and manage the risk. The result is modified designs as described above, along with additional hazard communication information placed on the design drawings to alert the constructor of safety hazards and communicate safety measures to be taken or regulations to follow.

Perhaps the most important impact of implementing PtD is the change in the project team. The research revealed a clear understanding amongst those involved in PtD efforts that there has been a transformation in how project team members interact, communicate, regard construction worker H&S, and conduct their work. These changes are the success of PtD, and what ultimately have led to safer construction sites and improved construction worker H&S. The changes can be summarized as follows:

- More and improved project team communication
- Greater integration of the project team members, and of the design and construction disciplines
- An increased number of planning and design sessions upstream of the construction stage to consider and ensure a safe project before it is too late
- Increased involvement of constructors in the design stage (involving the “right people at the right time”)
- Designers are:
  - more knowledgeable about construction H&S;
  - putting more thought into how their designs impact construction worker H&S;
  - and
  - more involved in safety discussions.
- Designers now feel like they can contribute to construction H&S
- Designers are now valued as an integral and necessary part to ensuring a safe worksite
- Better overall professional practice, as summarized in the following comment from a focus group participant:
  - “Now, the greater consideration of other disciplines leads to improved interfaces between design features and systems. Ultimately, it is recognized that it is now a much more thorough design approach. This change is significant for the US, as it is can be created through not necessarily legislation, but just better professional practice” (N11, Q6).

The positive impacts to the project team, and especially the design profession, are broadly recognized. The research reveals, however, that attitudes toward and acceptance of PtD (separate from the CDM Regulations) vary according to area of discipline. Constructors and H&S consultants almost universally believe PtD is a worthwhile H&S intervention. The attitude that designers have in regards to PtD is less positive. This result is a key consideration for the efforts to expand PtD in the US. Architects and engineers are central to the PtD concept given their role in the design. Positively affecting the designers’ attitudes and acceptance of PtD, along with supporting and enabling their contributions to PtD, should be at the core of the PtD initiative in the US.
The changes to the project team and industry culture with regards to construction safety and professional practice are important results, and one of the successes attributable in part to the CDM Regulations. There are many ways to address safety. The traditional model for construction worker H&S risk management in the US has been to rely solely on the constructor to implement primarily downstream, lower-level safety controls. Injury and fatality rates in the construction industry show that improvements in safety performance are still needed. The results of the present and previous PtD research reveal that PtD is one effective intervention that can be part of a new model to successfully address and improve construction worker health and safety. Much like the current trend towards integrated project delivery (IPD) and building information modeling (BIM), it is a model which involves integration of design and construction, collaboration between all project team members, and all parties playing a role. It is also a model in which a choice is made to design out the hazards before construction begins rather than protecting against them during construction.

Changing an industry such that it adopts a new model for construction worker H&S risk management is a difficult prospect. Making the change requires recognition that the current model, identified and held onto tightly as being standard practice, is not the best model. It must be accepted that standard practice is not necessarily synonymous with best practice. This point is highlighted in the T.J. Hooper legal case (Eastern Transportation Co. v. Northern Barge Corp., 60 F.2d 737). This 1932 case centered on ocean-going barges lost in a storm, including one named T.J. Hooper, that were not equipped with radio receiving sets to receive storm warnings. Billings Learned Hand, US Court of Appeals Second Circuit Judge, responded with the Court’s opinion regarding whether the barges should have had receiving stets onboard as follows:

“Is it then a final answer that the business had not yet generally adopted receiving sets? There are, no doubt, cases where courts seem to make the general practice of the calling the standard of proper diligence; we have indeed given some currency to the notion ourselves. Indeed in most cases reasonable prudence is in fact common prudence; but strictly it is never its measure; a whole calling may have unduly lagged in the adoption of new and available devices. It never may set its own tests, however persuasive be its usages. Courts must in the end say what is required; there are precautions so imperative that even their universal disregard will not excuse their omission.”

PtD as a construction safety intervention is currently being employed, not only in the UK and other countries, but also by some companies in the US. Information from the present and previous studies is available on how to implement it, potential barriers, enabling processes and tools, and expected impacts. Successful diffusion of PtD throughout the US construction industry requires dissemination of this information together with promotion of the concept.

In the 1950s, Dr. Alice Stewart, an award-winning epidemiologist at Oxford University in the UK, began her career studying childhood cancer (Greene 2001). Through extensive statistical analysis of data on children with cancer, Dr. Stewart found a convincing link between pre-natal
radiation exposure and cancer rates. However, such findings were not initially accepted by the medical community. At the time, nuclear energy and radiation treatments were new and filled with great potential. The medical community could not believe that this new technology, and certainly not the medical community itself, could be harmful to children. As a result, it took 25 years and additional studies before the use of x-rays during pregnancy and early childhood was curtailed (Greene 2001). Similarly, for PtD, an environment of acceptance is needed for it to diffuse throughout the industry. Those in architecture, engineering, and construction who are involved in its implementation must accept that current practice is insufficient and should be augmented with the inclusion of PtD. Causing this change, a change that requires internal reflection by the design community on its own practices, has so far been slow to occur and spurned by many. Continued reflection and consideration by the design community, and diligence by industry organizations in PtD promotion, are needed.
VIII. RECOMMENDATIONS

The research study was successful in providing information that can be used to develop recommendations for effective diffusion and implementation of the PtD concept within the US construction industry. Actions undertaken to expand PtD in the US must be selected and implemented with consideration given to the structure and nature of both the US construction industry and the PtD concept. Doing so increases the likelihood of PtD acceptance and diffusion, and ultimately its effectiveness and impact. The following recommendations are intended to provide guidance on how to expand and optimize PtD in construction for those involved in PtD promotion and implementation. The recommendations were identified and fashioned based on the results of the present study along with the researcher’s knowledge of PtD and the construction industry from prior research and experience.

Diffusion and implementation of a construction worker H&S intervention such as PtD requires attention to four key attributes: knowledge, desire (motivation), ability, and execution. Each attribute addresses a fundamental need for affecting positive change and enabling desired outcomes. The research findings reveal that each of the attributes needs to be fulfilled in some way to realize PtD success. For each attribute, a variety of components exist to address and accentuate the attribute within the context of PtD in the US construction industry. Selection and pursuit of each component depends on the resources available and industry environment. The key attributes and related components are shown in Figure 10.

![Figure 10. Attributes and Components for PtD Diffusion and Implementation](image)

Recommendations regarding the selection and implementation of each component are described in detail below. Careful consideration should be given to the selection, pursuit, and timing of components included in a PtD action plan. The availability of resources, industry
culture, political environment, and timing of implementation (i.e., the right information at the right time) must be considered. While a listed component may support a given attribute, its implementation may not be desired, or may be delayed, based on the current nature of the construction industry and expected impacts of implementation.

**Knowledge of PtD**

Increasing knowledge of the PtD concept within the US construction industry is the starting point for its diffusion and implementation. Project team members, and especially designers, need to know what PtD is and what it is not. The hierarchy of controls for OSH risk management is an integral part of PtD. The importance and application of the hierarchy of controls to the construction industry, especially in regards to construction worker H&S, also need to be known and understood by architects, engineers, and constructors. Lastly, project team members need to know what outcomes to expect when implementing PtD. An understanding of the expected impacts provides confidence and direction to those instituting the change.

Knowledge of PtD can be increased through incorporation of PtD concepts into: (1) education and training programs, (2) design and construction references, (3) academic and professional conferences and meetings, and (4) industry and academic literature. These efforts should include the descriptions of PtD and the knowledge and skills designers and other professionals need to acquire to foster and create education programs (in-house or elsewhere) to ensure that all have an opportunity to contribute their full potential (Christensen 2011). Supporting resources can be in the form of textbooks, case studies, slide presentations, and similar educational and training tools. Early adopters and champions of the PtD concept can provide demonstration projects and case studies so that the design industry can learn about the methods that work and do not work, i.e., the trickle-down concept (Behm and Culvenor 2011). These efforts would likely best be accomplished through government demonstration projects and partnerships with recognized industry leaders and industry associations.

Consideration should also be given to how PtD is characterized and presented. Managing safety risk through the design is the focus of PtD. Identifying PtD as a design concept, as opposed to a safety program, will be more attractive to the design community. The focus of PtD is on improving the design, which is part of the designer’s scope of work. Designers typically do not control or prescribe the construction means and methods, but they do control the design. Concentrating attention on the design, on constructability, and on the multiple project performance criteria that PtD positively affects (quality, cost, safety, and productivity) will help gain acceptance and maintain interest from designers. It also supports the message that designers can play a role in improving construction safety and that their role has value to the success of the project.

**Desire to Implement PtD**

After gaining a thorough understanding of PtD, motivation to change and implement PtD is needed. Given the existence of prior PtD research and current availability of information and
resources to support PtD implementation, this attribute is perhaps the most important to future diffusion of PtD across the US. It is likely the most difficult to materially and constructively affect as well due to the environment and fragmentation within the construction industry and the uncertainty associated with assessing and managing project risk. The following components will enhance the desire to implement PtD within the construction industry. As mentioned previously, careful consideration should be given to the likely acceptance and potential impacts of the components when planning actions to take to diffuse PtD within the US.

- **Contract**: Promote the inclusion of PtD roles, responsibility, and practice in design and construction contracts. Contractual obligations provide direction to designers and constructors on projects. When owners/clients include PtD practices in their contracts, design and construction firms will respond by incorporating PtD into their work practices. This effort can be undertaken by reaching out to owner organizations and associations, and by working collaboratively with publishers of standard design and construction contracts, to incorporate language on PtD in their contracts. Collaboration with insurance providers should occur as well to modify design and construction insurance policies, if needed, to account for and fairly allocate associated risk.

- **Business case – Return on Investment (ROI)**: Explain and promote the financial incentives associated with PtD. The relationship between PtD and construction project business measures should be researched more thoroughly (Behm and Culvenor 2011), and practical models should be created for evaluating and determining the associated return on investment. Representative case study examples should be prepared and made available to demonstrate the business case to project stakeholders. Those implementing PtD need to know what benefits they receive from implementation, as well as the costs of implementation. An understanding of the expected magnitude of the benefits and costs is also needed. Understanding the business case is especially important to design firms which may not immediately grasp the benefits of PtD to their firm if they are not the direct employers of the construction workers. In addition, potential economic disadvantages to one or more stakeholders must be recognized, and equitable compensation must be designed and incorporated into a PtD policy (Toole et al. 2013) and the project compensation structure.

- **Recognition**: Support the development of practices to formally recognize PtD implementation at the project, organization, and industry levels. Recognition is one factor that carries substantial influence in motivating employees, and has been identified as a driver of both innovation and PtD implementation (Gambatese and Hallowell 2011; Toole et al. 2012). Project team members who receive formal recognition of their PtD efforts and success will be motivated to repeat and expand its implementation. Recognition can occur in many ways. For example, owners/clients could include success in PtD as a criterion when selecting design firms, or include
success in PtD as an incentive in contracts. Given the benefit that PtD can provide to innovation, organizations can formally recognize employees who come up with new PtD solutions. At the industry level, industry associations or government agencies could create and present a national PtD award to those firms or projects which exemplify excellence in PtD practice. Pursuit of these and other opportunities for recognition is highly recommended.

- **Regulation**: Develop and promote the approval of formal legislation supporting the inclusion of PtD in project design and development and in efforts to ensure construction worker H&S. The CDM Regulations in the UK are an example of how legislation can be used to motivate the construction industry to implement PtD. As described above, the present and previous studies reveal how PtD is now implemented to a greater extent in the UK compared to before the ratification of the Regulations. In addition, almost all (97%) of the survey participants in the present study indicated that they would still practice PtD, as currently practiced or in some other form, if the Regulations were now abolished. If selected as a component to improve the desire to implement PtD, the CDM Regulations would be a good model as a starting point for discussion.

