AN ABSTRACT OF THE DISSERTATION OF

Nicholas Tymvios for the degree of Doctor of Philosophy in Civil Engineering presented on July 1, 2013.

Title: Direction, Method, and Model for Implementing Design for Construction Worker Safety in the US

Abstract approved: ____

John A. Gambatese

The construction industry employs about 7% of the total US workforce, and yet it accounts for 15.7% of all occupational fatalities. Specifically in 2011, there were 721 deaths in construction, second only to transportation with 733. The cause of a large number of these construction deaths can be attributed to factors that are distant from the construction site. A European study has shown that 60% of fatal accidents in construction are caused by decisions made "upstream" from the construction site. Similarly, an Australian study showed that 63% of fatalities and injuries are attributed to a lack of planning and design decisions, while a study in the US has shown that 42% of construction site fatalities can be linked to the design of the facilities constructed.

With such overwhelming evidence of fatalities attributed to design, other countries have enacted legislation to make designers aware of the impact their decisions have on construction sites, and to ultimately reduce construction hazards. In the US, designers are mostly unaware of the concept of Design for Construction Worker Safety (DCWS), or even that their design

decisions can affect the safety of the construction workforce. Professional organizations regularly resist change and refuse to even consider participating in the DCWS concept that would eventually assist in the improvement of construction site working conditions.

The research presented in this dissertation proposes the possibility of DCWS being implemented in the US. The first step of the research included a nationwide survey of the primary construction industry participants (owners, designers, and contractors) on the topic of DCWS. The survey investigated the extent of the acceptance of DCWS by industry participants, their opinions and identification of perceived obstacles or enablers of the concept, and the types of safety measures or safety plans they currently implement.

Using a Delphi panel consisting of industry professionals and the results gathered by the survey, the second part of the dissertation presents the identification of a framework for generating interest in DCWS in the US. The panel members were asked to identify which industry group has the greatest influence to generate that interest, and were given four possible approaches to achieve that goal: business case, education, industry standards, and legislation. The Delphi panel chose the business case as a method of generating interest and identified the owner group as the project team member who is best able to generate interest in DCWS in the US. To develop the business case, the Delphi panel also identified possible line items to be used in a benefit/cost analysis.

The third part of the dissertation discusses the development of a business case model using the line items identified in the second part. Two initial case studies were investigated where DCWS solutions were considered for the construction of two different projects. Personnel involved in these projects were asked to complete the business case model and compare the DCWS solutions with traditional solutions. The results showed that the DCWS solutions outscored traditional solutions. The benefit/cost model is a tool that can be used by owners to initially evaluate DCWS solutions. Additional projects need to be evaluated before the model can be an all-inclusive tool for all possible projects.

Direction, Method, and Model for Implementing Design for Construction Worker Safety in the US

by

Nicholas Tymvios

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Head of the School of Civil and Construction Engineering

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Nicholas Tymvios, Author

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CONTRIBUTION OF AUTHORS

Dr. Gambatese and Dr. Sillars assisted with the preparation of the various surveys for Chapter 1

Dr. Gambatese also assisted with the preparation of the Delphi panel surveys for Chapter 2 and the development of the Benefit/Cost model for Chapter 3.

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0.0 INTRODUCTION

The US construction industry has a disproportionate injury and illness rate as well as a disproportionate fatality rate when compared to other industries. In 2011, the construction industry employed about 7% of the total US workforce, and yet it accounted for 15.7% of all occupational fatalities. Specifically in 2011, there were 721 deaths in construction, second only to transportation with 733 (BLS 2013a).

Accident causality in a large number of construction incidences has been shown to be attributed to factors that are distant from the construction sites. A European study (European Foundation 1991) has shown that 60% of fatal accidents in construction are caused by decisions made "upstream" from the construction site. Similarly, an Australian study (NSW Workcover 2001) showed that 63% of fatalities and injuries are attributed to a lack of planning and design decisions, while a study in the US (Behm 2005) has shown that 42% of construction site fatalities can be linked to design. In light of such evidence, many countries have enacted legislation to encourage designer involvement in construction worker safety. In the US, similar legislation has been rejected and many designers are unaware of any plans or methods on how they can get involved in construction worker safety.

The main objective of this dissertation is to develop a framework for generating interest for designers to practice Design for Construction Worker Safety (DCWS). Other objectives include determining the extent of knowledge of DCWS in the US, as well as identifying potential obstacles and enablers for designers to be involved in construction safety.

In this dissertation, a nationwide survey is conducted in order to determine the obstacles and enablers for designer DCWS participation. The dissertation continues with an investigation using the Delphi method to determine the direction and method with which interest in DCWS can be generated. In the last section of the dissertation, a benefit/cost model is developed, based on the outcome of the Delphi method, to help compare DCWS solutions and traditional solutions, and be used as a tool to promote the use of DCWS in construction.

The dissertation is divided into three independent manuscripts which are intended to be developed for submission to scholarly journals. The structure of the dissertation and the topics discussed in each section are described below.

0.1 Dissertation Structure

Each manuscript in the dissertation covers one major theme and builds upon previous results. While each manuscript stands alone in its own right, significant information is referenced to previous manuscripts. Repetition has been avoided in most manuscripts, but some topics and description is revisited to provide appropriate context. A flowchart showing the direction of the research presented in this dissertation is shown in Figure 0-1.

0.1.1 Manuscript 1

The first manuscript is entitled “Designer, Owner, and Contractor Views on Design for Construction Worker Safety”. It includes a literature review to introduce the DCWS concept, and discusses the development and results of a nationwide survey of construction industry participants. The survey investigated the extent of current designer involvement in construction safety as well as the obstacles and enablers for designer DCWS participation. Portions of this manuscript were presented at the Construction Research Congress in West Lafayette, IN in 2012 (Tymvios et al.).

0.1.2 Manuscript 2

The second manuscript is entitled “The Use of a Delphi Panel to Determine the Direction of DCWS Interest Generation”. It includes a literature review of Delphi panels, and presents the development and results of three rounds of the Delphi process focused on identifying the group that has the greatest influence to generate interest in DCWS, and the method with which to generate that interest.

0.1.3 Manuscript 3

The third manuscript is entitled “Benefit/Cost Model for Evaluating DCWS Solutions”. It uses the results of the Delphi panel and develops a model for comparing DCWS solutions against traditional construction solutions in order to determine the best alternatives to be used in construction.

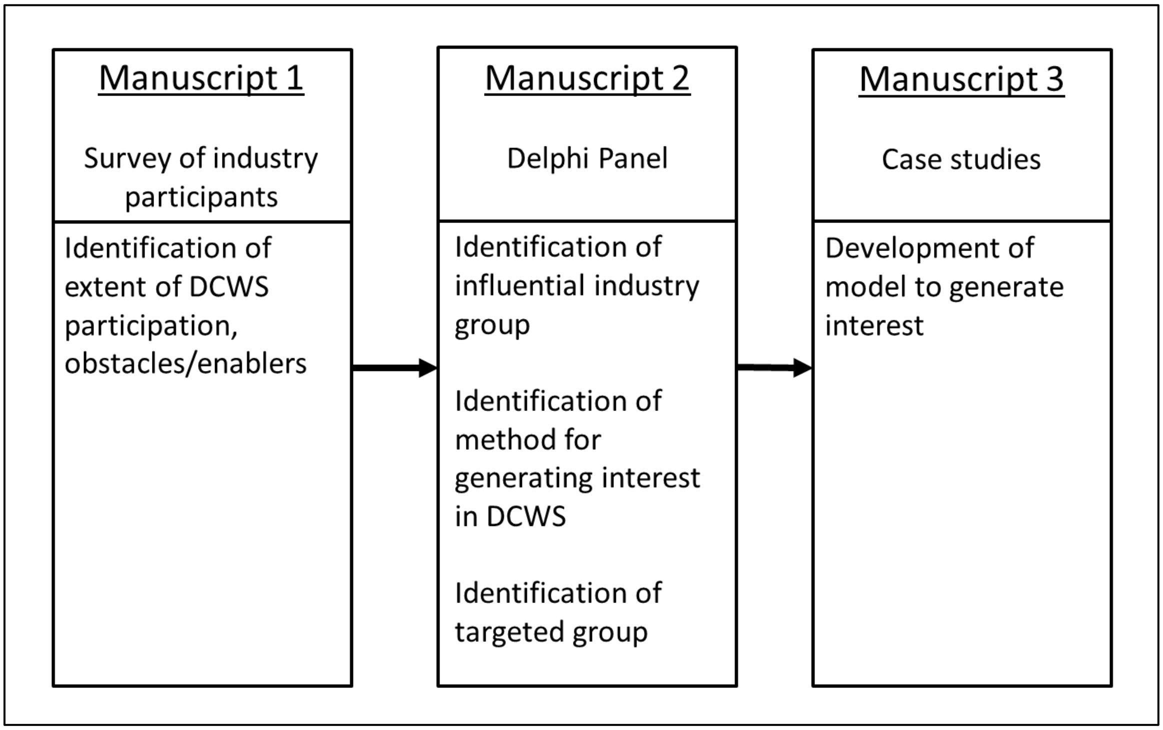

Figure 0-1: Flowchart of Dissertation Research

0.2 Primary Research Objective and Questions

The overall objective of the research presented in the dissertation is to develop a possible framework for the implementation of DCWS in the US. To meet this objective, several research questions were developed to guide the research. The research questions were as follows:

- What is the extent of DCWS knowledge and practice in the US?
- What are the obstacles and enablers for designers to practice DCWS?
- Which construction industry group can generate interest for DCWS implementation in the US construction industry?
- Which is the best method to generate interest for DCWS implementation?
- What is the best application for the identified method?

1.0 Manuscript 1 – Designer, Owner, Contractor Views on Design for Construction Worker Safety

1.1 Preface

The objective of this manuscript is to present the results of a survey that was conducted to identify designer, owner and contractor views on the possible implementation of the Design for Construction Worker Safety (DCWS) concept in the US construction industry. This manuscript introduces the impetus for conducting this research, namely the high number of injuries and fatalities that occur in construction, and continues to discuss the impact that each key construction group has on construction safety. Within the Design for Safety Process section of the manuscript, the concept is explained as well as its benefits to the construction industry and to construction workers in general.

DCWS is practiced in other countries in one form or another, and within this manuscript obstacles are described that limit the widespread use of DCWS in the US. The manuscript continues with methods that are practiced or suggested to be practiced in order to generate interest for DCWS implementation, as well as how the concept is expected to be implemented in the industry in the future.