However, many of the study participants recommend against pursuing formal PtD legislation in the US. Previous studies involving construction industry professionals here in the US also indicate that legislation is not a desired option. An aversion to legislated control of design, construction, and overall business practices in the US, along with the difficulties in fairly and consistently regulating such a large and diverse industry, greatly discourage the use of regulations as a motivator to implement PtD. Rather, if and before regulations are considered, efforts should be focused on developing supporting resources and an accepting culture for PtD. “The proper environment is needed to ensure a positive mood among the design community. If regulations are sought, the proper environment must be sought prior to the regulations” (Behm and Culvenor 2011). In addition, as different PtD processes and practices are developed and tested, what constitutes best practice will begin to take shape. Any prescriptive legislation which controls PtD implementation will be premature and limiting if it is enacted prior to the identification, acceptance, and regular implementation of best practices. That is, to be effective, regulations should prescribe best practice, not necessarily current practice, and not inhibit innovations in practice. Nobody likes to be told what to do without understanding the reasons behind the required actions. “Rather than merely focusing on legal compliance, designers need to see the rationale and effects of implementing safety into their designs. This attitudinal and behavioural change will occur when we have the right balance of elements to develop knowledge, capacity, and motivation to comply” (Langan 2009). As opposed to prescriptive legislation, self-regulation works well in the US in terms of compensating persons harmed by defective products and in influencing suppliers to reduce risk and prevent injuries (Main 2008). With self-regulation, organizations will become adaptive to enable designers to do
innovative thinking rather than constrain them through rules and standards (Behm et al. 2011). Similar self-regulation is recommended for PtD in the US at this time as well.

- **Duty:** Promote the inclusion of PtD in the standard of care of design professionals. Standard of care defines the degree of prudence and caution required of an individual who is in a position of care. For design professionals, the standard of care is determined by the standard that would be exercised by the reasonably prudent designer in the specific line of work. As learned professionals, designers have a duty to exercise such standard of care in their work. “One who undertakes to render professional services is under a duty to the person for whom the service is to be performed to exercise such care, skill, and diligence as men in that profession ordinarily exercise under like circumstances” (City of Eveleth v. Ruble, 302 Minn. 249, 253; 225 N.W.2d 521, 524). Breach of the duty (i.e., failure to perform according to the standard of care) constitutes a tort. Construction safety has been judged to be within the standard of care for design professionals. For example, the ruling in Hanna v. Huer, Johns, Neel, Rivers and Webb (233 Kan. 206, 662 P.2d 243) states, “An architect or engineer cannot stand idly by with actual knowledge of unsafe designs or construction practices and not take steps to address the hazards.” Promoting PtD within the defined standard of care for the design profession will act as a motivator for its implementation and is recommended. Such a result will also likely be a natural consequence of expanded diffusion and implementation of PtD in the US.

- **Morals/Ethics:** Endorse PtD implementation as a moral imperative and ethical responsibility. Personal beliefs are strong motivators for action. Motivation is also gained when the actions are supported and prescribed by one’s own profession. The research findings show that attitude towards and acceptance of PtD are greater for those who hold PtD as a moral imperative. Emphasis on safety and health is also found in professional codes of ethics. For example, as indicated previously, the code of ethics for the National Society of Professional Engineers (NSPE) states, “Engineers shall hold paramount the safety, health, and welfare of the public.” Promotion of PtD as being both morally and ethically responsible is recommended. This effort should focus on the design disciplines and be conducted in collaboration with professional associations such as the American Society of Civil Engineers (ASCE) and the American Institute of Architects (AIA).

- **Innovation:** Promote the benefits of PtD to innovation. Innovation is an exciting and attractive proposition, and potentially financially rewarding. The desire to innovate can also be a motivator. Those driven to innovate may expend significant amounts of time and energy in the pursuit of something new. Implementing PtD has been recognized as a means to enhance innovation (Behm et al. 2011). That is, as project teams study designs with the intent to optimize the design for construction worker H&S, new designs and new construction methods can arise. PtD offers designers the freedom to think, which is enabling because that is what they are good at doing (Behm et al. 2011). The research study revealed that innovative ideas
have resulted from the implementation of PtD. Promoting PtD as an avenue to innovation is recommended as one component of an action plan to help diffuse PtD in the US. To do so, examples of innovative ideas that were generated as part of a PtD process should be developed, published, and disseminated.

**Ability to Implement PtD**

In conjunction with the desire to implement PtD, the ability to implement PtD is needed in order for it to diffuse in the US. In the UK, concerns about not being able to respond to the CDM Regulations due to a lack of education, training, and resources were initially brought up (Anderson 2000; Baxendale and Jones 2000). Over the years since their enactment, useful resources, tools, and practical guidance have arisen in the UK to support the implementation of PtD. A similar ability needs to be established in the US. Resources and tools to identify hazards, assess risks, and develop and select safe designs need to be in place. Designers and constructors need to be able to recognize jobsite safety hazards during the design stage. Once the hazards are identified, project teams need to be able to identify and develop alternative solutions which lead to safer construction. Otherwise, selection of lower level safety controls (e.g., PPE) is likely. Based on the study findings, it is recommended that focus should be placed on the development and dissemination of resources and tools which support and enhance the ability of project teams to implement PtD. This can be accomplished through the development and publication of resources and tools which: highlight the safety hazards associated with specific designs; assist in the assessment of construction OSH risk associated with designs; and present databases of safe design solutions.

Two key aspects related to ability are timing and foreseeability. The ability of design professionals to mitigate OSH risk in their designs is dependent on the timing in which needed PtD information is available. Information about potential hazards, for example, is needed before the design is complete so that the design can be modified if needed before it becomes infeasible to do so. Meeting this need often requires constructor involvement in the design to provide the needed expertise. In addition, those involved in the design need to be able to foresee the OSH hazards associated with the expected construction means and methods. Identifying the hazards can be difficult when looking at simple design drawings, especially for very complex structures. Electronic visualization, virtual reality, and 4-D drawing tools greatly assist in this effort. Further efforts to promote effective timing of PtD activities and the development and use of tools to visualize the design and the construction process, are recommended.

**PtD Execution**

Lastly, successful diffusion and implementation of PtD requires execution. Given the desire and ability to implement PtD, the next requirement is to actually implement it. It is important for design professionals to understand that, while they may not contractually have the responsibility for safety of construction workers, designers still play an important and valued role in making jobsites safer. This role takes place through the design within their contracted
scope of work. Continued and expanded communication of the role of design professionals in PtD is recommended. Design publications, professional conferences, education and training programs, and other professional outreach settings are examples of opportunities through which this role can be communicated.

Incorporating PtD within the design scope of work essentially constitutes including construction worker H&S as an additional design criterion along with structural integrity, cost, quality, sustainability, etc. Conflict can arise when trying to optimize all of the project performance criteria. To enhance PtD, construction safety needs to be both included as a design criterion, and given high priority with respect to other design criteria. In addition, the owner/client needs to communicate both of these conditions to the project team. Project-specific design objectives and measurable performance standards should then be developed and audited to confirm and optimize their attainment. It is recommended that those involved in diffusing PtD in the US promote the inclusion of construction safety as a design criterion and that it be given high priority. This can be accomplished through continued outreach to design and owner/client organizations, and the development and publication of case studies which show the benefits of designing for safety to total cost, duration, quality, productivity, and other project characteristics.

Execution of PtD on a regular basis can be greatly facilitated through the application of standard practices. Standard PtD practices are beginning to develop in the UK which help to ensure that PtD is included in projects and is implemented consistently and with high quality. Standards could be developed on how to conduct safety in design reviews, assess and value risk, and select appropriate risk mitigation options. Clarity on the selection of H&S controls and the extent to which hazards should be designed out within practical limits, are especially important. During the course of the research, it was found that some of the participants are uncertain as to how far they need to go in terms of designing out hazards. That is, given practical limitations of projects, in some cases it may be more prudent to manage the risk through the constructor’s capabilities and influence rather than through the design. Hazard analysis and risk assessment and mitigation procedures must be established to ensure that projects achieve an acceptable level of risk (Christensen 2011). To do so, there must be collaboration between owners/clients, designers, constructors, and other functions, including H&S. Standards for PtD in construction should be developed and made available. Government agencies could collaborate with private industry to assist with developing standards, which the government agencies can then adopt by reference. In this manner partnering between industry organizations and governments may prove to be an effective means to increase safety in design. This approach may provide the benefits of self-regulation with the enforcement of government regulations (Main 2008).

Implementation of PtD on projects can also be limited if there is unclear authority and responsibility for doing so. Depending on the nature and extent, design modifications may affect the use, appearance, cost, value, and other aspects of a completed facility. When there is a lack of confidence in the extent to which a design is allowed to be modified to improve construction safety, alternative lower level risk mitigation alternatives may be selected.
Responsibility for implementing PtD should be clearly communicated to an appropriate project team member by the owner/client. Additionally, the team member with the responsibility should be given the authority to make design changes when warranted. It is recommended that efforts be taken to work with owner/client groups to communicate the need to assign authority and responsibility for PtD on projects.

Implementing the PtD concept can stimulate innovation and creativity in design (Behm and Culvenor 2011). Likewise, the ability to innovate may be necessary in order to design out hazards. In some cases, when a hazard is identified, it may be difficult to initially identify design alternatives to mitigate the risk. The ability to visualize and create alternative designs can facilitate designing out the hazards as opposed to defaulting to an administrative control, PPE, or other lower level control measure. Efforts to promote innovation in design throughout the design community are recommended to enhance PtD.

**Summary and Outcomes**

The research study provided valuable evidence of the potential organizational and professional impacts of implementing the PtD concept in the US. The recommendations presented above are intended to provide guidance on developing a strategy for effective implementation of PtD. There are a variety of components which can be included in an action plan to address each of the key attributes for successful diffusion and implementation. All or a subset may be selected and pursued. Further research into the PtD concept – in particular, understanding and promoting the business-case need for it – is crucial to its acceptance and implementation by industry. A combined approach of strategic action plans with measurable targets, publicity, and educational campaigns will also help in this regard” (Langan 2009). As a result, and with widespread and continued implementation, it is expected that the occupational safety and health performance of the US construction industry will improve. Importantly, PtD provides an opportunity to change our perspective of how we address OSH in construction. Viewing safe design as an opportunity rather than a pain is a positive first step in the maturity path to a generative environment (Behm et al. 2011).
IX. REFERENCES


Construction: Proceedings from a Research and Practice Symposium, September 15-16, Portland, Oregon, USA, pp. 165-177.


APPENDIX A: FOCUS GROUP QUESTIONS

Prevention through Design Focus Group Interviews

INTRODUCTION

Loughborough University is assisting the National Institute for Occupational Safety and Health (NIOSH) in the United States with a study of the Prevention through Design (PtD) concept, also known as Design for Safety, in the design and construction sector. The study focuses in part on the application of the PtD concept to the design of the permanent features of a facility to enhance the health and safety of the construction workers. NIOSH is interested in learning about the U.K.’s experience with PtD through the CDM regulations in order to develop guidance documents for the implementation of the PtD concept in the U.S.

As part of the study, NIOSH is conducting focus group interviews of representatives from six different professional “communities” within the U.K. construction industry: architects, design engineers, facility owners/developers, constructors (general contractors and trade contractors), manufacturers/suppliers, and health and safety consultants. The focus group interviews are intended to gather information on organizational and industry impacts related to safety and health perceptions, roles, and culture that result from implementation of the PtD concept. In addition, NIOSH is interested in learning about innovative processes and products that have evolved from the implementation of the PtD concept.

Please respond to the following questions. Your responses will be kept confidential and summarized results from the research will not identify individual participants or companies.

If you have any questions or comments about the interview, or would like additional information about the study, please contact Dr. Alistair Gibb at A.G.Gibb@lboro.ac.uk, or Dr. John Gambatese at john.gambatese@oregonstate.edu. You can also find more information about PtD in the U.S. at: http://www.cdc.gov/niosh/topics/PTD.

Thank you for your participation! We very much appreciate your taking some time to participate in the survey and to communicate your attitudes and experiences regarding PtD.
Focus Group Interview Questions

A. BACKGROUND AND EXPERIENCE WITH PtD

1. Round robin: Can you briefly tell us about your involvement in PtD under the CDM regulations, as an individual? (How does PtD fit into your work?)

2. How does your company approach PtD concept on projects? (What process and resources are used?)

3. Is it a struggle to prioritize health and safety ahead of other project objectives, such as cost and schedule? (examples from projects)

B. ORGANIZATIONAL AND INDUSTRY IMPACTS (How PtD changed ways things are done)

4. Think back to practice before CDM - what is done differently now in your work [as architect, etc.]? Has the 2007 CDM regulations had a greater impact on your work?

5. How has PtD specifically changed the management of projects?

6. Have any project team roles changed significantly because of PtD?

C. BARRIERS AND ENABLERS TO IMPLEMENTING PtD

7. Has the biggest assistance with the implementation of PtD come from within or outside your company? (External: training, funding, cross-industry relationships) (Does CDM legislation help or hinder your application of PtD?) (Which is more powerful, internal or external?)

8. What do you feel are the barriers to implementing PtD on projects?

9. What capabilities, resources, and/or training are needed by architects and engineers in order to address construction worker health and safety in a design?
D. SPECIFIC IMPACTS AND INNOVATION OF PtD

10. What are you aware of that has had, for you and your company, a significant impact on health and safety performance, culture, and practice in construction since 1994?

11. Can you tell me about any types of innovative processes and products, both design and construction, that have been developed as a result of the PtD effort?

E. PERSPECTIVES OF PtD (people’s views/attitudes)

12. As an [engineer, etc.] how has your perception of health and safety changed since the introduction of PtD?

13. What are the industry attitudes to health and safety now as compared to before the introduction of the CDM Regulations? (in terms of organizational and professional culture)

14. Do you see PtD more as a fundamental ‘moral’ imperative or rather as a requirement from legislation, and why? (Or, would you still practice PtD if the CDM Regulations had never existed, and why?)

15. How important is PtD to construction worker health and safety compared to other health and safety programs and processes that are implemented on projects?

F. FUTURE IMPLEMENTATION OF PtD

16. How would you suggest PtD should be further developed in the future?

17. How would you change your specific role in PtD in order to enhance its effectiveness?
Please provide the following demographic information about you and your firm.

The category that best fits your firm is:

___ Architect  ___ Facility owner/developer  ___ Manufacturer/supplier
___ Design engineer  ___ Health and safety consultant  ___ Principal contractor
___ Subcontractor  ___ Other

Which of the following capabilities does your firm have within its own in-house employees and which your firm uses for its construction projects? Please select all that apply.

___ Architecture  ___ Construction  ___ Health and safety consultation
___ Engineering  ___ Project management  ___ Other: _______________________

Approximately how many employees work in your firm?

___ 0-9  ___ 50-99  ___ 250-499  ___ over 1000
___ 10-49  ___ 100-249  ___ 500-1000

Approximately what percentage of your firm’s projects is in each of the following categories?

Commercial buildings: _____ %  Infrastructure/heavy civil: _____ %
Industrial: _____ %  Residential: _____ %

What is your job title? ___________________________________________________________

Years of experience that you have in the design and construction sector as an:

Architect: _____ years  Health and safety consultant: _____ years
Design engineer: _____ years  Principal contractor: _____ years
Facility owner/developer: _____ years  Subcontractor: _____ years
Manufacturer/supplier: _____ years  Project manager: _____ years

How has each of the following changed as a result of implementing PtD on projects?

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<th>No Change</th>
<th>Increase</th>
<th>I don’t know</th>
<th>Approx. % change</th>
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<td>Design costs</td>
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<td>Construction costs</td>
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<td>Design duration</td>
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<td>Construction duration</td>
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<td>Construction quality</td>
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<td>Construction worker productivity</td>
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<td>Construction worker health and safety</td>
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<tr>
<td>End-user health and safety</td>
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<td>Other</td>
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</table>
Years of experience that you have with the CDM regulations?  ______ years

Do you hold any professional licenses, certifications, or memberships associated with the design or construction sector?  ______ Yes  ______ No  If so, please list below.
APPENDIX B: ON-LINE SURVEY QUESTIONNAIRE

Prevention through Design Survey Questionnaire

INTRODUCTION

Loughborough University and Scott Wilson Ltd. are assisting the National Institute for Occupational Safety and Health (NIOSH) in the United States with a study on the ‘Design for Safety’ concept, also known as ‘Prevention through Design’.

The study focuses in part on the application of the Design for Safety concept to the design of the permanent features of a facility to enhance the health and safety of the construction workers. NIOSH is interested in learning about the U.K.’s experience with Design for Safety through the CDM regulations in order to develop guidance documents for the implementation of the Prevention through Design concept in the U.S.

As part of the study, NIOSH is conducting a survey of the U.K. design and construction sector regarding common Design for Safety practices and project performance under the CDM regulations. We would very much appreciate your participation in the study by completing this brief survey questionnaire.

Completing the survey is expected to take no more than 10-15 minutes.

Your responses will be kept confidential and summarized results from the research will not identify individual participants or companies.

If you have any questions or comments about the survey, or would like additional information about the study, please contact Prof. Alistair Gibb at A.G.Gibb@lboro.ac.uk, or Dr. John Gambatese at john.gambatese@oregonstate.edu. You can also find more information about Prevention through Design in the U.S. at: http://www.cdc.gov/niosh/topics/PTD.

If you have any questions or comments about the survey design or tool used to create this survey, please contact Charlotte Brace (charlotte.brace@scottwilson.com) or Emma Ridsdale (emma.ridsdale@scottwilson.com).

Thank you very much in advance for your participation.

We very much appreciate you taking the time to take part in the survey and to communicate your attitudes and experiences regarding Design for Safety.
DESIGN FOR SAFETY IMPLEMENTATION

1. What professional institute(s), if any, are you a member of? (Select all that apply)
   ___ Chartered Institute of Building
   ___ Royal Institute of British Architects (RIBA)
   ___ Institution of Civil Engineers (ICE)
   ___ British Safety Council
   ___ Association for Project Safety (APS)
   ___ The Institution of Structural Engineers (IStructE)
   ___ The Institution of Mechanical Engineers (IMechE)
   ___ Chartered Institution of Building Services Engineers (CIBSE)
   ___ Royal Institution of Charters Surveyors (RICS)
   ___ Institution of Engineering and Technology (IET)
   ___ Institute of Electrical and Electronics Engineers (IEEE)
   ___ Institution of Occupational Safety and Health (IOSH)
   ___ I am not a member of any professional institutes
   ___ Other: _________________________________

2. What of the following most closely represents your involvement on Design for Safety projects? (Select 1 only)
   ___ I am an architect/engineer and incorporate designs that are safe to build in the projects which I design.
   ___ I provide Design for Safety input on project designs through design and/or constructability reviews.
   ___ I oversee and/or coordinate design professionals who incorporate Design for Safety in their designs.
   ___ I am NOT regularly involved in Design for Safety efforts on projects.
   ___ Other: _________________________________

3. Which statement best matches the Health and Safety efforts of your role on Design for Safety projects? (Select 1 only)
   ___ All of my role is specifically related to Design for Safety.
   ___ Design for Safety is integrated throughout my role (but not a specific part of my role).
   ___ Design for Safety is tagged onto a small part of my role.
   ___ Design for Safety is no part of my role on projects.
   ___ Other: _________________________________
4. What resources, if any, do you or your company typically use to address Design for Safety on projects? Please select all that apply.
   ___ Risk assessment pro forma
   ___ Risk matrix
   ___ In-house design guides
   ___ Design checklists
   ___ On-line design resources
   ___ Computer program to visualize the design
   ___ Design for Safety education and training
   ___ Design consultants (external)
   ___ In-house staff
   ___ Constructor input
   ___ Periodic design reviews
   ___ Constructability reviews
   ___ None of the above
   ___ Other: ____________________________________________

5. Which of the following tools, if any, do you or your company use to address Design for Safety on projects? Please select all that apply.
   ___ Design advice
   ___ Checklists
   ___ Any Approved Code of Practice (ACoP)
   ___ HSE Guidance – Health and Safety in Construction (HSG 150)
   ___ Safety in Design (SID)
   ___ CIRIA reports
   ___ The CONIAC Green Book
   ___ Reducing Risks Protecting People (R2P2)
   ___ British Standards
   ___ Guidance from professional institutions
   ___ Construction Hazard Assessment Implication Review (CHAIR)
   ___ None of the above
   ___ Other: ____________________________________________

6. Does your company have a formal Design for Safety process it uses on projects? (Select 1 only)
   ___ Yes
   ___ No
   ___ Don’t know

If yes, please briefly describe it below:

____________________________________________________________________
7. For each of the following work stages, please state when your involvement typically occurs on projects? (Select 1 only)

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<thead>
<tr>
<th></th>
<th>No involvement</th>
<th>Partial involvement</th>
<th>Full involvement</th>
<th>Don’t know</th>
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<tr>
<td>Preparation</td>
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<td>Design</td>
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<td>Pre-construction</td>
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<td>Construction</td>
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<td>Use</td>
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8. For each of the following project team members, please indicate in your opinion, their typical level of input to the Design for Safety process on projects?

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<tr>
<th></th>
<th>No input</th>
<th>Minimal input</th>
<th>Moderate input</th>
<th>Significant input</th>
<th>Major driver</th>
<th>No experience</th>
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<tr>
<td>Architect</td>
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<td>Design engineer</td>
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<td>Facility owner/developer</td>
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<td>Manufacturer/supplier</td>
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<td>Health and safety consultant</td>
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<td>CDM coordinator</td>
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<td>Principal contractor</td>
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<td>Subcontractor</td>
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If you have any comments, please provide them below:

___________________________________________________________________________
**DESIGN FOR SAFETY IMPACTS**

9. In your opinion, what impact does Design for Safety have on each of the following project characteristics?

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<th>Increase</th>
<th>No experience</th>
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<td>Design costs</td>
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<td>Construction costs</td>
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<tr>
<td>Total project costs</td>
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<tr>
<td>Design duration</td>
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<td>Construction duration</td>
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<tr>
<td>Total project duration</td>
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<tr>
<td>Construction quality</td>
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<tr>
<td>Construction worker productivity</td>
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</tr>
<tr>
<td>Construction worker health and safety</td>
<td></td>
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<tr>
<td>End-user health and safety</td>
<td></td>
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<tr>
<td>Your own view of the importance of health and safety</td>
<td></td>
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</tbody>
</table>

If you have any comments, please provide them below:

10. In your experience, to what extent have Design for Safety efforts affected the role of each of the different project team members on a project?

<table>
<thead>
<tr>
<th></th>
<th>Very positive impact</th>
<th>Some positive impact</th>
<th>No impact</th>
<th>Some negative impact</th>
<th>Very negative impact</th>
<th>No experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architect</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Design engineer</td>
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<tr>
<td>Facility owner/developer</td>
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<tr>
<td>Manufacturer/supplier</td>
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<tr>
<td>Health and safety consultant</td>
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<td></td>
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<tr>
<td>CDM coordinator</td>
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<tr>
<td>Principal contractor</td>
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<tr>
<td>Subcontractor</td>
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</tr>
</tbody>
</table>

If you have any comments, please provide them below:

______________________________________________________________________________

______________________________________________________________________________

158
11. To what extent has Design for Safety efforts affected the design and the construction of projects (e.g., different design features, modified construction methods, etc.)?