In the methodology section, the manuscript presents the hypotheses that the author developed prior to creating and distributing a survey to the selected industry groups. An analysis of the survey results is included along with the conclusions to the hypotheses.

1.2 Introduction

The construction process for bringing projects to completion requires the contribution and commitment of multiple entities that need to collaborate for a relatively short period of time. The majority of these entities are grouped into three major groups: owners, designers and construction contractors. Owners, whether they are public or private, are the driving force for the initiation of any construction project. Owners come up with the idea or identify that there is a need for a project and more importantly they possess the capital in order to finance it.

Owners then employ designers that are assigned the task of bringing their concept of a project from an idea to a tangible set of instructions. These instructions are then given to a construction contractor who is assigned to construct the project and bring it to reality.

The above description is an extreme simplification of the construction project delivery process. In reality, the process to construct a project can be very complicated and require tremendous amounts of work hours from all the stakeholders involved. Moreover, the project delivery methods used can be very diverse with combinations of responsibilities and requirements from all parties. These characteristics increase project complexity and the construction industry as a whole.

While complexity is present in many aspects of a project, traditional practice has kept the responsibility of some of the project requirements and features very simple. One of these responsibilities is construction worker safety. The consideration of construction worker safety, at least in the US, has traditionally been left up to construction contractors and their subcontractors. In other countries though, guidelines have been developed and legislation enacted to expand the responsibility for addressing construction worker safety to other industry participants. These efforts fall under the general theme of Prevention through Design (PtD), and in literature the concept can be identified, besides PtD, as “Safety in Design” (SiD) (Weinstein et al. 2005), “Safety through Design” (StD) (McClimans 2011), and others.

A general definition can be obtained from an article written by Manuele (2008) in the Journal of Safety Research, where he defines PtD as *“ … The integration of hazard analysis and risk assessment methods early in the design and engineering stages, and taking the actions necessary so that risks of injury or damage are at an acceptable level.”* This is the definition that is used within this research project.

The key concept in the above definition is “… early in the design and engineering stages ….” With this phrase the whole concept of PtD encourages and expects designers to find any possible hazard sources to personnel, facilities and the environment, caused by industrial processes, construction, and products, early during their design phase and eliminating these hazards, prior to production or use. The term "acceptable level" is also important in the above definition, which according to Hagan et al. (2009), is defined as the level at which the probability of a hazard related incident and the severity of the damage are as low as practically possible for each particular situation.

Within this manuscript the concept of PtD is described as Design for Construction Worker Safety (DCWS) to differentiate it from PtD efforts in other industries and to highlight the PtD efforts in construction and for construction workers.

1.2.1 Research Motivation

The construction industry is one of the most dangerous industries in the US, with high incidence rates for injuries and fatalities. The Bureau of Labor Statistics keeps a record of all occupational injuries and fatalities for all industries in the US, through their "Injuries, Illnesses, and Fatalities (IIF)" program. IIF summarizes information regarding the rate and number of work related safety incidents and how these vary by type of incidence, the industry in which they occur, their geographic location, the type of occupation, and other characteristics (BLS 2013b).

The IIF program shows that the construction industry is one of the most dangerous industries in the US. Figure 1-1 shows the number of Injury and Illnesses that were recorded in 2011 across the US in a variety of industries, as well as the incidence rates for these occurrences. The incidence rate for illnesses and Injuries is a value that is calculated with Equation 1-1:

Equation 1-1

$$Incidence\ Rate\ (Illness\ \&\ Injuries) = \left(\frac{N}{EH}\right) * 2000\ hours * 100\ Workers$$

Where, N is the number of injuries and illnesses and EH is the total number of hours worked by employees (BLS 2013b).

As observed, there were about 184.7 thousand occurrences of injuries and illnesses in construction in 2011. This value is not very high compared to the recorded occurrences in other sectors such as "Educational & Health Services" (628 thousand), "Local Government" (598 thousand), "Retail Trade" (413.2 thousand), "Manufacturing" (455.6 thousand), and "Leisure & Hospitality" (320.9 thousand). The Illness and Injury incidence rate for construction is lower than other industries. With a value of 3.8, the construction industry is far behind "Local Government" (5.8), "Agricultural, forestry, fishing and hunting" (5.2), "Educational & Health Services" (4.4), "State Government" (4.2), and "Manufacturing" (3.9).

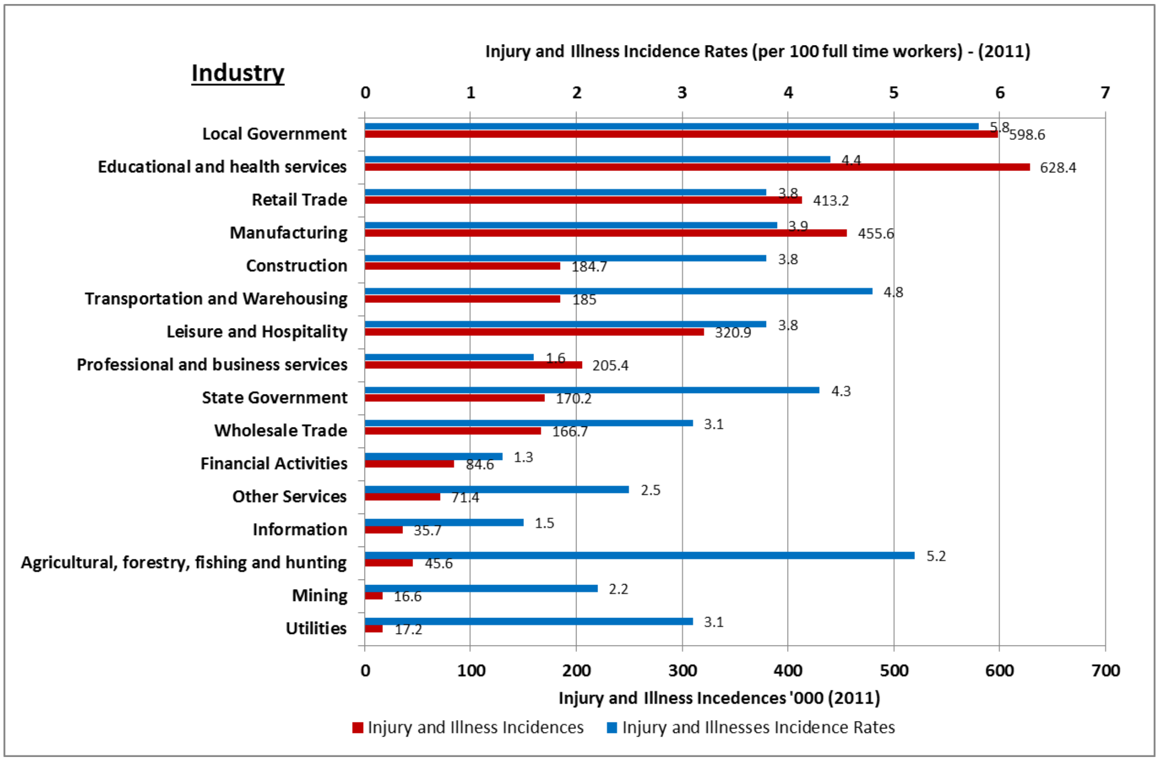

Figure 1-1: Injury and Illness (Index and Incidences) 2011

The dangerous construction environment might not be apparent by the Illness and Injury information, but it becomes extremely evident when the number of fatalities is considered. Figure 1-2 shows the number of fatalities and fatality incidence rates recorded by the various industries in the US. The incidence rate for fatalities is a value that is calculated with Equation 1-2:

Equation 1-2

$$Incidence\ Rate\ (Fatalities) = \left(\frac{N}{EH}\right) * 2000\ hours * 100{,}000\ Workers$$

Where, N is the number of fatalities and EH is the total number of hours worked by employees (BLS 2013b).

As observed, the number of fatalities in construction in 2011 was 721 and was only followed by

"Transportation and Warehousing" which had 733 fatalities. The fatality incidence rate for construction was 8.9 deaths per 100,000 full time workers. That value is the fourth worst fatality rate among the US industries, behind "Agriculture, forestry, fishing & hunting" (24.4), "Mining" (15.8), and "Transportation & Warehousing" (15).