<table>
<thead>
<tr>
<th></th>
<th>Very positive impact</th>
<th>Some positive impact</th>
<th>No impact</th>
<th>Some negative impact</th>
<th>Very negative impact</th>
<th>No experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you have any comments, please provide them below:

________________________________________

12. Have any innovative processes and products, for both design and construction, been developed by your company to assist with implementing Design for Safety on projects?

________________________________________

DESIGN FOR SAFETY BARRIERS AND ENABLERS

13. In your experience, what do you feel are BARRIERS to implementing Design for Safety on projects? (Please select all that apply)
   ___ Architects/engineers lack the requisite knowledge and skills to design for construction worker health and safety
   ___ A lack of financial compensation for architects/engineers to consider construction worker health and safety in their designs
   ___ A lack of time available for architects/engineers to consider construction worker health and safety in their designs
   ___ Architects/engineers lack sufficient resources (tools, guidelines, etc.) to address construction worker health and safety in their designs
   ___ The effort required to address construction worker health and safety in designs is great
   ___ Other project objectives are given higher priority by architects/engineers
   ___ Other project objectives are given higher priority by project owners/clients
   ___ Construction means and methods are not known when designs are created
   ___ Other: ___________________________________________
14. In your experience, what do you feel ENABLES implementing Design for Safety on projects? (Please select all that apply)

- Architects/engineers have the required knowledge and skills to design for construction worker health and safety
- There is financial compensation for architects/engineers to consider construction worker health and safety in their designs
- Adequate time is available for architects/engineers to consider construction worker health and safety in their designs
- Architects/engineers are provided with sufficient resources (tools, guidelines, etc.) to address construction worker health and safety in their designs
- The effort required to address construction worker health and safety in designs is minimal
- Design for safety is a high priority against other project objectives by architects/engineers
- Design for safety is a high priority against other project objectives by project owners/clients
- Construction means and methods are known when designs are created
- Other: ____________________________________________

15. What motivates your company to improve its implementation of Design for Safety on projects? Please select all that apply.

<table>
<thead>
<tr>
<th>Motivation</th>
<th>Much motivation</th>
<th>Some motivation</th>
<th>Neutral</th>
<th>Little motivation</th>
<th>No motivation</th>
<th>Don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced project cost</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Shorter project schedules</td>
<td></td>
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<td></td>
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<tr>
<td>Improved construction worker health and safety</td>
<td></td>
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<td></td>
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<tr>
<td>Improved facility occupant health and safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enhanced firm reputation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved quality of construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competitive advantage</td>
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<tr>
<td>Recognition from client</td>
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<tr>
<td>Possibility of litigation against the firm</td>
<td></td>
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</tbody>
</table>

If you have any comments, please provide them below:

__________________________________________________________________________
ROLE OF CDM REGULATIONS IN DESIGN FOR SAFETY

16. To what extent does the current CDM legislation help or hinder your application of Design for Safety? (Select 1 only)
   ___ Significantly helps
   ___ Moderately helps
   ___ No impact
   ___ Moderately hinders
   ___ Significantly hinders
   ___ Don’t know

   If you have any comments, please provide them below:

   _______________________________________________________________________

17. Would you still practice Design for Safety if the CDM regulations had NEVER existed? (Select 1 only)
   ___ No, I would not be practicing Design for Safety
   ___ Yes, I would be practicing Design for Safety as currently practiced
   ___ Yes, I would be practicing Design for Safety but differently than my current practices

   If you have any comments, please provide them below:

   _______________________________________________________________________ 

18. Would you still practice Design for Safety if the CDM regulations were now ABOLISHED? (Select 1 only)
   ___ No, I would not practice Design for Safety
   ___ Yes, I would practice Design for Safety as currently practiced
   ___ Yes, I would practice Design for Safety but modify my current practices

   If you have any comments, please provide them below:

   _______________________________________________________________________
PERSPECTIVE OF DESIGN FOR SAFETY

19. Which statement best matches your overall attitude towards the Design for Safety concept? (Select 1 only)
   ____ There are no recognizable benefits of Design for Safety.
   ____ The benefits of Design for Safety are promising but there are too many barriers for it to be effective.
   ____ The benefits of Design for Safety are promising but the effort required to implement it is too great.
   ____ The expected benefits of Design for Safety are worth the effort to implement it.
   ____ Design for Safety is an important aspect of construction health and safety, and it should be given greater importance on projects.

20. In your opinion, what priority does your company place on each of the following criteria with respect to its importance on construction projects? (Please rate each criteria from 1-5 with 1 = high priority and 5 = low priority)
   Quality of the work: _____
   Project cost: _____
   Project schedule: _____
   Construction worker health and safety: _____
   Facility occupant health and safety: _____
   Aesthetics: _____

   If you have any comments, please provide them below:
   ___________________________________________________________

21. In your opinion, how important is Design for Safety to construction worker health and safety compared to other health and safety programs/processes that are implemented? (Select 1 only)
   ____ Insignificant
   ____ Less important
   ____ About the same importance
   ____ More important
   ____ Significantly more important
   ____ I don’t know

   Please list any other Health and Safety initiatives that are important to you:
   ___________________________________________________________

22. What is your perspective of Design for Safety? (Select 1 only)
   ____ Design for Safety is a fundamental ‘moral’ imperative, not just a requirement from legislation
   ____ Design for Safety is only a requirement from legislation
   ____ Other: ___________________________________________________
23. Do you have any advice or guidance with regards to implementing PtD (Design for Safety) in the U.S.?

DEMOGRAPHICS

Please provide the following demographic information about you and your company.

24. Which of the following categories best fits your organisation? (Select 1 only)
   ___ Architecture
   ___ Engineering
   ___ Construction
   ___ Health and safety consultation
   ___ Project management
   ___ Other: __________________________

25. From the following, please indicate your current role. (Select 1 only)
   ___ Architect
   ___ Design Engineer
   ___ Facility owner/developer
   ___ Manufacturer/supplier
   ___ CDM coordinator
   ___ Principal contractor
   ___ Subcontractor
   ___ Other: __________________________

26. Does your organization have any of the following capabilities in-house (amongst own employees) that are used for its construction projects? Please select all that apply.

<table>
<thead>
<tr>
<th>Role</th>
<th>Yes, in-house and used for construction projects</th>
<th>Yes, in-house but not used for construction projects</th>
<th>No, none in-house</th>
<th>Don’t know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architect</td>
<td></td>
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<tr>
<td>Design engineer</td>
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<tr>
<td>Facility owner/developer</td>
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<tr>
<td>Manufacturer/supplier</td>
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<tr>
<td>Health and safety consultant</td>
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<td>CDM coordinator</td>
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<td>Principal contractor</td>
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<tr>
<td>Subcontractor</td>
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<tr>
<td>Other:</td>
<td></td>
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</tr>
</tbody>
</table>
27. Approximately how many employees work in your organisation? (Select 1 only)
   ___ 0-9
   ___ 10-49
   ___ 50-99
   ___ 100-249
   ___ 250-499
   ___ 500-1000
   ___ 1001-5000
   ___ over 5000

28. Approximately what percentage (%) of your organisation’s projects is in each of the following categories?
   Commercial buildings: ______ %
   Industrial: ______ %
   Infrastructure/heavy civil: ______ %
   Residential: ______ %
   Other: ________________ ______ %

29. How many years of experience have you had in the design and construction sector in the following roles:
   Architect: ______ years
   Design engineer: ______ years
   Facility owner/developer: ______ years
   Manufacturer/supplier: ______ years
   Health and safety consultant: ______ years
   Principal contractor: ______ years
   Subcontractor: ______ years
   Project manager: ______ years

30. How many years of experience have you had working with the CDM regulations?
    ______ years

SUMMARY

Thank you for taking the time to complete this survey.

Your input is appreciated and valuable to the success of the research study.

If you have any questions or comments on the research topic, or would like additional information about the study, please contact Prof. Alistair Gibb at A.G.Gibb@lboro.ac.uk, or Dr. John Gambatese at john.gambatese@oregonstate.edu. You can also find more information about PtD in the U.S. at: http://www.cdc.gov/niosh/topics/PTD.
If you have any questions or comments about the survey design or tool used to create this survey (SurveyMonkey), please contact Charlotte Brace at charlotte.brace@scottwilson.com or Emma Ridsdale at emma.ridsdale@scottwilson.com.

31. If you would like a copy of the results of the survey, please provide your email address below.

32. May we contact you again with further questions about Design for Safety/PtD? If yes, please provide your contact information below:

   Name: 
   E-mail address: 
   Phone number: 
APPENDIX C: SELLAFIELD SITE VISIT FOCUS GROUP QUESTIONS

1. General demographics of participants: discipline, years of experience in construction industry, position, involvement with PtD.

2. Who do they work for? What is the project organization?

3. Is there any aspect of the culture that URS has brought that is different than what you are used to? What have been the impacts of the URS PtD program on the project?

4. How is PtD implemented? Does your company have a formal PtD process?

5. What is the level of input of the different project team members now, and what do you think it should be?

6. How is PtD impacting the project (physical features and people)? What are some examples of modifications that have been made on behalf of PtD?

7. Have any innovative processes and products been developed to assist with implementing PtD or have come out as a result of implementing PtD?

8. What are the barriers and enablers to PtD? What are motivators? Who is pushing PtD or overseeing PtD?

9. What is the culture towards health and safety on the project? What priority is given to health and safety compared to other project objectives?

10. To what extent does CDM legislation help or hinder your application of PtD?

11. Would you still practice PtD if the CDM regulations had never existed?

12. Would you still practice PtD if the CDM regulations were now abolished?

13. What would you say is your attitude towards PtD: accepting, neutral, discouraged?

14. How important is PtD compared to other health and safety programs/processes?
APPENDIX D: AUSTRALIA FOCUS GROUP QUESTIONS

A. BACKGROUND AND EXPERIENCE WITH PtD

1. Round robin: Can you briefly tell us about your involvement in PtD, as an individual? *(How does PtD fit into your work?)*
2. How does your company approach PtD concept on projects? *(What process and resources are used?)*
3. Is it a struggle to prioritize health and safety ahead of other project objectives, such as cost and schedule? *(Examples from projects)*

B. ORGANIZATIONAL AND INDUSTRY IMPACTS *(How PtD changed ways things are done)*

4. Think back to practice before you implemented PtD (or before the PtD regulations) - what is done differently now in your work [as architect, etc.]? Has there been an impact on your work?
5. How has PtD specifically changed the management of projects?
6. Have any project team roles *roles* changed significantly because of PtD?

C. BARRIERS AND ENABLERS TO IMPLEMENTING PtD

7. Has the biggest assistance with the implementation of PtD come from within or outside your company? *(External: training, funding, cross-industry relationships)* *(Does legislation help or hinder your application of PtD?)* *(Which is more powerful, internal or external?)*
8. What do you feel are the barriers to implementing PtD on projects?
9. What capabilities, resources, and/or training are needed by architects and engineers in order to address construction worker health and safety in a design?

D. SPECIFIC IMPACTS AND INNOVATION OF PtD

10. What are you aware of that has had, for you and your company, a significant impact on health and safety performance, culture, and practice in construction?
11. Can you tell me about any types of innovative processes and products, both design and construction, that have been developed as a result of the PtD effort?

E. PERSPECTIVES OF PtD *(People’s views/attitudes)*

12. As an [engineer, etc.] how has your perception of health and safety changed since the introduction of PtD?
13. What are the industry attitudes to health and safety now as compared to before the introduction of PtD and/or PtD legislation? *(in terms of organizational and professional culture)*
14. Do you see PtD more as a fundamental ‘moral’ imperative or rather as a requirement from legislation, and why? (Or would you still practice PtD if the legislation had never existed, and why?)
15. How important is PtD to construction worker health and safety compared to other health and safety programs and processes that are implemented on projects?

F. FUTURE IMPLEMENTATION OF PtD

16. How would you suggest PtD should be further developed in the future?
17. How would you change your specific role in PtD in order to enhance its effectiveness?
APPENDIX E: ON-LINE SURVEY ANALYSIS SUMMARY RESULTS

The following tables provide a summary of the results from the Chi-squared tests of the on-line survey data. The information provided in each table includes the following: independent variable name and value, dependent variable name and value, odds ratio, p-value that the odds ratio is different than 1.0, and the lower and upper bounds for the 95% confidence interval for the odds ratio. The following description provides an example of how to interpret the data in the tables:

Example: A test was conducted to determine whether the timing of involvement in projects (Question 7) is a determining factor in the respondent’s opinion regarding the impact of PtD on design costs (Question 9). For this test, the respondents were separated into three groups: (1) those who are not involved, (2) those who are fully involved, and (3) those who are involved either partially or fully. The analysis results show that those respondents who are involved, either partially or fully, in the planning/preparation stage, are 2.86 times as likely to report an increase in design cost due to PtD as compared to those who are not involved with a one-sided p-value of 0.0021 that the odds ratio is different than 1.0 and a 95% confidence interval from 1.37 to 5.96 for the odds ratio.

Tests were conducted for all of the identified independent and dependent variables indicated in Table 7 in Section VI of the report. For the results of each test, only 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, are included in the summary tables below.

The variables and possible values for each variable used in the analyses are as follows:

- Independent variables:
  - Years of work experience (Question 29)
    - None = no experience
    - Low = <5 years of experience (new to role)
    - Medium = 5 – 10 years of experience
    - High = 10 – 15 years of experience
    - Extensive = >15 years of experience
  - Timing of involvement in projects (Question 7)
    - Fully involved = full involvement in specific phase under consideration
    - Involved = either partial or full involvement in specific phase under consideration
    - Not involved = no involvement in specific phase under consideration
  - Role on the project (Question 25)
    - Architect
    - Design engineer
    - Facility owner/developer
Manufacturer/supplier
CDM coordinator
Principal contractor
Subcontractor

- Performance criteria priority (Question 20)
  - High priority (1)
  - Above average priority (2)
  - Average priority (3)
  - Below average priority (4)
  - Low priority (5)

- Organization’s industry sector (Question 28): commercial buildings, industrial, infrastructure/heavy civil, or residential
  - Involved = >50% of organization’s projects in industry sector
  - Not involved = <50% of organization’s projects in industry sector

- Type of firm (Question 24)
  - Architecture
  - Engineering
  - Construction
  - H&S consultant
  - Project management

- Firm capabilities (Question 26)
  - In-house + Const = in-house and used for construction projects
  - In-house = in-house but not used for construction projects
  - None = no in-house capabilities

- Size of firm (Question 27)
  - 0-9 employees
  - 10-49 employees
  - 50-99 employees
  - 100-249 employees
  - 250-499 employees
  - 500-1,000 employees
  - 1,001-5,000 employees
  - Over 5,000 employees

- Extent of involvement in PtD (aggregate of the following three questions):
  - Question 2: Type of involvement in PtD
    - Work as designer and incorporate H&S in designs = 1
    - Provide H&S input through constructability reviews = 1
    - Oversee others who implement PtD = 1
    - No regular involvement = 0
  - Question 3: Extent to which PtD is part of personal H&S efforts/role
    - All of role related to PtD = 1
    - Integrated throughout, but not a specific part = 1
    - Only small part of role = 0
    - Not part of role = 0
Question 30: Years of experience working with CDM Regulations
   3 or more years = 1
   Less than 3 years = 0
For the extent of involvement in PtD, the values corresponding to their responses were summed to get an overall involvement score. The total score can range from 0 to 3, with 0 = no involvement, 1 = low involvement, 2 = medium involvement, and 3 = high involvement. This involvement score was used as the value for the independent variable in the analyses.

- Dependent variables:
  - Impact of PtD on different project performance criteria (Question 9)
    Increase = performance criterion increases/improves
    Decrease = performance criterion decreases/declines
    No change = performance criterion does not change
  - Impact of PtD on each project team member role (Question 10), filtered by respondent role (Question 25)
    Positive = positive impact on role
    Negative = negative impact on role
  - Impact of PtD on project design or construction (Question 11)
    Positive = improvement in design or construction
    Negative = adverse effect on design or construction
  - Impact of CDM legislation on PtD implementation (Question 16)
    Helps = positive impact on PtD implementation
    Hinders = negative impact on PtD implementation
  - Attitude toward PtD (aggregate of the following five questions):
    Question 17: Practice PtD if CDM Regulations never existed?
      Yes, as currently practiced = 1
      Yes, but differently = 1
      No = 0
    Question 18: Still practice PtD if CDM Regulations were abolished?
      Yes, as currently practiced = 1
      Yes, but differently = 1
      No = 0
    Question 19: Overall attitude towards PtD?
      Important and should be given greater importance = 1
      Benefits are worth the effort = 1
      Benefits are promising but not worth the effort = 0
      Benefits are promising but too many barriers = 0
      No benefits = 0
    Question 21: How important is PtD compared to other H&S programs/processes?
      Significantly more important = 1
      More important = 1
      About the same importance = 0
Less important = 0
Insignificant = 0
I don’t know = 0

Question 22: Perspective of PtD?
PtD is a fundamental, moral imperative = 1
PtD is only a requirement from legislation = 0

For the overall attitude towards PtD, the values corresponding to their responses were summed to get an overall attitude score. The total score can range from 0 to 5, with 0 = very negative attitude, 1 = negative attitude, 2 = poor attitude, 3 = medium attitude, 4 = positive attitude, and 5 = very positive attitude. This attitude score was used as the value for the dependent variable in the analyses.
**Test No.:** 1.1

**Independent variable:** Years of work experience (Question 29)

**Dependent variable:** Impact of PtD on different project performance criteria (Question 9)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Arch. experience</td>
<td>None</td>
<td>Design cost</td>
<td>Increase</td>
<td>2.94</td>
</tr>
<tr>
<td>2</td>
<td>Arch. experience</td>
<td>None</td>
<td>Construction duration</td>
<td>Increase</td>
<td>2.75</td>
</tr>
<tr>
<td>3</td>
<td>Arch. experience</td>
<td>None</td>
<td>Total project duration</td>
<td>Increase</td>
<td>3.72</td>
</tr>
<tr>
<td>4</td>
<td>Arch. experience</td>
<td>Low, medium, high</td>
<td>Worker productivity</td>
<td>Increase</td>
<td>9.33</td>
</tr>
<tr>
<td>5</td>
<td>Des. engr. exper.</td>
<td>Any</td>
<td>Construction cost</td>
<td>Increase</td>
<td>2.01</td>
</tr>
<tr>
<td>6</td>
<td>Des. engr. exper.</td>
<td>Any</td>
<td>Total project cost</td>
<td>Increase</td>
<td>2.18</td>
</tr>
<tr>
<td>7</td>
<td>Des. engr. exper.</td>
<td>None</td>
<td>Worker productivity</td>
<td>Increase</td>
<td>1.83</td>
</tr>
<tr>
<td>8</td>
<td>H&amp;S consult. exp.</td>
<td>None</td>
<td>Construction cost</td>
<td>Increase</td>
<td>3.54</td>
</tr>
<tr>
<td>9</td>
<td>H&amp;S consult. exp.</td>
<td>Any</td>
<td>Construction cost</td>
<td>Decrease</td>
<td>5.40</td>
</tr>
<tr>
<td>10</td>
<td>H&amp;S consult. exp.</td>
<td>None</td>
<td>Total project cost</td>
<td>Increase</td>
<td>2.93</td>
</tr>
<tr>
<td>11</td>
<td>H&amp;S consult. exp.</td>
<td>None</td>
<td>Construction duration</td>
<td>Increase</td>
<td>2.64</td>
</tr>
<tr>
<td>12</td>
<td>H&amp;S consult. exp.</td>
<td>None</td>
<td>Total project duration</td>
<td>Increase</td>
<td>3.21</td>
</tr>
<tr>
<td>13</td>
<td>Contractor exp.</td>
<td>Any</td>
<td>Construction duration</td>
<td>Decrease</td>
<td>2.21</td>
</tr>
<tr>
<td>14</td>
<td>Subcontract. exp.</td>
<td>Low, medium</td>
<td>Worker productivity</td>
<td>Increase</td>
<td>7.33</td>
</tr>
</tbody>
</table>
Test No.: 1.2

Independent variable: Years of work experience (Question 29)

Dependent variable: Impact of PtD on each project team member role (Question 10), filtered by respondent role (Question 25)

Chi-squared odds ratio test results (significant results only):

There were no test results 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.
Test No.: 1.3

**Independent variable:** Years of work experience (Question 29)

**Dependent variable:** Impact of PtD on project design or construction (Question 11)

**Chi-squared odds ratio test results (significant results only):**

There were no test results 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.
Test No.: 1.4

Independent variable: Years of work experience (Question 29)

Dependent variable: Impact of CDM legislation on PtD implementation (Question 16)

Chi-squared odds ratio test results (significant results only):

There were no test results 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.
Test No.: 1.5

Independent variable: Years of work experience (Question 29)

Dependent variable: Attitude toward PtD (Q17+Q18+Q19+Q21+Q22)

Chi-squared odds ratio test results (significant results only):

There were no test results 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.
Test No.: 2.1

**Independent variable:** Extent of involvement in PtD (Q2+Q3+Q30)

**Dependent variable:** Impact of PtD on different project performance criteria (Question 9)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Extent of PtD involvement</td>
<td>None, low, medium</td>
<td>Construction duration</td>
<td>Increase</td>
<td>2.20</td>
</tr>
<tr>
<td>2</td>
<td>Extent of PtD involvement</td>
<td>Medium, high</td>
<td>Construction quality</td>
<td>Increase</td>
<td>2.24</td>
</tr>
<tr>
<td>3</td>
<td>Extent of PtD involvement</td>
<td>Medium, high</td>
<td>Worker productivity</td>
<td>Increase</td>
<td>2.31</td>
</tr>
<tr>
<td>4</td>
<td>Extent of PtD involvement</td>
<td>Medium, high</td>
<td>Construction H&amp;S</td>
<td>Increase</td>
<td>4.83</td>
</tr>
<tr>
<td>5</td>
<td>Extent of PtD involvement</td>
<td>High</td>
<td>Construction H&amp;S</td>
<td>Increase</td>
<td>3.16</td>
</tr>
<tr>
<td>6</td>
<td>Extent of PtD involvement</td>
<td>Medium, high</td>
<td>End-user H&amp;S</td>
<td>Increase</td>
<td>5.82</td>
</tr>
<tr>
<td>7</td>
<td>Extent of PtD involvement</td>
<td>High</td>
<td>End-user H&amp;S</td>
<td>Increase</td>
<td>3.74</td>
</tr>
</tbody>
</table>

**Ordered contingency Chi-squared test results (significant results only):**

- The greater the level of involvement in PtD, the more likely the respondent will have an opinion that the construction duration increases (one-sided p-value = 0.002).
- The greater the level of involvement in PtD, the more likely the respondent will have an opinion that PtD increases construction worker H&S (one-sided p-value = 0.002).
- The greater the level of involvement in PtD, the more likely the respondent will have an opinion that PtD increases end-user H&S (one-sided p-value = 0.0000).
Test No.: 2.2

Independent variable: Extent of involvement in PtD (Q2+Q3+Q30)

Dependent variable: Impact of PtD on each project team member role (Question 10), filtered by respondent role (Question 25)

Chi-squared odds ratio test results (significant results only):