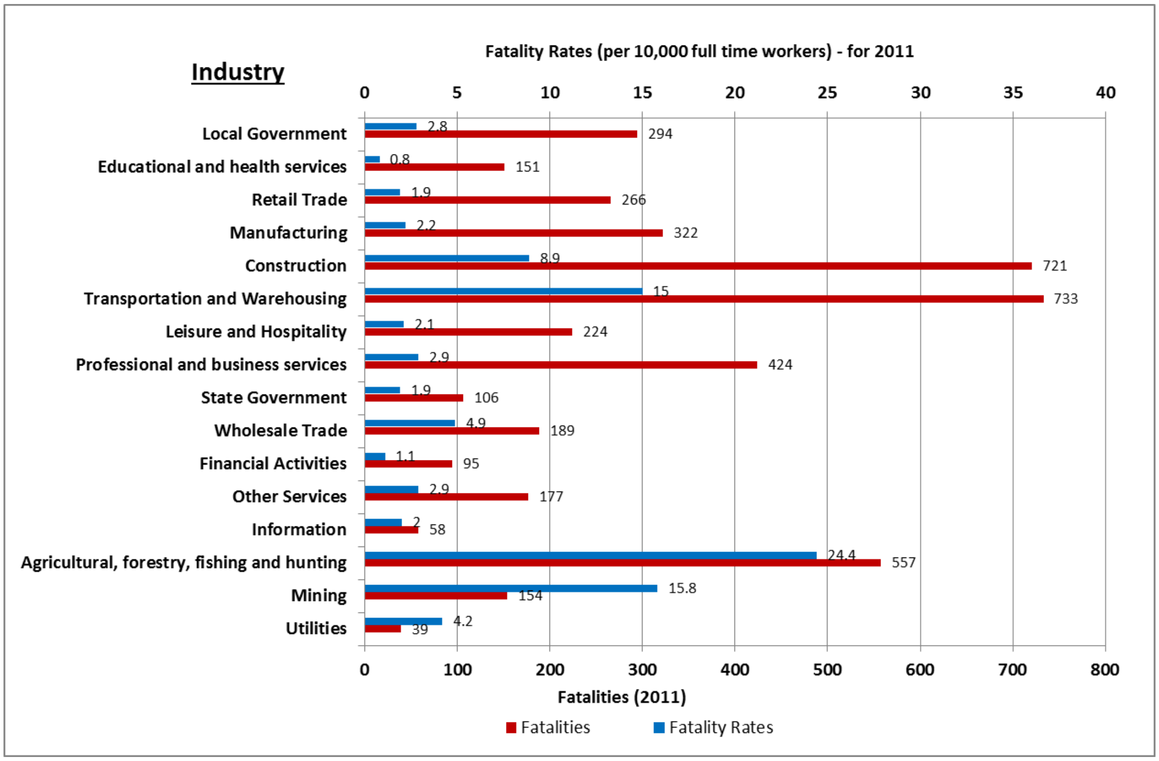

Figure 1-2: Fatality (Index and Incidences) 2011

Historically the safety record of the US construction industry has shown some improvement, as observed in Figure 1-3. The number of fatalities, shown in red, presented a steady increase from 1992 – 2007, with a peak of 1234 construction worker fatalities in 2004. In recent years, after 2008, a sudden decline in the number of deaths has been observed which, it is speculated was due to the decline in the economy, as observed from the most recent figure obtained from BLS indicating that in 2011 there were 721 fatalities in construction. The incidence rate of fatalities in construction shows that there has been a decrease in the rate of fatalities since 1992, where there were 14 deaths per 10,000 equivalent full time workers. In 2007 there were 10.3 deaths per 10,000 equivalent full time workers. After 2007 the rate of fatalities has been steady, with values of 9.6, 9.7 9.5 and 8.9 for the years between 2008 and 2011. This suggests that even with the slowing economy, the rate of construction deaths remains about the same.

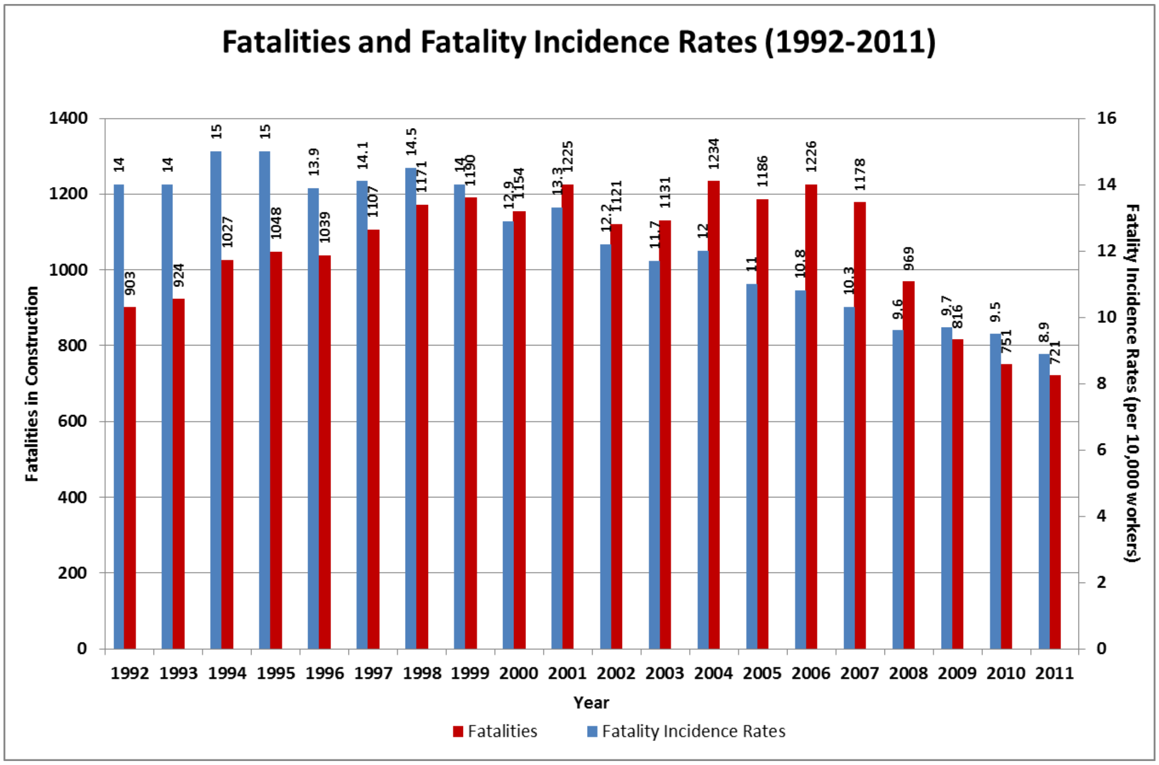

Figure 1-3: US Construction Fatalities and Construction Incidence rates (1992 – 2011)

The US safety record is comparable to other countries as it is shown in Table 1-1. Because of the size of the US population, a direct comparison of number of accidents would not be accurate. As observed, the US incidence rate in construction fatalities is compared to several European countries, Australia and Singapore. Data from the European Countries was obtained from Eurostat, which is the European Union agency for obtaining statistical information from European Union member states (Eurostat 2013). Data from Australia was obtained from the National Occupational Health & Safety Commission (NOH&SC 2013), and data from Singapore was obtained from the Workplace Safety and Health Council (WSHC 2013). Entries with an NA in the table were not available. Even though each country has different characteristics for workplace fatalities as discussed in a later section, these numbers are a comparative approximation of the differences in fatality rates among countries.

The incidence rate for all the countries listed on the table is for 100,000 equivalent full time workers as described in Equation 1-2. In many of the countries, the incidence rate for fatalities is lower than the incidence rate in the US. The country with the best record is Great Britain with incident rates of 1.78, 1.9 and 2.36 for the three years between 2008 and 2010. By comparison, the US had incident rates of 9.6, 9.7 and 9.5 for the same time period.

A better comparison for the relationship of the US fatality incidence rates with a territory of a similar population and economic activity would be a comparison with the EU countries as a whole. The last entries in Table 1-1 correspond to the estimated fatality incidence rate for all the 27 EU countries (Eurostat 2013). Between 2008 and 2010, the incidence rates for the EU27 were 7.94, 7.21 and 6.59 respectively.

Table 1-1: Incidence Rates for Fatal Accidents in the US and other countries

Country	2008	2009	2010	2011
Australia	4.45	4.08	3.77	NA
Austria	7.48	14.19	7.64	NA
Belgium	11.35	7.11	7.36	NA
Denmark	5.69	4.44	5.11	NA
Finland	3.27	4.65	4.01	NA
France	4.99	6.98	6.08	NA
Germany	4.81	3.5	3.15	NA
Great Britain	1.78	1.9	2.36	NA
Ireland	5.43	5.97	4.18	NA
Italy	9.27	9.23	9.22	NA
Netherlands	9.52	5.16	2.35	NA
Norway	4.84	NA	4.14	NA
Singapore	6.9	8.1	8.1	5.3
Spain	9.95	8.94	7.99	NA
Sweden	5.57	3.08	4.61	NA
Switzerland	13.63	5.7	7.34	NA
USA	9.6	9.7	9.5	8.9
EU 27	7.94	7.21	6.59	NA

These fatalities as a statistic are attributed to falls, electrocutions, etc. (BLS 2013b) A direct cause of the fatality is not always apparent from the data. Several studies though have attempted to identify their root causes. A European study concluded that 60% of fatal accidents in construction are caused by decisions made "upstream" from the construction site (European Foundation 1991). Similarly, an Australian study found that 63% of fatalities and injuries are attributed to a lack of planning and design decisions (NSW Workcover 2001), while in the US, Behm (2005) found that 42% of construction site fatalities can be linked to design.

With such a high percentage of accidents linked to design, lack of planning and decisions made prior to the construction phase, DCWS seems to be a very obvious approach to employ in order to reduce these injuries and fatalities.

1.3 Key Construction Groups and Safety Role

The three parties that are almost always involved in the project delivery process are owners, architects/engineers or designers, and contractors/subcontractors. Each of these groups has a different role in construction safety and is discussed in this section of the manuscript.

1.3.1 Construction Contractors

The traditional view on construction worker safety is that it lies solely with the contractor. In addition the main governing body responsible for occupational health and safety in the US, OSHA, clearly states that employers are responsible for providing a safe place for their workers to work without mentioning designers and owners (Hinze et al. 1992). Of the eight behavioral root causes of accidents that were identified by Toole (2002) five of them are associated with unsafe conditions. These are: lack of proper training, deficient enforcement of safety, safe equipment not provided, unsafe methods or sequencing, and unsafe site conditions. These root causes indicate a lack of safety management, which is greatly influenced by the construction contractor (Toole 2002).

Furthermore, the traditional contracting method, Design Bid Build (DBB) and the contracts associated with DBB, such as the AIA and AGC contract documents, place sole responsibility for construction safety on the contractor (AGC 2007; AIA 2007).

In summary, the construction contractors are seen as having sole responsibility for and the biggest role in construction safety.

1.3.2 Owners

Owners are the stakeholder group that has the need for construction projects and will ultimately be the end users of the facilities constructed. Traditionally though, owners do not take any active role during the construction process except in certain instances where the owner has the necessary expertise and personnel to supervise construction. In most cases where owners hire the project designers to supervise construction and the designers act as the owners' agents (Hinze 2001).

The consideration of safety has been traditionally avoided by the owners primarily due to their consideration that the contractor and subcontractors are the primary liable parties since they have the primary control of the work site (Nwaelele 1996). Recent litigation proceedings though have shown that increasingly owners are being held responsible for accidents that occurred on work sites (Nwaelele 1996; Hinze 2006; Huang et al. 2006) .

Owners can play an important role in reducing the number of accidents in the workplace by their active involvement during project design and planning. Gambatese (2000b) lists a sample of these practices that an owner can implement:

- Schedule different projects or construction phases that occur at the same location to take place at the same time,
- Toxic substances and materials used in projects should be listed and their locations noted,
- Avoid sustained overtime and night work,
- Impose limits on worker numbers on site,
- Confirm that the contractors are aware of the proper use and storage of hazardous materials,
- Provide the original as-built drawings to contractors when renovations are taking place,
- Conduct preconstruction meetings with contractors and subcontractors to discuss safety concerns, and
- Involve OSHA for the planning of safety measures prior to construction (Gambatese 2000b).

The author continues with a six point program to act as a model for a formal owner safety plan.