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Value</th>
<th>Dependent variable</th>
<th>Value</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Variable</td>
<td>Value</td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Extent of PtD involvement</td>
<td>Medium, high</td>
<td>Impact on owner role (contractor responses)</td>
<td>Positive</td>
<td>4.13</td>
<td>0.0161</td>
<td>1.07</td>
</tr>
<tr>
<td>2</td>
<td>Extent of PtD involvement</td>
<td>High</td>
<td>Impact on owner role (contractor responses)</td>
<td>Positive</td>
<td>4.09</td>
<td>0.0045</td>
<td>1.32</td>
</tr>
<tr>
<td>3</td>
<td>Extent of PtD involvement</td>
<td>High</td>
<td>Impact on manufacturer/supplier role (designer responses)</td>
<td>Positive</td>
<td>6.19</td>
<td>0.0027</td>
<td>1.55</td>
</tr>
<tr>
<td>4</td>
<td>Extent of PtD involvement</td>
<td>High</td>
<td>Impact on CDM coordinator role (designer responses)</td>
<td>Positive</td>
<td>5.57</td>
<td>0.0136</td>
<td>1.01</td>
</tr>
<tr>
<td>5</td>
<td>Extent of PtD involvement</td>
<td>High</td>
<td>Impact on principal contractor role (designer responses)</td>
<td>Positive</td>
<td>24.5</td>
<td>0.0001</td>
<td>1.69</td>
</tr>
<tr>
<td>6</td>
<td>Extent of PtD involvement</td>
<td>High</td>
<td>Impact on subcontractor role (designer responses)</td>
<td>Positive</td>
<td>6.22</td>
<td>0.0040</td>
<td>1.42</td>
</tr>
</tbody>
</table>
**Test No.:** 2.3

**Independent variable:** Extent of involvement in PtD (Q2+Q3+Q30)

**Dependent variable:** Impact of PtD on project design or construction (Question 11)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Value</th>
<th>Dependent variable</th>
<th>Value</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Extent of PtD involvement</td>
<td>Medium, high</td>
<td>Impact on design</td>
<td>Positive</td>
<td>5.28</td>
<td>0.0012</td>
<td>1.60</td>
</tr>
<tr>
<td>2</td>
<td>Extent of PtD involvement</td>
<td>High</td>
<td>Impact on design</td>
<td>Positive</td>
<td>3.47</td>
<td>0.0011</td>
<td>1.41</td>
</tr>
<tr>
<td>3</td>
<td>Extent of PtD involvement</td>
<td>Medium, high</td>
<td>Impact on construction</td>
<td>Positive</td>
<td>7.16</td>
<td>0.0007</td>
<td>1.71</td>
</tr>
<tr>
<td>4</td>
<td>Extent of PtD involvement</td>
<td>High</td>
<td>Impact on construction</td>
<td>Positive</td>
<td>3.07</td>
<td>0.0073</td>
<td>1.13</td>
</tr>
</tbody>
</table>
Test No.: 2.4

**Independent variable:** Extent of involvement in PtD (Q2+Q3+Q30)

**Dependent variable:** Impact of CDM legislation on PtD implementation (Question 16)

**Chi-squared odds ratio test results (significant results only):**

There were no test results 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.
**Test No.:** 2.5

**Independent variable:** Extent of involvement in PtD (Q2+Q3+Q30)

**Dependent variable:** Attitude toward PtD (Q17+Q18+Q19+Q21+Q22)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Value</th>
<th>Dependent variable</th>
<th>Value</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Extent of PtD involvement</td>
<td>Medium, high</td>
<td>Attitude toward PtD</td>
<td>Positive, very positive</td>
<td>5.07</td>
<td>0.0000</td>
<td>2.54 10.14</td>
</tr>
<tr>
<td>2</td>
<td>Extent of PtD involvement</td>
<td>High</td>
<td>Attitude toward PtD</td>
<td>Positive, very positive</td>
<td>9.90</td>
<td>0.0000</td>
<td>5.20 18.85</td>
</tr>
</tbody>
</table>
**Test No.:** 3.1

**Independent variable:** Timing of involvement in projects (Question 7)

**Dependent variable:** Impact of PtD on different project performance criteria (Question 9)

### Chi-squared odds ratio test results (significant results only):

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Involvement in planning/preparation</td>
<td>Involved</td>
<td>Design costs</td>
<td>Increase</td>
<td>2.86</td>
</tr>
<tr>
<td>2</td>
<td>Involvement in construction</td>
<td>Not involved</td>
<td>Design costs</td>
<td>Increase</td>
<td>1.94</td>
</tr>
<tr>
<td>3</td>
<td>Involvement in construction</td>
<td>Not involved</td>
<td>Construction costs</td>
<td>Increase</td>
<td>1.84</td>
</tr>
<tr>
<td>4</td>
<td>Involvement in construction</td>
<td>Fully involved</td>
<td>Total project costs</td>
<td>Decrease</td>
<td>2.39</td>
</tr>
<tr>
<td>5</td>
<td>Involvement in planning/preparation</td>
<td>Involved</td>
<td>Construction duration</td>
<td>Increase</td>
<td>3.38</td>
</tr>
<tr>
<td>6</td>
<td>Involvement in pre-construction</td>
<td>Involved</td>
<td>Construction quality</td>
<td>Increase</td>
<td>13.04</td>
</tr>
<tr>
<td>7</td>
<td>Involvement in construction</td>
<td>Fully involved</td>
<td>Construction quality</td>
<td>Increase</td>
<td>2.05</td>
</tr>
<tr>
<td>8</td>
<td>Involvement in construction</td>
<td>Involved</td>
<td>Construction quality</td>
<td>Increase</td>
<td>5.63</td>
</tr>
<tr>
<td>9</td>
<td>Involvement in construction</td>
<td>Not involved</td>
<td>Construction quality</td>
<td>No change</td>
<td>3.38</td>
</tr>
<tr>
<td>10</td>
<td>Involvement in design</td>
<td>Fully involved</td>
<td>End-user H&amp;S</td>
<td>No change</td>
<td>3.41</td>
</tr>
<tr>
<td>11</td>
<td>Involvement in pre-construction</td>
<td>Fully involved</td>
<td>End-user H&amp;S</td>
<td>No change</td>
<td>3.97</td>
</tr>
<tr>
<td>12</td>
<td>Involvement in pre-construction</td>
<td>Involved</td>
<td>Importance of H&amp;S</td>
<td>Increase</td>
<td>8.89</td>
</tr>
<tr>
<td>13</td>
<td>Involvement in facility use</td>
<td>Fully involved</td>
<td>Importance of H&amp;S</td>
<td>Increase</td>
<td>4.13</td>
</tr>
<tr>
<td>14</td>
<td>Involvement in facility use</td>
<td>Not involved</td>
<td>Importance of H&amp;S</td>
<td>No change</td>
<td>3.38</td>
</tr>
</tbody>
</table>
**Test No.:** 3.2

**Independent variable:** Timing of involvement in projects (Question 7)

**Dependent variable:** Impact of PtD on project design or construction (Question 11)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Value</th>
<th>Dependent variable</th>
<th>Value</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td></td>
<td>Variable</td>
<td>Value</td>
<td></td>
<td></td>
<td>Lower bound Upper bound</td>
</tr>
<tr>
<td>1</td>
<td>Involvement in planning/preparation</td>
<td>Involved</td>
<td>Impact on design</td>
<td>Positive</td>
<td>3.31</td>
<td>0.0173</td>
<td>1.01 10.81</td>
</tr>
<tr>
<td>2</td>
<td>Involvement in design</td>
<td>Involved</td>
<td>Impact on design</td>
<td>Positive</td>
<td>10.85</td>
<td>0.0004</td>
<td>2.13 55.14</td>
</tr>
<tr>
<td>3</td>
<td>Involvement in facility use</td>
<td>Involved</td>
<td>Impact on design</td>
<td>Positive</td>
<td>2.96</td>
<td>0.0071</td>
<td>1.13 7.76</td>
</tr>
<tr>
<td>4</td>
<td>Involvement in planning/preparation</td>
<td>Involved</td>
<td>Impact on construction</td>
<td>Positive</td>
<td>4.08</td>
<td>0.0131</td>
<td>1.04 16.04</td>
</tr>
<tr>
<td>5</td>
<td>Involvement in design</td>
<td>Involved</td>
<td>Impact on construction</td>
<td>Positive</td>
<td>8.62</td>
<td>0.0027</td>
<td>1.51 49.03</td>
</tr>
</tbody>
</table>
Test No.: 3.3

Independent variable: Timing of involvement in projects (Question 7)

Dependent variable: Impact of CDM legislation on PtD implementation (Question 16)

Chi-squared odds ratio test results (significant results only):

There were no test results 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.
**Test No.:** 3.4

**Independent variable:** Timing of involvement in projects (Question 7)

**Dependent variable:** Attitude toward PtD (Q17+Q18+Q19+Q21+Q22)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Involvement in design</td>
<td>Involved</td>
<td>Attitude toward PtD</td>
<td>Positive, very positive</td>
<td>3.91</td>
</tr>
<tr>
<td>2</td>
<td>Involvement in pre-construction</td>
<td>Involved</td>
<td>Attitude toward PtD</td>
<td>Positive, very positive</td>
<td>5.37</td>
</tr>
</tbody>
</table>
Test No.: 4.1

**Independent variable:** Role on project (Question 25)

**Dependent variable:** Impact of PtD on different project performance criteria (Question 9)

Chi-squared odds ratio test results (significant results only):