The owners should first establish a clear position on safety that can be as simple as avoiding OSHA citations, limiting exposure to third-party liability suits, and minimizing safety responsibility. A more proactive approach would be to minimize accidents and injuries. This position should be communicated to all project participants by implementing it within the project documents and through formal communications (Gambatese 2000b).

The owners can address safety during planning and design by selecting designers that have knowledge and are actively involved in construction safety, and by insisting that designers address construction safety through contract documents and the equivalent compensation

(Gambatese 2000b).

The safety performance of construction contractors should also be considered during bidding, Safety performance is observed with the experience modification rate (EMR), the injury incidence rates, the loss ratio, OSHA citations and fines, litigation related to worker injuries, and performance record of construction personnel. A further evaluation can include the examination of the contractors' safety programs (Gambatese 2000b).

The owner can also address safety in the construction contract by inserting clauses that would require contractors to abide by safety laws and regulations, the firm provide an accurate description of the responsibilities related to safety on the jobsite, the requirement that a safety program be submitted prior to work start, the requirement that there is a plan in place to avoid and detect substance abuse, and the requirement of an emergency plan and accident reporting procedure (Gambatese 2000b).

During construction the owner can assign a competent person or organization to oversee safety thus eliminating the confusion for that responsibility. The entity responsible could be the architect, engineer, construction manager or even an external safety consultant (Gambatese 2000b).

Finally, owners can actively participate in safety during construction by attending and conducting safety meetings, making independent jobsite safety inspections, and by providing safety training for hazardous materials used on site (Gambatese 2000b).

1.3.3 Designers

The traditional focus on safety for designers is for the "end user" personnel of the facility being designed, with no consideration for the personnel constructing the facility. The reasons given for this lack of involvement in construction safety are the lack of training and education to address worker safety concerns, and the contractual inability to direct worksite activities (Gambatese 2000a).

The influence of design on construction site safety is immense. Each design decision such as connection details, material selection and facility component arrangement, influences the way workers will perform their work. Hinze (2006) argues that the contention of designers not being responsible for construction safety simply because they do not instruct contractors on the means and methods but only the end result is false, but it is very common in the industry.

Research has shown though that designers have the capabilities to address safety. Toole (2005) describes five methods with which designers can increase their involvement in construction site safety through their designs. These methods are:

- Review for safety – This involves the review of the designs for safety concerns, much like the current practices for review for cost and functionality, by a qualified professional within the design firm or by an external consultant
- Create design documents for safety – Design firms can create a review process during design that addresses construction worker safety. In addition plans and specifications issued can have sections that facilitate safety.
- Procure for safety – Designers can help owners decide on contractor selection for a particular project by including a review of the contractor's recent safety performance.
- Review submittals for safety – Designers can ask for a safety plan from potential contractors during the bidding process and evaluate that plan as part of the contractor evaluation along with cost and schedule.
- Inspect site operations for safety – The designers can be actively involved in the construction process and inspect construction sites for possible safety concerns.

1.4 The Design for Safety Process

As shown in Figure 1-4, which is a modification of the figure found in Hagan et al. (2009), projects typically have a lifecycle consisting of five phases: Conception, Design, Build, Operate, and Eliminate/Recycle/Revise. Designers are actively involved in the delivery of a project for a limited time. This short involvement reduces their capability to be effective, and for that reason they need to provide safety input early in the project delivery process; during the conception and design phase. The ease of considering safety is greater when it is considered early in the project life cycle, where the effort required is less and the people required to make safety changes are fewer. If safety changes are considered later in the project lifecycle, then there is a greater amount of coordination required and work to be performed. This increased amount of work leads to increased cost for implementing safety measures because in later phases, the project is significantly constructed and affords less opportunity to be augmented with safety measures.

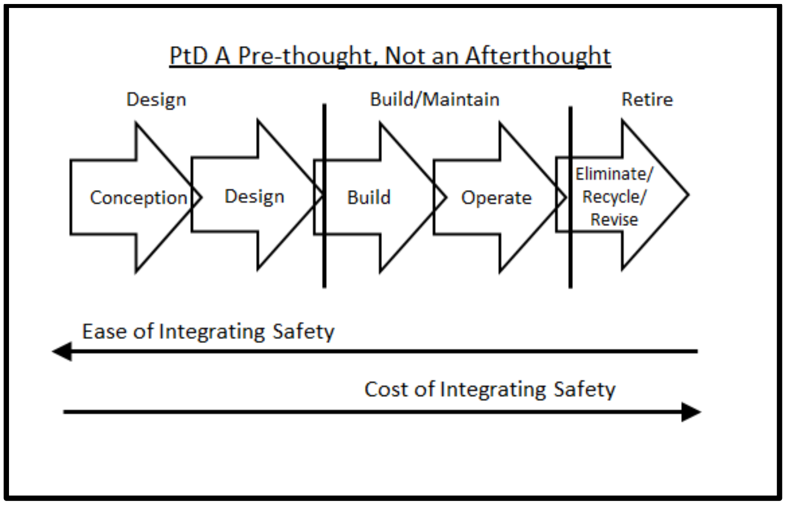

Figure 1-4: Life cycle of a project adapted from (Hagan et al. 2009)

1.4.1 Hierarchy of Controls

The hierarchy of controls is a means to understand the importance of considering safety early in the lifecycle of a project. A diagram of these controls is shown in Figure 1-5. The term "hierarchy" suggests a systematic ranking of the controls according to a set of attributes. The attribute that is considered when implementing safety solutions is the effectiveness of the control in removing or decreasing risks from potential hazards (Hagan et al. 2009). As observed, the six levels of controls are:

1. Elimination
2. Substitution
3. Engineering controls
4. Warning systems
5. Administrative controls
6. Personal protective equipment (PPE)

An increase in the effectiveness and financial value is observed when controls from a higher level are chosen to be implemented over controls that are lower on the hierarchy. This follows from the previous section where ease of integrating safety is achieved best when considered early in the life cycle of any project. In addition the higher level controls are more effective because they are preventative actions, their success does not rely on the performance of the personnel, and they are less likely to be rendered ineffective by that same personnel (Hagan et al. 2009).

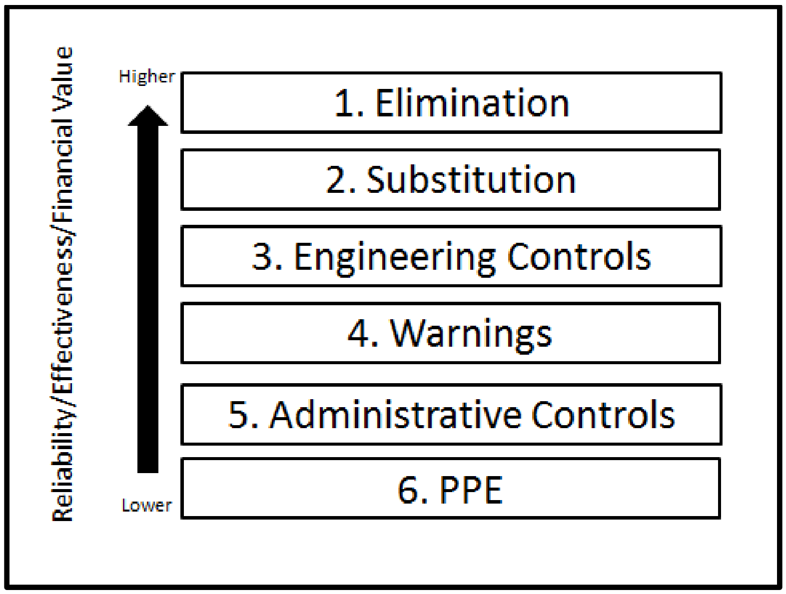

Figure 1-5: Hierarchy of controls

The first level of control is “Elimination”. As the name suggests, if hazards are eliminated in the design and redesign phase, then the risks are can also be eliminated. While this is desired, this is not always possible, so a decreased probability of personnel making human errors due to design inadequacies is most likely achieved. Examples of hazards that can be eliminated are: fall hazards, ergonomic hazards, confined space hazards, chemical hazards (Hagan et al. 2009).

The “Substitution” level of control aims to substitute an existing method, system or material with alternatives that are less hazardous. Substitution solutions can be implemented by the use of automated equipment, the replacement of hazardous chemicals, reduction in speed, force, amperage, pressure and temperature (Hagan et al. 2009).

Engineering controls intend to reduce access to hazards by implementing physical measures or barriers. These controls can be machine guards, interlock systems, circuit breakers, start-up alarms, the presence sensing devices, safety nets, ventilation systems, sound enclosures, fall prevention systems, lift tables, conveyors and balances (Hagan et al. 2009).

The last three levels of control are contingent actions and rely greatly on the performance of personnel

Warning systems are the fourth level of control, and are only effective in conjunction with administrative controls. Warning systems can also be reactionary since they alert people only after a hazard's potential is in the process of being realized. Such items might be smoke detectors, alarm systems, chemical detection systems, and signs (Hagan et al. 2009).

Administrative controls rely on the methods that management deems as appropriate to respond to the needs and capabilities of the people working at a particular location. The success of this method depends greatly on the quality of the supervision, and the experience of the workers. Administrative controls that are most commonly used include personnel selection, training, the selection of appropriate methods and procedures, as well as supervision (Hagan et al. 2009).

The last level of controls, PPE, is the last resort for worker safety and it relies heavily on effective supervision and personnel. It is also the least effective method of protection when dealing with hazards and risks. Such items could be the use of safety glasses, respirators, hardhats, safety shoes, etc. (Hagan et al. 2009).

1.4.2 DCWS Benefits

Proponents of DCWS list several benefits that can be achieved when implementing DCWS in the design process. The primary benefit that is achieved is the reduction in injuries and fatalities on work sites and the associated costs that arise when they occur (Gambatese 1998; Hagan et al. 2009). These costs are worker compensation premiums and delay costs due to accidents during construction.

In addition safety benefits during construction can also be extended when performing maintenance operations on the constructed facilities (Gambatese 1998). Manuele (2008) also states that by applying DCWS concepts productivity can be improved, along with decreased operating costs and retrofitting costs. One of the biggest benefits results from designers and contractors placed in a situation where they have to work together, thus increasing collaboration between them (Gambatese 1998).

1.4.3 DCWS in other Countries

The DCWS Concept has been introduced in other countries through a variety of forms. Some of the most prominent cases are discussed below.

1.4.3.1 Europe

In an attempt to curb the increasing number of work site accidents that were happening in Europe, the European Union developed a set of directives. The first one was the Council Framework Directive 89/391/EEC (EEC 1989). This directive introduced provisions and guidelines for worker safety and health by specifying obligations for employers and workers in various topics such as prevention, training, worker consultation, etc.

The provisions described in the above directive instructed the EU to create and adopt additional directives in areas that were deemed to be of high risk to workers. These areas were:

- Work places,
- Work equipment,
- Personal protective equipment,
- Work with visual display units,
- Handling of heavy loads involving risk and back injury,
- Temporary or mobile work sites, and
- Fisheries and agriculture. (EEC 1989)

Directive 89/391/EEC also instructed the EU member countries to adopt it, and all subsequent directives, and at the same time repealing all local regulations that were in place in the local governments (EEC 1989). The member countries were given until December 31 of 1992 to draw up, enact and enforce laws that were to make the 89/391/EEC directive active universally in all EU states. This goal was not achieved by all the countries, with only very few of them (Denmark, Sweden, France) actually meeting the December 1992 deadline. Finland was the last county of the EU15 to enforce the directive and that did not happen until 2002, ten years after the original deadline(Martínez Aires et al. 2010).

In total 19 other directives were developed from the original 89/391/EEC directive. One of them in particular, 92/57/EEC, was solely devoted to construction under the title "… implementation of minimum safety and health requirements at temporary or mobile construction sites ..."(EEC

1992) The directive placed legal responsibility on owners and on those associated with the design of the work. In articles 4 and 5, the directive clearly gives instructions to designers to practice DCWS, by appointing a project supervisor responsible for all aspects of safety and health during the stages of design and preparation (EEC 1992). Article 14 of the directive instructs member states to "… bring into force the laws, regulations and administrative provisions …" by December 31, 1992. That goal, as in directive 89/391/EEC, was not achieved. The only country that managed to complete the task by that date was Denmark. Austria and Belgium were the last countries of the EU 15 countries to enforce the directive (Martínez Aires et al. 2010).

The 92/57/EEC directive produced legislation in the member countries, and the most notable being the Construction Design and Management (CDM) in the UK in 1994 (later revised in 2007), and Spain's Royal Decree 1627/1997 "Minimum provisions for health and safety at construction sites"

1.4.3.1.1 UK

The CDM regulations were introduced to the construction industry in the UK in 1994 as a set of guidelines for everyone involved in the construction industry to follow in order to improve the health and safety of construction workers in the UK. The revisions that took place in 2007 combined the CDM regulations with the Construction (Health, Safety and Welfare) regulations of 1996. The CDM regulations are enforced and managed in the UK by the Health & Safety Executive (HSE) which is the non-departmental public entity for the encouragement, regulation and enforcement of workplace health, safety and welfare (HSE 2013).

One unique aspect of the CDM regulations was that they created a new role in the construction process, that of the CDM coordinator who acts as an overarching entity for communication and cooperation between all project participants on safety topics and to communicate and eliminate hazards by coordinating the efforts of all project participants (Government 2007). The CDM coordinator has the responsibility to:

- Assist and advice the owners of their duties,
- Notify the HSE when necessary,
- Coordinate health and safety aspects of design and cooperate with everyone involved in the project,

- Facilitate good communication between owners, designers and contractors,
- Cooperate with the general contractor on matters concerning design,
- Identify, collect and pass on pre-construction information, and
- Prepare/update the health and safety file for the project (Government 2007; HSE 2013).

The CDM regulations also assign responsibilities to all other construction participants, including clients (owners), designers, principal contractors, other contractors (subcontractors) and workers.

Owners are responsible for checking the competence and resources of everyone responsible for designing and constructing the project, ensuring that there are suitable arrangements for project welfare facilities, managing and distributing the preconstruction information to designers and contractors, and appointing the CDM coordinator and the principal contractor (Government 2007; HSE 2013)

Designers are responsible for eliminating hazards and minimizing risks during design, providing information regarding risks they did not manage to eliminate, and providing any necessary information that needs to be included in the H&S file of the project (Government 2007; HSE 2013).

The responsibilities of the principal contractor include:

- Planning, managing and monitoring of the construction phase in cooperation with all other contractors,
- The preparation, implementation, and development of a written plan and site rules for H&S,
- Distributing of the pertinent information of the plan and site rules to all appropriate individuals,
- Providing welfare facilities to the construction site,
- Checking the competence of all appointed individuals on the site,
- Ensuring that all workers have the necessary health and safety training, and
- Coordinating with the CDM coordinator for information regarding ongoing design (Government 2007; HSE 2013).

Subcontractors in turn have the responsibility for coordinating with the principal contractor in all matters relating to H&S, preparing their own H&S plan, and reporting any incidences that occur. Workers have the responsibility for checking their own competence in performing their tasks, cooperating with all others involved on the site to ensure a safe environment, and reporting any obvious risks (Government 2007; HSE 2013).

1.4.3.1.2 Spain

Similar to the UK and the CDM regulations, Spain enacted its Royal Decree (REAL DECRETO) 1727/1997 (INSHT 1997). The guidelines described in the Decree as very similar to CDM and also call for the creation of a new role among construction project participants, that of the Health & Safety Coordinator (Coordinador en Materia de Seguridad y de Salud).

As described in the decree the Health & Safety Coordinator has the following duties:

- Coordinate and apply the principles of prevention and safety,
- Coordinate work activities and ensure that the contractors and subcontractors apply the principles of prevention through design,
- Approve the safety plan that is prepared by the contractor,
- Organize the activities of prevention through design,
- Coordinate the activities and functions for the proper execution of the work, and
- Take the necessary measures so that only the authorized persons can enter the work. (INSHT 1997; Antonio et al. 2013)

The role of the Health & Safety Coordinator in Spain is not regulated, and there is not a mutual agreement between the organizations or trainers involved with this type of work. The minimum requirements include a 200 hour training course, which is not binding. Researchers in the area of DCWS recognize that there is a need for improved education and training for Health & Safety Coordinators in Spain, and have proposed plans to improve their role and competency (Antonio et al. 2013).

1.4.3.1.1 Effectiveness of European Measures in Accident prevention

It is very difficult to evaluate whether and how these measures have improved accident prevention in the European Union. Each member country has different definitions for characterizing a fatal workplace accident and when an injury is related to work conditions. The length of time after an accident in which a fatality is connected to the accident also differs between the countries. In addition, the level of reporting differs since some countries have "Universal Social Security Systems" while others have "Insurance – Based Systems". In addition, the definition of a work place accident/fatality can vary from country to country. (Martínez Aires et al. 2010)

The accident rates among in the EU countries have shown a variety of trends. After looking at the trend of incidence rates for 11 years (1995-2005), ten of the countries experienced a reduction in their accident incidence rates by more than 10%. In three of the countries the safety rates were reduced by less than 10%, while in two of the countries the incidence rate increased by a significant amount (Martínez Aires et al. 2010).

A recent investigation conducted for NIOSH in 2010 by researchers at Oregon State University and Loughborough University in the UK investigated opinions of construction professionals in the UK on various topics that included project cost, duration, quality, productivity, and safety (Gambatese 2011). The study was based on an on-line survey of 258 construction industry professionals, and 14 focus groups involving 110 construction industry professionals. Ninety percent of the survey respondents and 88% of the focus groups participants feel that DCWS as implemented under the CDM Regulations has had a positive impact on construction worker health and safety.

1.4.3.2 Australia

The Australian efforts in DCWS are summarized in a paper by Creaser (2008). Specifically, work on DCWS began by the National Occupational Health and Safety Commission (NOHSC) in the late 1980's, and soon after, in the early 1990's, a teaching tool was developed to help engineering students learn the role of design in improving Occupational Safety and Health. In 1994, NOHSC produced initial guidelines/duties for all individuals participating in the construction of a project to eliminate or reduce the hazard exposure to workers. The individuals who were mentioned in the report included designers, manufacturers, importers, suppliers, installers/erectors, employers and owners (NOHSC 1994).

Through that initial work it was decided that a larger program was required in order to change the culture and attitude of designers towards designing for safety (Creaser 2008), and in 1998/1999 a project called "Safe Design" was initiated by NOHSC focusing on aspects relating to design for plants, buildings and structures, as well as materials and substances that would impact worker safety and health. The Safe Design Project started with assistance from industry consultants such as engineers and architects, and several reports were developed. The first report included a literature review and legal implications relating to safe design. A second report analyzed 225 work fatalities of which 117 of the fatalities were attributed to at least one design factor (Creaser 2008) . According to the author, this initial work along with subsequent reports by other Australian firms and agencies strengthen the need for improving design in order to reduce injuries and deaths in the workplace.

In 2002 a nationwide 10 year campaign was initiated, the Australian National Occupational Health Strategy (2002 – 2012), with the goal of improving Australian safety performance by ultimately reducing fatalities by 20% and other incidences by 40% (Creaser 2008) through the implementation of five strategies. One of these strategies was titled "Eliminate Hazards at the Design Phase". This strategy has a requirement called "duty of care" and places requirements on all who have influence on the hazards in a work place such as employers, owners, employees, designer organizations, and suppliers of equipment and materials. The intent is to require all to use reasonably practical means to identify the hazards and provide solutions within the constraints of the business environment (Landis Floyd 2010).

In order to enhance the education of designers and architects in matters of work safety, the Australian Safety and Compensation Council (ASCC), the agency in charge of delivering consistency in regulations for occupational safety and health in Australia, has developed several reports and educational tools. Some of these include but are not limited to:

- Guidance on the principles of safe design for work, and
- Safe design for engineering students (Creaser 2008).

1.4.4 Prevention through Design in the US

The concept of DCWS was introduced in the US in 1955 by the National Safety Council's 1955 edition of the Accident Prevention Manual. However its application to construction was not introduced until the Construction Industry Institute sponsored a research project in the 1990's (Gambatese et al. 1997; Toole 2013). Since then the National Institute for Occupational Safety & Health (NIOSH) has taken the initiative of generating interest in the US and the concept was incorporated within its National Occupational Research Agenda (NORA), a program that was developed to encourage innovative research for improved research practices (CDC 2013). NIOSH has also conducted several conferences to showcase current efforts for DCWS inclusion in education and practice (NIOSH 2011). In addition several Design-Build construction companies developed their own DCWS programs and started generating their own guidelines within their companies (Toole 2013).