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Role on project</td>
<td>Engineer</td>
<td>Construction cost</td>
<td>Increase</td>
<td>3.56</td>
</tr>
<tr>
<td>2</td>
<td>Role on project</td>
<td>Not Engineer</td>
<td>Construction cost</td>
<td>Decrease</td>
<td>5.13</td>
</tr>
<tr>
<td>3</td>
<td>Role on project</td>
<td>Not CDM Coord.</td>
<td>Construction cost</td>
<td>Increase</td>
<td>2.73</td>
</tr>
<tr>
<td>4</td>
<td>Role on project</td>
<td>CDM Coord.</td>
<td>Construction cost</td>
<td>Decrease</td>
<td>3.18</td>
</tr>
<tr>
<td>5</td>
<td>Role on project</td>
<td>Arch/Eng</td>
<td>Construction cost</td>
<td>Increase</td>
<td>3.10</td>
</tr>
<tr>
<td>6</td>
<td>Role on project</td>
<td>Not Arch/Eng</td>
<td>Construction cost</td>
<td>Decrease</td>
<td>4.26</td>
</tr>
<tr>
<td>7</td>
<td>Role on project</td>
<td>Arch/Eng vs Contr. only</td>
<td>Construction cost</td>
<td>Increase</td>
<td>2.99</td>
</tr>
<tr>
<td>8</td>
<td>Role on project</td>
<td>Arch/Eng vs CDM only</td>
<td>Construction cost</td>
<td>Increase</td>
<td>4.84</td>
</tr>
<tr>
<td>9</td>
<td>Role on project</td>
<td>Engineer</td>
<td>Total project cost</td>
<td>Increase</td>
<td>2.81</td>
</tr>
<tr>
<td>10</td>
<td>Role on project</td>
<td>Not Engineer</td>
<td>Total project cost</td>
<td>Decrease</td>
<td>3.05</td>
</tr>
<tr>
<td>11</td>
<td>Role on project</td>
<td>Not CDM Coord.</td>
<td>Total project cost</td>
<td>Increase</td>
<td>2.68</td>
</tr>
<tr>
<td>12</td>
<td>Role on project</td>
<td>Arch/Eng</td>
<td>Total project cost</td>
<td>Increase</td>
<td>2.47</td>
</tr>
<tr>
<td>13</td>
<td>Role on project</td>
<td>Not Arch/Eng</td>
<td>Total project cost</td>
<td>Decrease</td>
<td>2.84</td>
</tr>
<tr>
<td>14</td>
<td>Role on project</td>
<td>Arch/Eng vs CDM only</td>
<td>Total project cost</td>
<td>Increase</td>
<td>4.05</td>
</tr>
<tr>
<td>15</td>
<td>Role on project</td>
<td>Not Architect</td>
<td>Design duration</td>
<td>Increase</td>
<td>5.19</td>
</tr>
<tr>
<td>16</td>
<td>Role on project</td>
<td>Arch/Eng</td>
<td>Design duration</td>
<td>Increase</td>
<td>2.58</td>
</tr>
<tr>
<td>Role on project</td>
<td>vs CDM only</td>
<td>Impact on</td>
<td>Increase</td>
<td>p-value</td>
<td>Effect size</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------</td>
<td>-----------</td>
<td>----------</td>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>17 CONTR. VS CDM only</td>
<td>Design duration</td>
<td>Increase</td>
<td>3.33</td>
<td>0.0019</td>
<td>1.40</td>
</tr>
<tr>
<td>18 Engineer</td>
<td>Construction duration</td>
<td>Increase</td>
<td>2.82</td>
<td>0.0047</td>
<td>1.25</td>
</tr>
<tr>
<td>19 Not CDM Coord.</td>
<td>Construction duration</td>
<td>Increase</td>
<td>8.83</td>
<td>0.0000</td>
<td>3.19</td>
</tr>
<tr>
<td>20 Arch/Eng</td>
<td>Construction duration</td>
<td>Increase</td>
<td>2.20</td>
<td>0.0177</td>
<td>1.03</td>
</tr>
<tr>
<td>21 Arch/Eng vs CDM only</td>
<td>Construction duration</td>
<td>Increase</td>
<td>10.96</td>
<td>0.0000</td>
<td>2.67</td>
</tr>
<tr>
<td>22 CONTR. VS CDM only</td>
<td>Construction duration</td>
<td>Increase</td>
<td>5.74</td>
<td>0.0012</td>
<td>1.35</td>
</tr>
<tr>
<td>23 Engineer</td>
<td>Total project duration</td>
<td>Increase</td>
<td>2.18</td>
<td>0.0207</td>
<td>1.01</td>
</tr>
<tr>
<td>24 Not Engineer</td>
<td>Total project duration</td>
<td>Decrease</td>
<td>2.18</td>
<td>0.0207</td>
<td>1.01</td>
</tr>
<tr>
<td>25 Not CDM Coord.</td>
<td>Total project duration</td>
<td>Increase</td>
<td>4.80</td>
<td>0.0000</td>
<td>2.06</td>
</tr>
<tr>
<td>26 Not Arch/Eng</td>
<td>Total project duration</td>
<td>Decrease</td>
<td>2.93</td>
<td>0.0151</td>
<td>1.01</td>
</tr>
<tr>
<td>27 Arch/Eng vs CDM only</td>
<td>Total project duration</td>
<td>Increase</td>
<td>5.24</td>
<td>0.0002</td>
<td>1.73</td>
</tr>
<tr>
<td>28 CDM vs Arch/Eng only</td>
<td>Total project duration</td>
<td>Decrease</td>
<td>4.34</td>
<td>0.0086</td>
<td>1.02</td>
</tr>
<tr>
<td>29 CONTR. VS CDM only</td>
<td>Total project duration</td>
<td>Increase</td>
<td>3.66</td>
<td>0.0054</td>
<td>1.19</td>
</tr>
<tr>
<td>30 Owner vs CDM only</td>
<td>Total project duration</td>
<td>Increase</td>
<td>6.45</td>
<td>0.0093</td>
<td>1.01</td>
</tr>
<tr>
<td>31 Principal Contractor</td>
<td>Construction quality</td>
<td>Increase</td>
<td>2.01</td>
<td>0.0203</td>
<td>1.02</td>
</tr>
<tr>
<td>32 CDM Coord.</td>
<td>Construction H&amp;S</td>
<td>Increase</td>
<td>3.29</td>
<td>0.0139</td>
<td>1.02</td>
</tr>
</tbody>
</table>
Test No.: 4.2

Independent variable: Role on project (Question 25)

Dependent variable: Impact of PtD on project design or construction (Question 11)

Chi-squared odds ratio test results (significant results only):

There were no test results 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.
Test No.: 4.3

**Independent variable:** Role on project (Question 25)

**Dependent variable:** Impact of CDM legislation on PtD implementation (Question 16)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Role on project</td>
<td>CDM Coord.</td>
<td>Impact of CDM legislation on PtD</td>
<td>Helps</td>
<td>10.64</td>
</tr>
<tr>
<td>2</td>
<td>Role on project</td>
<td>CDM vs Arch/Eng only</td>
<td>Impact of CDM legislation on PtD</td>
<td>Helps</td>
<td>9.58</td>
</tr>
<tr>
<td>3</td>
<td>Role on project</td>
<td>CDM vs Contr. only</td>
<td>Impact of CDM legislation on PtD</td>
<td>Helps</td>
<td>8.28</td>
</tr>
</tbody>
</table>
Test No.: 4.4

**Independent variable:** Role on project (Question 25)

**Dependent variable:** Attitude toward PtD (Q17+Q18+Q19+Q21+Q22)

Chi-squared odds ratio test results (significant results only):

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Role on project</td>
<td>Architect</td>
<td>Attitude towards PtD</td>
<td>Negative, poor</td>
<td>6.75</td>
</tr>
<tr>
<td>2</td>
<td>Role on project</td>
<td>Principal contractor</td>
<td>Attitude towards PtD</td>
<td>Positive, very positive</td>
<td>3.70</td>
</tr>
<tr>
<td>3</td>
<td>Role on project</td>
<td>Arch/Eng</td>
<td>Attitude towards PtD</td>
<td>Negative, poor</td>
<td>2.61</td>
</tr>
<tr>
<td>4</td>
<td>Role on project</td>
<td>Arch/Eng vs Contr. only</td>
<td>Attitude towards PtD</td>
<td>Negative, poor</td>
<td>3.44</td>
</tr>
</tbody>
</table>
Test No.: 5.1

**Independent variable:** Performance criteria priority (Question 20)

**Dependent variable:** Attitude toward PtD (Q17+Q18+Q19+Q21+Q22)

Chi-squared odds ratio test results (significant results only):

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Performance criteria – Aesthetics</td>
<td>Low, below average, average</td>
<td>Attitude towards PtD</td>
<td>Positive, very positive</td>
<td>2.60</td>
</tr>
</tbody>
</table>

Ordered contingency Chi-squared test results (significant results only):

- The higher the priority given to construction worker H&S, the more likely the respondent will have a positive attitude towards PtD (one-sided p-value = 0.0217).
- The lower the priority given to aesthetics, the more likely the respondent will have a positive attitude towards PtD (one-sided p-value = 0.0482).
Test No.: 6.1

Independent variable: Organization’s industry sector (Question 28)

Dependent variable: Impact of PtD on different project performance criteria (Question 9)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Industry sector – Industrial</td>
<td>Involved</td>
<td>Construction duration</td>
<td>Increase</td>
<td>3.21</td>
</tr>
<tr>
<td>2</td>
<td>Industry sector – Industrial</td>
<td>Involved</td>
<td>Total project duration</td>
<td>Increase</td>
<td>2.38</td>
</tr>
<tr>
<td>3</td>
<td>Industry sector – Commercial buildings</td>
<td>Involved</td>
<td>Construction quality</td>
<td>Increase</td>
<td>2.29</td>
</tr>
<tr>
<td>4</td>
<td>Industry sector – Industrial</td>
<td>Involved</td>
<td>Construction quality</td>
<td>Increase</td>
<td>2.35</td>
</tr>
<tr>
<td>5</td>
<td>Industry sector – Industrial</td>
<td>Involved</td>
<td>Worker productivity</td>
<td>Decrease</td>
<td>5.82</td>
</tr>
</tbody>
</table>
Test No.: 6.2

Independent variable: Organization’s industry sector (Question 28)

Dependent variable: Impact of PtD on each project team member role (Question 10), filtered by respondent role (Question 25)

Chi-squared odds ratio test results (significant results only):

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Value</th>
<th>Dependent variable</th>
<th>Value</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Industry sector – Infrastructure/ heavy civil</td>
<td>Not involved</td>
<td>Impact on architect role (contractor responses)</td>
<td>Positive</td>
<td>4.11</td>
<td>0.0105</td>
<td>1.14</td>
</tr>
<tr>
<td>2</td>
<td>Industry sector – Infrastructure/ heavy civil</td>
<td>Not involved</td>
<td>Impact on CDM coordinator role (contractor responses)</td>
<td>Positive</td>
<td>5.92</td>
<td>0.0072</td>
<td>1.08</td>
</tr>
</tbody>
</table>
Test No.: 6.3

**Independent variable:** Organization’s industry sector (Question 28)

**Dependent variable:** Impact of PtD on project design or construction (Question 11)

**Chi-squared odds ratio test results (significant results only):**

There were no test results 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.
Test No.: 6.4

**Independent variable:** Organization’s industry sector (Question 28)

**Dependent variable:** Impact of CDM legislation on PtD implementation (Question 16)

**Chi-squared odds ratio test results (significant results only):**

There were no test results 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.
Test No.: 6.5

**Independent variable:** Organization’s industry sector (Question 28)

**Dependent variable:** Attitude toward PtD (Q17+Q18+Q19+Q21+Q22)

**Chi-squared odds ratio test results (significant results only):**

There were no test results 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.
Test No.: 7.1

**Independent variable:** Type of firm (Question 24)

**Dependent variable:** Impact of PtD on different project performance criteria (Question 9)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Type of firm</td>
<td>Arch/Eng vs PM only</td>
<td>Construction cost</td>
<td>Increase</td>
<td>3.97</td>
</tr>
<tr>
<td>2</td>
<td>Type of firm</td>
<td>Engineering</td>
<td>Construction duration</td>
<td>Increase</td>
<td>2.21</td>
</tr>
<tr>
<td>3</td>
<td>Type of firm</td>
<td>Arch/Eng vs PM only</td>
<td>Construction duration</td>
<td>Increase</td>
<td>4.52</td>
</tr>
</tbody>
</table>
**Test No.:** 7.2

**Independent variable:** Type of firm (Question 24)

**Dependent variable:** Impact of PtD on each project team member role (Question 10), filtered by respondent role (Question 25)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Type of firm</td>
<td>Construction</td>
<td>Impact on owner role (contractor responses)</td>
<td>Positive</td>
<td>4.98</td>
</tr>
<tr>
<td>2</td>
<td>Type of firm</td>
<td>Not design</td>
<td>Impact on owner role (contractor responses)</td>
<td>Positive</td>
<td>14.88</td>
</tr>
<tr>
<td>3</td>
<td>Type of firm</td>
<td>Arch/Eng vs Construction only</td>
<td>Impact on manufacturer/supplier (designer responses)</td>
<td>Positive</td>
<td>5.67</td>
</tr>
<tr>
<td>4</td>
<td>Type of firm</td>
<td>Not design</td>
<td>Impact on subcontractor (CDM coordinator responses)</td>
<td>Positive</td>
<td>7.84</td>
</tr>
</tbody>
</table>
Test No.: 7.3

Independent variable: Type of firm (Question 24)

Dependent variable: Impact of PtD on project design or construction (Question 11)

Chi-squared odds ratio test results (significant results only):

There were no test results 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.
Test No.: 7.4

**Independent variable:** Type of firm (Question 24)

**Dependent variable:** Impact of CDM legislation on PtD implementation (Question 16)

**Chi-squared odds ratio test results (significant results only):**

There were no test results 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.
Test No.: 7.5

**Independent variable:** Type of firm (Question 24)

**Dependent variable:** Attitude toward PtD (Q17+Q18+Q19+Q21+Q22)

Chi-squared odds ratio test results (significant results only):