A major breakthrough occurred when the American Society of Safety Engineers (ASSE) developed a national standard for DCWS that is entitled *“Prevention through Design: Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes”*. The standard does not only include the construction industry, but it is a first step for DCWS to be implemented in the US (ANSI/ASSE Z590.3 2011; Toole 2013).

Proponents of the concept try to educate the industry through a variety of methods that include education modules for college engineering courses, continuing education courses and continuing research. The “Prevention through Design” website that is maintained by researchers at Bucknell University contains a wealth of information for DCWS with resources for its use in the US construction industry. Within the website, the researchers describe what DCWS is and what it is not, as follows

DCWS is a process that:

- explicitly considers the safety of construction workers in the design of a project;
- encourages engineers to be conscious of and valuing the safety of construction workers when performing design tasks;
- encourages making design decisions based in part on how the project's inherent risk to construction workers may be affected; and
- includes worker safety considerations in the constructability review process. (Toole 2013)

DCWS is not a process that

- suggests designers take an active role in construction safety **DURING** construction;
- endorses future legislation mandating that designers design for construction safety;
- endorses the principle that designers can or should be held partially responsible for construction accidents; and
- implies that the vast majority of U.S. design professionals are currently equipped to design for construction safety.(Toole 2013)

With all of the efforts by NIOSH and the individuals involved with DCWS, the US construction industry is largely unaware of the concept, and some industry individuals appear to be set against the concept’s implementation in any form (Toole 2011).

1.4.5 Example of a DCWS review process during design

Since the majority of US designers do not have sufficient experience to design for DCWS, Toole and Gambatese developed a DCWS process to help guide designers. That process is shown in

Figure 1-6 (Toole 2013). The authors recognize that smaller firms would not have the necessary capability and expertise to implement such a process on their own, and suggest that the firms employ the services of external professionals who possess safety constructability knowledge. Their services, according to the authors, would be needed at specific points during the design phase, at 30%, 60% and 90% completion. As shown in the diagram, key project personnel would be providing safety input to the designers at these milestones.

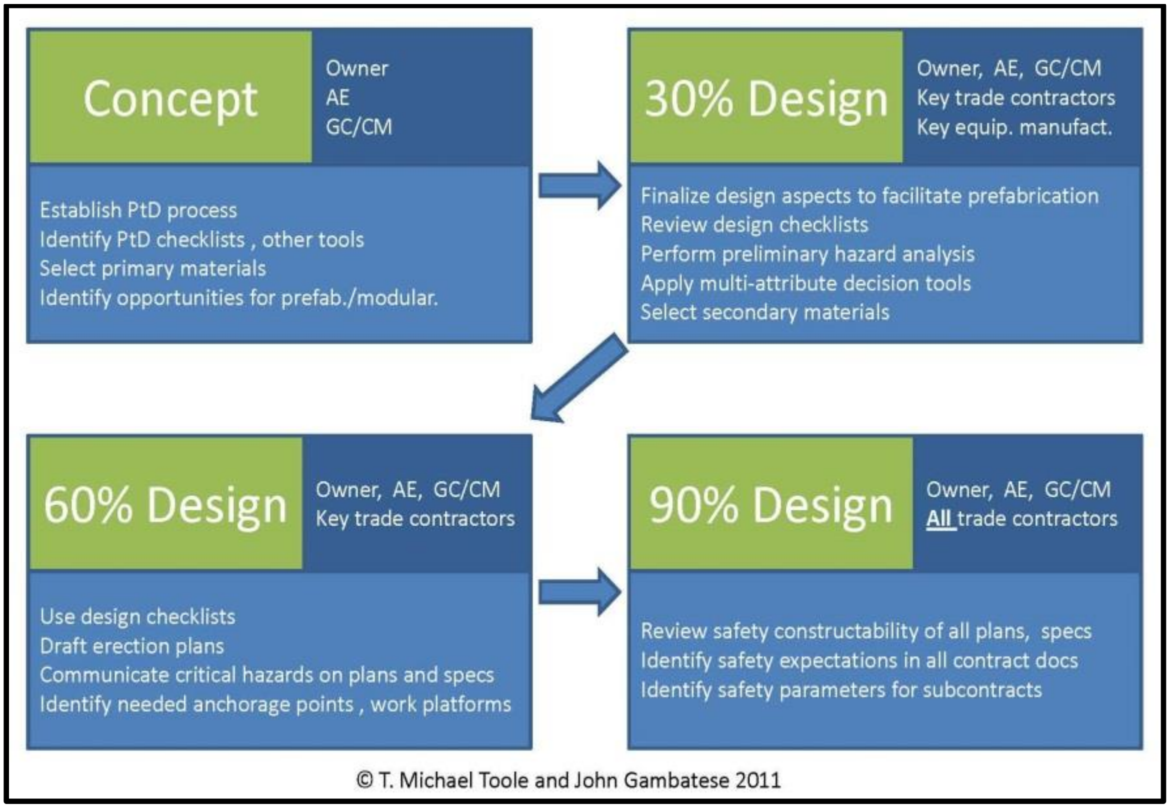

Figure 1-6: Example of a DCWS review process during design

1.4.6 Obstacles/Enablers Encountered

Obstacles and enablers for DCWS implementation in the industry have been identified in 7 key areas. These are: 1) Regulatory, 2) Legal, 3) Contractual, 4) Economic, 5) Ethical, 6) Cultural, and 7) Knowledge. The following section discusses how each area relates to DCWS.

1.4.6.1 Regulatory

Attempts to enact DCWS legislation in the US have been turned down. Specifically, after the deadly L'Ambience Plaza Building collapse that was under construction in Connecticut two bills were introduced both in the House and Senate; Senate Bill 2518 and House Bill 4856. These bills essentially required design professionals to be involved in the safety aspects of the construction sites and they faced tremendous opposition from industry professionals. As a result, they did not pass (Gambatese 2000a; Behm 2005).

Formal regulations for the practice of DCWS in the US construction industry do not exist. The occupational Safety and Health (OSHA) has recognized the importance of DCWS and started mandating some design involvement within their regulations. One example is the requirement that there be a minimum of 4 anchor bolts on every column in steel construction. Requirements such as this one, do not force designers to actually practice DCWS, since the "General Duty Clause" does not place any responsibility on any designer for worker OSH unless the workers are working for the designers (Behm 2005; Toole et al. 2013).

1.4.6.2 Legal

A major concern for designers that keeps them from being actively involved in worker safety is the potential for increased liability, and as a result only a small percentage of designers are taking the initiative to participate (Behm 2005; Gambatese et al. 2005; Toole 2005). A primary focus of design firms is survivability and to achieve that they need to avoid additional unnecessary risks that would increase their potential liability (Coble et al. 1999).

1.4.6.3 Contractual

The nature of construction contracting might be seen as a major obstacle for designers to participate in construction safety. In traditional contacting using the Design-Bid-Build contracting method, the owner enters into a contract with a designer entity to prepare a design, which is then given to contractors to bid. The lowest bidder gets assigned the job and construction begins. This separation of the construction and design phases does not allow designers to be actively involved in construction worker safety (Behm 2005). In addition, traditional contracting language clearly identifies contractors as being solely responsible for all construction operations that include, in addition to safety, the means, methods, techniques, procedures and sequences (Hinze 2001).

Alternative contracting methods that change the traditional roles between designers and contractors and encourage greater collaboration include, among others, Design-Build, Construction Management, and Construction Management/General Contractor.

The Design-Build (DB) contracting method requires the owner to come into contract with one entity that is in charge of the delivery of the project from design to completion (Hinze 2001). DB is gaining acceptance because this single contract is believed to be cost-effective and reduces litigation. Designers are asked to work together with contractors and be more aware of construction site operations and procedures. DB also allows designers to be aware of what is best for construction related programming, allowing them to realize the project's identity and give the project the appropriate consideration for design, quality control, safety and cost savings (Coble et al. 1999). Constructability reviews during design can also improve work site means and methods. In DB since the contractors are involved in the design process and designers are involved in the construction process, there is an increased likelihood for anticipating and mitigating construction site hazards before they become an incident (Beard et al. 2001).

In the construction management (CM) method, a construction company is hired to perform construction management services on the owner's behalf. The CM is employed by the owner at a very early stage in the construction of a project, and sometimes before the selection of the designer. The role of the Construction Manager is to give advice to the owner and act as his agent on topics such as cost, scheduling, site supervision, site safety and financing. As with the DB build method there is great opportunity for construction worker safety to be considered during the design phase, since the CM and the designers conduct several constructability meetings (Hinze 2001; Mehta et al. 2008).

In the Construction Management / General Contractor (CM/GC) method, the CM company acts like a general contractor, with the difference that the CM is brought in early in the project, before design is complete. This allows the owner and the designer to gain from the CM's experience prior to the bidding process. The CM acts as an independent contractor and bids on portions of the job that are not to be subcontracted (Hinze 2001; Mehta et al. 2008). With the CM/GC there is great potential for designers to gain construction knowledge by this early interaction with contractors.

1.4.6.4 Economic

Designers view that indirect costs would increase if DCWS is practiced by their firms. According to Toole (2005), indirect costs can increase in two ways. Firstly, through the need for additional safety training that would not be billable to projects and through increased insurance premiums.

Direct costs might also increase since the actions necessary to review designs for safety would not also be billable, and time required for design tasks might increase.

The real magnitude of the increased direct and indirect costs design firms might experience if they implement DCWS, cannot be accurately calculated since that value would vary between firms and on the method chosen to implement DCWS. The result of these cost increases is translated into fee increases, and that discourages designers since they feel that owners would not be willing to pay for the additional service.

1.4.6.5 Ethical

As with any other professional organization both the American Society of Civil Engineers (ASCE) and the American Institute of Architects (AIA) have codes of ethics. These codes of ethics are an overview of the expected conduct that the members of these organizations should have when they interact with the public, government and with other members (ASCE 2009; AIA 2012).

The first canon in the ASCE code of ethics states the following:

"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."(ASCE 2009)

A further investigation of the guidelines to practice, the first canon has an additional comment where *"… the lives, safety, health and welfare of the general public are dependent upon engineering judgments, decisions and practices …"* (ASCE 2009)

With the canon above the code of ethics states that all civil engineers must and should consider public safety to be of the utmost importance. This suggests that there is an ethical duty for civil engineers to do anything in their power to not endanger the public through the actions of their professional duties.

In 2007, ASCE published its "Vision for Civil Engineering in 2025" where the ASCE steering committee prepared its vision for the civil engineering profession for 2025 (ASCE 2007). Within that report the description of the tactics suggested that ASCE was very much interested in promoting DCWS, and soon after the Prevention through Design committee was formed within ASCE. Since then, increased liability concerns from within ASCE prompted the dissolution of the DCWS committee, much to the protests of its members (Toole 2011).

The AIA Code of Ethics has six canons and these are: I) General Obligations, II) Obligations to the public, III) Obligations to the Client, IV) Obligations to the Profession, V) Obligations to Colleagues, and VI) Obligations to the Environment. (AIA 2012)

Under general obligations, the canon states: *"… thoughtfully consider the social and environmental impact of their professional activities …"* (AIA 2012)

Under obligations to the public, the canon states: *"… should promote and serve the public interest in their professional activities"*(AIA 2012).

These two canons suggest that the safety of the construction workers is of interest to the architects. But a further examination of the cannon commentary suggests that the safety of the workers is not considered. Under the first canon, the ethical standards and rules of conduct talk about improving professional knowledge, raising aesthetic standards, natural heritage, human rights, and promoting the knowledge and capability of the building industry. Under the second canon, the standards and rules talk about architects following the law in conduct of their professional activities, pro bono services and public interest services. In summary the AIA canons do not mention worker safety. (AIA 2012)

With just the code of ethics it is not very clear if there are any ethical incentives for designers to start designing with construction workers in mind. ASCE recognized this omission, and in 1989 formed Policy Statement 350 that looked at Construction Site Safety (Jackson 1992). The Policy Statement has evolved over the years, and in its more recent edition in 2012, the policy has guidelines for owners, design engineers and contractors. According to the statement, designers have a responsibility:

to recognize that safety and constructability are considerations that need to be addressed during the preparation of plans and specifications, and

to provide through specifications the designs and details of the critical elements of temporary construction and procedures be designed by professional engineers (ASCE 2012).

In summary the ethical codes for design professionals suggest that there is some interest, at least from civil engineers, to be involved in construction worker safety. The ethical code for architects does not have such guidelines, and as a result, the ethical code for them is an obstacle. The ethical code at least for them would be considered as an enabler for DCWS and PtD participation.

1.4.6.6 Cultural

Researchers and scholars have defined the term "culture" in many ways, and the term varied through time and each definition was affected by the times the various researchers lived in (Moore 2009). In construction, research is concentrated on "safety culture" and "organizational culture" (Maloney et al. 1991; Hartley et al. 2009), so a broader culture that encompasses the whole construction industry is difficult to define.

The definition of culture in this manuscript is obtained from the organizational culture definition by Maloney et al. (1991) where *"… Organizational culture is the values and beliefs that govern behavior in an organization."*

A definition for construction industry culture would be:

"Construction industry culture is the values and beliefs that govern behavior in the construction industry"

The term of "Safety Culture" was first used after the Chernobyl nuclear disaster when the International Atomic Energy Agency (IAEA) identified "Poor Safety Culture" as a prominent factor in the cause of the accident (Cox et al. 1998).

The current culture within the US construction industry is not favorable for DCWS. As described in the previous sections there are no regulations for designers to practice DCWS, there are major legal concerns for designers to consider construction safety, and standard contracts do not encourage designers to be engaged in safety. As a result, the current culture is an obstacle for DCWS to be practiced widely in the US.

1.4.6.7 Lack of Knowledge and Experience

A last concern that designers have when asked to consider construction safety is their lack of knowledge of construction operations and procedures. A reason for this lack of understanding is the fact that construction knowledge is gained by many years of "on-the-job" training and active involvement. To gain this knowledge engineering students and professionals need to be engaged and involved in construction operations for an extended period of time that is impractical to be implemented. College engineering curricula would need to be modified to incorporate some experience from the construction site. Such a modification would be problematic to implement since existing programs are already packed with a vast array of classes (Toole 2005).

1.4.7 Generating Interest in DCWS

Experts in the field have discussed methods to generate interest in DCWS and to make it acceptable to practicing professionals. A report by Howe (2008) suggests that there are four methods with which to generate that interest, and these are:

- Cost/Benefit analysis and incentives,
- Culture,
- Standards, codes and regulations, and
- Strategic alliance development.

The author states that it is important to showcase the benefits of DCWS and research efforts are required to prove the business case. It is difficult to sell the DCWS solutions to management that only sees the short-term profitability, when the nature of accident prevention asks for long-term analysis to value the benefits. The suggestions given to promote the DCWS solution through the business case solution include the promotion of DCWS by large employers, the establishment of certification for DCWS, encourage and expand financial incentives for DCWS solutions, the development of business case solutions based on the impact on the business process, etc. (Howe 2008)

The cultural change that is needed to promote DCWS, needs to be generated in the high ranks of an organization. It is important that upper management officials be invested for any corporate program generating cultural change to become a norm and a success within an organization. Suggestions for encouraging cultural change include the engagement of CEO's and workers equally in the DCWS process, the changing of the performance criteria to include DCWS, the making of workplace safety a fundamental value, the incorporation of worker safety in the design process, etc. (Howe 2008)

Howe reports also that the impact of standards, codes and regulations have a great impact on the performance of business, as well as on health and safety, and uses the example of the ISO standards 9001 and 14001 that, although European in origin, had an impact in the US. The author also acknowledges that legal requirements for DCWS might not be accepted in the US, but suggests the development of a national standard that would incorporate DCWS in all industries (Howe 2008). The American Association of Safety Engineers (ASSE) has developed a set of guidelines to address DCWS in the design and redesign processes. The standard is not specific to construction but it can be applied to the construction industry since it includes processes that can be included in the design and redesign (ANSI/ASSE Z590.3 2011).

To encourage DCWS, there is also a need to create a strategic alliance between major key organizations that would encourage their members to practice DCWS and promote the research in DCWS practices in areas that need improvement (Howe 2008).

Government agencies could also generate interest through various methods. OSHA can promote DCWS by consulting firms similar to its voluntary partnership program, or use OSHA funded training grants to employ external organizations in order to train designers (Toole et al. 2013).

NIOSH has also showed interest in DCWS within its National Occupational Research Agenda (NORA). That is observed in Strategic Goal 13 where NIOSH aims to conduct research to address the identification of obstacles for DCWS, the development of incentives to promote DCWS along with tangible solutions and methods for implementing DCWS (Toole et al. 2013).

Education is also viewed as another outlet for generating interest for DCWS. In his paper, Manuele (2008) proposes three strategies that need to be adopted in order to make DCWS known and accepted by the various decision making individuals. These are:

- Expand the knowledge and concepts of Safety through Design
- Develop engineering curricula and course materials
- Establish liaisons with schools, societies, industry, and labor to increase awareness.

The above strategies concentrate greatly in educating young designers that enter professional life on the DCWS concept. This is due to the fact that these will be the people that make the majority of the decisions in the field, and their designs will eventually be implemented for the various products, processes, and facilities. Safety professionals currently in the field, feel that there is not enough enforcement of safety in the current education programs and feel that they have to re-educate young professionals by making them consider safety in their designs. The above comments were obtained after a personal interview with an Instrumentation and Control (I&C) engineer (Intel 2010).

The same thoughts were also reflected in an article written by (Zagres et al. 2008) from Washington Group International (WGI), a US infrastructure company that operates in 30 countries, where they would like engineers to have some formal training in the concept of DCWS. WGI sees that there is a lack of training on issues relating to safety and health procedures in US universities and their firm employs a variety of training programs to educate their engineers, designers, schedulers, estimators, procurement agents and contract administrators. These are:

- Safer design principles for construction, which is a class that instructs designers on improving their designs for construction safety.
- Safety Qualifies Supervisor program, where students take the OSHA 10 hour class, and additional instruction on economics of safety, job hazard analysis, hazard recognition, control of hazardous energy and accident investigation.
- Project Execution Plan, where the design team meets at the start of the design phase to discuss formally all the design requirements and design consequences.
- The firm formally participates in the OSHA Alliance workshop for Safety in Design (Zagres et al. 2008).

1.4.8 DCWS trajectories

After taking into account all the barriers and enablers of DCWS, as well all the benefits considered in literature, researchers have developed four trajectories on which DCWS will progress in the future. These trajectories are:

- Increased prefabrication,
- Increased use of less hazardous materials and systems,
- Increased application of construction engineering, and
- Spatial investigation and investigation. (Toole et al. 2008)

The prefabrication of building components allows the assembly of large building components and their transportation to the construction sites to be assembled with the use of large lifting equipment. The popularity of prefabrication has increased in the past 100 years because of its inherent benefits associated with reduced cost, shorter schedule and improved performance (Hewitt et al. 2002). In addition to the above benefits, prefabrication can also improve safety for construction workers since hazard exposure that is experienced is significantly reduced. This reduction is achieved by moving work from a higher hazard work environment (the worksite, high elevation etc.) to a lower hazard environment (the fabrication plant, lower elevation, etc.) (Toole et al. 2008).

In recent years there has been an increase in the number of products that are less hazardous to the environment that designers started specifying for buildings in order to satisfy LEED criteria for building certification. These materials are also less hazardous to human health and include coatings, adhesives and cleaners that are becoming more and more available and have a similar performance as their more hazardous counterparts. As more designers are becoming aware of such products and their benefits, more and more they will be integrated in specifications and used in the construction of more projects (Toole et al. 2008)

Construction engineering is expected to become increasingly utilized in the future through the use of industry standards that require engineering related involvement. Already engineering calculation are needed for soil retention systems, crane lifts, soil bearing analysis, the design of temporary structures, fall protection anchorage systems and temporary load analysis. Engineer involvement is required for these tasks in order to improve their safety performance. The increasing use of design-build and other alternative delivery methods will only increase designer involvement during construction as well as the fact that designers can perform design tasks more effectively than construction site personnel (Toole et al. 2008).

Finally, the authors believe that with the increased popularity of design-build, the designers will have to document in their drawings the hazards that are associated with the sites and incorporate them into guidelines for the common trades and equipment. One example of this trajectory is the specification of the existence of power lines and the safe working distances for cranes and other lifting equipment (Toole et al. 2008).

1.5 Methodology

The method selected to conduct the research for this manuscript was the use of the online survey method.