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Type of firm</td>
<td>Construction</td>
<td>Attitude towards PtD</td>
<td>Positive, very positive</td>
<td>14.20</td>
</tr>
<tr>
<td>2</td>
<td>Type of firm</td>
<td>Arch/Eng</td>
<td>Attitude towards PtD</td>
<td>Negative, poor</td>
<td>3.11</td>
</tr>
<tr>
<td>3</td>
<td>Type of firm</td>
<td>Arch/Eng vs Construction only</td>
<td>Attitude towards PtD</td>
<td>Negative, poor</td>
<td>0.32</td>
</tr>
</tbody>
</table>
Test No.: 8.1

**Independent variable:** Firm capabilities (Question 26)

**Dependent variable:** Impact of PtD on different project performance criteria (Question 9)

Chi-squared odds ratio test results (significant results only):

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Variable</td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Principal contractor</td>
<td>None</td>
<td>Design cost</td>
<td>Increase</td>
<td>1.92</td>
</tr>
<tr>
<td>2</td>
<td>Architect</td>
<td>In-house + Const</td>
<td>Construction cost</td>
<td>Increase</td>
<td>2.00</td>
</tr>
<tr>
<td>3</td>
<td>Architect</td>
<td>In-house</td>
<td>Construction cost</td>
<td>Increase</td>
<td>1.88</td>
</tr>
<tr>
<td>4</td>
<td>H&amp;S consultant</td>
<td>In-house + Const</td>
<td>Construction cost</td>
<td>Decrease</td>
<td>3.22</td>
</tr>
<tr>
<td>5</td>
<td>H&amp;S consultant</td>
<td>In-house</td>
<td>Construction cost</td>
<td>Decrease</td>
<td>4.96</td>
</tr>
<tr>
<td>6</td>
<td>Architect</td>
<td>In-house + Const</td>
<td>Total project cost</td>
<td>Increase</td>
<td>2.12</td>
</tr>
<tr>
<td>7</td>
<td>Architect</td>
<td>In-house</td>
<td>Total project cost</td>
<td>Increase</td>
<td>1.95</td>
</tr>
<tr>
<td>8</td>
<td>H&amp;S consultant</td>
<td>In-house</td>
<td>Total project cost</td>
<td>Decrease</td>
<td>4.32</td>
</tr>
<tr>
<td>9</td>
<td>CDM coordinator</td>
<td>In-house + Const</td>
<td>Total project duration</td>
<td>Decrease</td>
<td>4.02</td>
</tr>
<tr>
<td>10</td>
<td>CDM coordinator</td>
<td>In-house</td>
<td>Total project duration</td>
<td>Decrease</td>
<td>3.39</td>
</tr>
<tr>
<td>11</td>
<td>Subcontractor</td>
<td>In-house + Const</td>
<td>Worker productivity</td>
<td>Increase</td>
<td>2.19</td>
</tr>
</tbody>
</table>
Test No.: 8.2

**Independent variable:** Firm capabilities (Question 26)

**Dependent variable:** Impact of PtD on each project team member role (Question 10), filtered by respondent role (Question 25)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Architect</td>
<td>In-house + Const</td>
<td>Impact on architect role (Arch/Eng responses)</td>
<td>Positive</td>
<td>4.09</td>
</tr>
<tr>
<td>2</td>
<td>Architect</td>
<td>In-house + Const</td>
<td>Impact on architect role (Contractor responses)</td>
<td>Positive</td>
<td>4.98</td>
</tr>
<tr>
<td>3</td>
<td>Architect</td>
<td>In-house</td>
<td>Impact on architect role (Contractor responses)</td>
<td>Positive</td>
<td>3.67</td>
</tr>
<tr>
<td>4</td>
<td>Design engineer</td>
<td>In-house + Const</td>
<td>Impact on manufacturer/supplier role (Owner responses)</td>
<td>Positive</td>
<td>40.00</td>
</tr>
<tr>
<td>5</td>
<td>Facility owner</td>
<td>In-house</td>
<td>Impact on facility owner role (Contractor responses)</td>
<td>Positive</td>
<td>3.38</td>
</tr>
<tr>
<td>6</td>
<td>Facility owner</td>
<td>No in-house</td>
<td>Impact on H&amp;S consultant role (CDM coord. responses)</td>
<td>Positive</td>
<td>5.00</td>
</tr>
<tr>
<td>7</td>
<td>H&amp;S consultant</td>
<td>No in-house</td>
<td>Impact on subcontractor role (Arch/Eng responses)</td>
<td>Positive</td>
<td>6.15</td>
</tr>
<tr>
<td>8</td>
<td>CDM coordinator</td>
<td>No in-house</td>
<td>Impact on subcontractor role (Arch/Eng responses)</td>
<td>Positive</td>
<td>7.33</td>
</tr>
<tr>
<td>9</td>
<td>Principal contractor</td>
<td>In-house + Const</td>
<td>Impact on subcontractor role (Arch/Eng responses)</td>
<td>Positive</td>
<td>6.78</td>
</tr>
<tr>
<td>10</td>
<td>Subcontractor</td>
<td>No in-house</td>
<td>Impact on architect</td>
<td>Positive</td>
<td>4.98</td>
</tr>
<tr>
<td></td>
<td>Subcontractor</td>
<td>No in-house</td>
<td>Impact on design engineer role (Contractor responses)</td>
<td>Positive</td>
<td>5.36</td>
</tr>
<tr>
<td>---</td>
<td>--------------</td>
<td>-------------</td>
<td>------------------------------------------------------</td>
<td>----------</td>
<td>------</td>
</tr>
<tr>
<td>12</td>
<td>Subcontractor</td>
<td>No in-house</td>
<td>Impact on manufacturer/supplier role (Arch/Eng responses)</td>
<td>Positive</td>
<td>4.44</td>
</tr>
</tbody>
</table>
Test No.: 8.3

**Independent variable:** Firm capabilities (Question 26)

**Dependent variable:** Impact of PtD on project design or construction (Question 11)

**Chi-squared odds ratio test results (significant results only):**

There were no test results 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.


Test No.: 8.4

**Independent variable:** Firm capabilities (Question 26)

**Dependent variable:** Impact of CDM legislation on PtD implementation (Question 16)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Architect</td>
<td>In-house + Const</td>
<td>Impact of CDM legislation on PtD</td>
<td>Hinders</td>
<td>6.47</td>
</tr>
</tbody>
</table>
Test No.: 8.5

**Independent variable:** Firm capabilities (Question 26)

**Dependent variable:** Attitude toward PtD (Q17+Q18+Q19+Q21+Q22)

Chi-squared odds ratio test results (significant results only):

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Value</th>
<th>Dependent variable</th>
<th>Value</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td></td>
<td>Variable</td>
<td>Value</td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>H&amp;S consultant</td>
<td>No in-house</td>
<td>Attitude towards PtD</td>
<td>Positive, very positive</td>
<td>4.23</td>
<td>0.0110</td>
<td>1.11</td>
</tr>
<tr>
<td>2</td>
<td>CDM coordinator</td>
<td>In-house + Const</td>
<td>Attitude towards PtD</td>
<td>Negative, poor</td>
<td>4.17</td>
<td>0.0007</td>
<td>1.51</td>
</tr>
<tr>
<td>3</td>
<td>CDM coordinator</td>
<td>In-house</td>
<td>Attitude towards PtD</td>
<td>Negative, poor</td>
<td>3.48</td>
<td>0.0036</td>
<td>1.27</td>
</tr>
<tr>
<td>4</td>
<td>CDM coordinator</td>
<td>No in-house</td>
<td>Attitude towards PtD</td>
<td>Positive, very positive</td>
<td>3.17</td>
<td>0.0075</td>
<td>1.16</td>
</tr>
</tbody>
</table>
Test No.: 9.1

Independent variable: Size of firm (Question 27)

Dependent variable: Impact of PtD on different project performance criteria (Question 9)

Chi-squared odds ratio test results (significant results only):

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td>Lower bound</td>
</tr>
<tr>
<td>1</td>
<td>Size of firm</td>
<td>&gt;500</td>
<td>Construction duration</td>
<td>Decrease</td>
<td>3.71</td>
</tr>
<tr>
<td>2</td>
<td>Size of firm</td>
<td>&gt;500 vs 10-499 only</td>
<td>Construction duration</td>
<td>Decrease</td>
<td>5.61</td>
</tr>
<tr>
<td>3</td>
<td>Size of firm</td>
<td>&gt;500 vs 10-499 only</td>
<td>Total project duration</td>
<td>Decrease</td>
<td>4.48</td>
</tr>
<tr>
<td>4</td>
<td>Size of firm</td>
<td>&gt;10</td>
<td>Construction quality</td>
<td>Increase</td>
<td>6.50</td>
</tr>
<tr>
<td>5</td>
<td>Size of firm</td>
<td>&gt;500</td>
<td>Construction H&amp;S</td>
<td>Increase</td>
<td>4.44</td>
</tr>
<tr>
<td>6</td>
<td>Size of firm</td>
<td>&gt;500 vs 10-499 only</td>
<td>Construction H&amp;S</td>
<td>Increase</td>
<td>4.27</td>
</tr>
</tbody>
</table>

Ordered contingency Chi-squared test results (significant results only):

- The larger the size of firm, the more likely the respondent will have the opinion that PtD leads to a decrease in construction duration (one-sided p-value = 0.0200).
Test No.: 9.2

**Independent variable:** Size of firm (Question 27)

**Dependent variable:** Impact of PtD on each project team member role (Question 10), filtered by respondent role (Question 25)

**Chi-squared odds ratio test results (significant results only):**

<table>
<thead>
<tr>
<th>No.</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Odds ratio</th>
<th>p-value</th>
<th>95% C.I. for odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable</td>
<td>Value</td>
<td>Variable</td>
<td>Value</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Size of firm</td>
<td>0-499</td>
<td>Impact on architect role (CDM coordinator responses)</td>
<td>Positive</td>
<td>8.45</td>
</tr>
<tr>
<td>2</td>
<td>Size of firm</td>
<td>10-499 vs &gt;500 only</td>
<td>Impact on architect role (CDM coordinator responses)</td>
<td>Positive</td>
<td>6.50</td>
</tr>
<tr>
<td>3</td>
<td>Size of firm</td>
<td>0-499</td>
<td>Impact on subcontractor (Designer responses)</td>
<td>Positive</td>
<td>3.61</td>
</tr>
<tr>
<td>4</td>
<td>Size of firm</td>
<td>0-499</td>
<td>Impact on subcontractor (CDM coordinator responses)</td>
<td>Positive</td>
<td>6.86</td>
</tr>
</tbody>
</table>
Test No.: 9.3

**Independent variable:** Size of firm (Question 27)

**Dependent variable:** Impact of PtD on project design or construction (Question 11)

**Chi-squared odds ratio test results (significant results only):**

There were no test results 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.

**Ordered contingency Chi-squared test results (significant results only):**

There were no test results in which there is at least suggestive evidence of an association between the variables (one-sided p-value < 0.05).
Test No.: 9.4

**Independent variable:** Size of firm (Question 27)

**Dependent variable:** Impact of CDM legislation on PtD implementation (Question 16)

**Chi-squared odds ratio test results (significant results only):**

There were no test results 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.

**Ordered contingency Chi-squared test results (significant results only):**

There were no test results in which there is at least suggestive evidence of an association between the variables (one-sided p-value < 0.05).
Test No.: 9.5

Independent variable: Size of firm (Question 27)

Dependent variable: Attitude toward PtD (Q17+Q18+Q19+Q21+Q22)

Chi-squared odds ratio test results (significant results only):

There were no test results 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.

Ordered contingency Chi-squared test results (significant results only):

There were no test results in which there is at least suggestive evidence of an association between the variables (one-sided p-value < 0.05).