1.5.1 Surveys

Surveys are a method of collecting information from a specific population. Because of the difficulties in collecting information from the whole population a survey allows the collection of the same information from only a fraction of the population, and that is known as a sample. Depending on the method of selecting the sample, the results of the survey can be used to describe the whole population (Bethlehem 2009).

Survey research has some inherent advantages over other methods of collecting information from large populations that make it attractive for research. Some of these advantages are:

- Survey methods are very versatile and can be applied to a variety of research topics, including construction,
- When questions are asked appropriately, the information collected can be analyzed using statistical tests,
- They are very cost effective, especially when information needs to be drawn from very large populations,
- Surveys can be administered in a variety of methods, such as face to face interviews, phone interviews, traditional mail, and online,
- Their scope can be constrained to meet budget requirements without sacrificing the value of the findings,
- Surveys are not constrained by boundaries of geography(McCormack et al. 1997; Wimmer et al. 2010).

Just like any other research method, surveys also have some disadvantages that include the following:

- The restrictive nature of some survey questions might force responses from participants even if they do not have the capability or knowledge to answer,
- In some surveys, the independent variables cannot be manipulated as is possible in laboratory experiments,
- The wording of the questions can create bias in participant responses,
- There is an increased chance of participants answering surveys when they are not the intended focus group of the research, especially during mail-in and online surveys.
- The response rate of surveys has been seen to decline and that also happens with phone surveys and on-line surveys (McCormack et al. 1997; Wimmer et al. 2010).

For this manuscript online surveys were chosen as the method to collect information from the four major industry groups that were mentioned in section 1.3; contractors, owners, designers (architects and engineers). Online surveys have some inherent advantages:

- Primarily, online surveys require considerable less time to administer by the survey

administrators over other types of survey, such as phone and face-to-face.
- The cost of conducting online surveys is considerably less from all other types of survey research. Survey programs can be free and e-mail costs are minimal.
- Online surveys allow researchers to reach unique populations that would be difficult or impossible to reach otherwise. That is very true of professionals in construction are very difficult to get a hold of. (Wright 2005)

Some disadvantages that are unique to online surveys include the following:

- Contact information of the community that needs to be surveyed might be difficult to obtain. By its nature, online surveys require participants to have access to the internet, and that might not be the case for everyone, especially with older individuals,
- Email lists are not always readily available. Some professional organizations do not have contact information of their members readily available for a variety of reasons (Wright 2005).

A description of the selection process for the survey participants in this research is included in section 1.5.5.

1.5.2 Research Hypotheses

In order to understand the level of safety and DCWS understanding in the US, several questions needed to be answered. In total, thirteen hypotheses (H1-H13) were developed to help answer these questions. The hypotheses are as follows:

H1: Design for Construction Worker Safety is not prevalent in the US

For this hypothesis, questions were asked to gauge whether DCWS is known by the US construction industry participants.

H2: DCWS is not understood in the US.

For this hypothesis, questions were asked to gauge whether DCWS is understood by the US construction industry participants.

H3: DCWS is rarely practiced in the US.

To test this hypothesis, the surveys asked questions to determine the level of DCWS participation and the methods with which the various industry participants practice DCWS.

H4: Owner and designer participation in safety has many obstacles.

Construction industry participants were asked to identify whether the nature of the industry allows owners and designers to actively participate in construction safety.

H5: The obstacles to DCWS are not clear.

To test this hypothesis, the survey participants were asked to identify the possible obstacle areas that hinder designer participation in construction safety. The areas of obstacles that were listed to be identified were: a) Regulatory, b) Economic, c) Contractual, d) Legal, e)Ethical, and f) Cultural.

H6: Incentives to implement are not clear

To test the hypothesis whether there are incentives for owner and designer participation in construction safety, the survey participants were asked to identify the possible enablers in the same areas as the obstacles in H5.

H7: Designers understand the dangerous nature of construction sites.

The survey participants were asked to identify if designers understand how construction procedures take place, and if they understand what constitutes a hazard on construction sites.

H8: Owners understand the dangerous nature of construction site.

The survey participants were asked to identify if owners understand how construction procedures take place, and if they understand what constitutes a hazard on construction sites.

H9: Contractors understand the dangerous nature of construction site.

All participants were asked to agree with a statement concerning the dangerous nature of the construction industry.

H10: Designers believe that all construction site hazards are taken care of by the constructor.

Industry participants were asked to identify if construction hazards are taken care of by construction contractors and if they are solely responsible for all construction hazards.

H11: Owners believe that all construction site hazards associated with the design are taken

care of by contractors.

As in H10, industry participants were asked to identify if construction hazards are taken care of by construction contractors and if they are solely responsible for all construction hazards.

H12: Decisions made during the entire construction process affect construction site safety hazards.

Industry participants were asked to identify whether design decisions made during various project phases (pre-design, design, and construction) affect construction safety.

H13: It is not clear if owners and designers should be involved with construction site safety.

Industry participants were asked to identify whether owners and designers should be involved in construction site safety.

1.5.3 Survey Structure and Question development

The main industry participants who were surveyed belonged to four groups; owners, designers (architects and engineers), and contractors. To test the hypotheses stated in section 1.5.2, three similar surveys were developed to be distributed to the four construction groups.

An introductory page in each survey explained the research and defined the DCWS concept. The survey questions were geared to identify the level of knowledge regarding the concept of DCWS, and DCWS in general, and to try to identify what the community feels are the enablers and obstacles to implementation of the concept in the US.

The questions were separated into several groups according to their theme. These themes were:

A: Questions for identification, differentiation and statistics: These questions asked the survey participants for information on their firm, their title, their years of experience in design or construction, the types of project delivery methods they participated in, and the types of structures and projects they construct or design. Respondents from design firms were asked to identify the types of building systems they design.

B: Questions on their knowledge of the DCWS concept: These questions asked about their prior knowledge of DCWS, the type and extent of participation in construction safety and DCWS, and their participation in constructability meetings. The participants were also asked to identify the reasons for their firm's decision to start participating in DCWS if applicable.

C: Opinions: Questions in this section were 5-scale Likert type questions (Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree) that concentrated on collecting participant opinions on various statements regarding designers, owners, and safety in the construction industry in general. The statements addressed the level of knowledge of each group about construction site operations, their understanding of hazards to construction workers, capacities and opportunities for education in construction safety, and possible involvement in construction safety. The survey participants were asked to state their agreement on whether decisions made during project conception, design, and construction affect construction worker safety. They were also asked whether their firm would be supportive of legislation for designers to practice DCWS, and whether their firm would be supportive of the DCWS concept if designers were legally protected from liability in practicing DCWS.

D: Obstacles & Enablers: In this set of questions, the participants were asked to state their agreement or disagreement in a set of 5-scale Likert type questions on the existence of obstacles and enablers for designer participation in DCWS. Obstacles and enablers were identified to be in six categories: Regulatory, Economic, Contractual, Legal, Ethical and Cultural. The terms were identified as follows for the survey participants:

- Regulatory: guidelines enforced by professional and governmental organizations
- Economic: costs/benefits, direct and/or indirect, and insurance costs/benefits
- Contractual: standard language used in contracts
- Legal: federal, state, and local statutes
- Ethical: principles of conduct that are considered correct
- Cultural: standards of construction industry practice

All three surveys are shown in detail in the Appendix section of this document. The contractor survey is shown in Appendix A – Contractor Survey. The designer survey is shown in Appendix B – Designer Survey, and the owner survey is shown in Appendix C – Owner Organization Survey.

1.5.4 IRB review Board

In order to conduct the various surveys, all documents associated with the contact of survey respondents were submitted to the Oregon State University Institutional Review Board (IRB).

IRB approval is required every time research is conducted with the participation of human subjects. Documents that were submitted included the following:

- Research Protocol
- Contractor Survey
- Owner Survey
- Designer Survey
- Email templates
- Reminder email templates
- Telephone conversation guidelines

IRB approval was received on May 16, 2011, giving permission to conduct the various surveys.

1.5.5 Sampling

This section describes the method with which the various sampling and observation units were chosen for the survey.

An observation unit is the object on which a measurement is taken (Lohr 2010). In this survey the individuals responding to the various surveys are the observation units, since they are the ones providing the answers to the questions.

The sampling unit is the unit that is selected for the sample within which the observation unit can be collected and surveyed (Lohr 2010). Because of the large number of observation units (architects, engineers contractors, owners), multiple levels of sampling units were introduced. The levels of sampling units are described as primary, secondary, tertiary, etc. A depiction of the sampling and observation units for each group is shown in Table 1-2.

Table 1-2: Sampling Units and Observation Units used in Survey

	Owners	**Architects**	**Engineers**	**Contractors**
Primary Sampling Unit	Census Division	Census Division	Census Division	Census Division
Secondary Sampling Unit	State	State	State	State
Tertiary Sampling Unit	University		Firm	Firm
Observation Unit	Individual	Individual	Individual	Individual

As observed, for the architect group there was only a primary and a secondary sampling unit, while the observation unit was the individual architect in the state. This was possible because the American Institute of Architects (AIA) has a list of AIA members available for each state, which is accessible online.

A similar situation is not available for the engineers and the contractors, since their corresponding professional societies do not have a list of available engineer and contractor individuals available. To remedy that issue, a tertiary sampling unit was introduced. For engineers, that tertiary sampling unit was the engineering firms, and for contractors the construction contracting firms. Within each firm, internet searches were used to find engineers and contractors to survey.

For the owner survey, the tertiary sampling unit was the universities within each state, and the observation units were the individuals working in the various facility services departments. A more detailed description for the selection of the sampling and observation units is shown in the following sections of the manuscript.

1.5.5.1 Selection of Investigated States

The participation of participants from all states was not possible and a scheme for randomly selecting the states to be included in the survey needed to be developed. To ensure geographic diversity among participants, the states were grouped according to the nine divisions in which the US Census Bureau separates the country, as illustrated in Figure 1-7 (USCB 2011). Specifically the US Census Bureau divides the country into nine divisions, which are:

- Pacific: Alaska, California, Hawaii, Oregon and Washington;
- Mountain: Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah and Wyoming;
- West North Central: Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota and South Dakota;
- West South Central: Arkansas, Louisiana, Oklahoma and Texas;
- East North Central: Illinois, Indiana, Michigan, Ohio and Wisconsin;
- East South Central: Alabama, Kentucky, Mississippi and Tennessee;
- New England: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont;
- Middle Atlantic: New Jersey, New York and Pennsylvania; and

- South Atlantic: Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia and West Virginia.

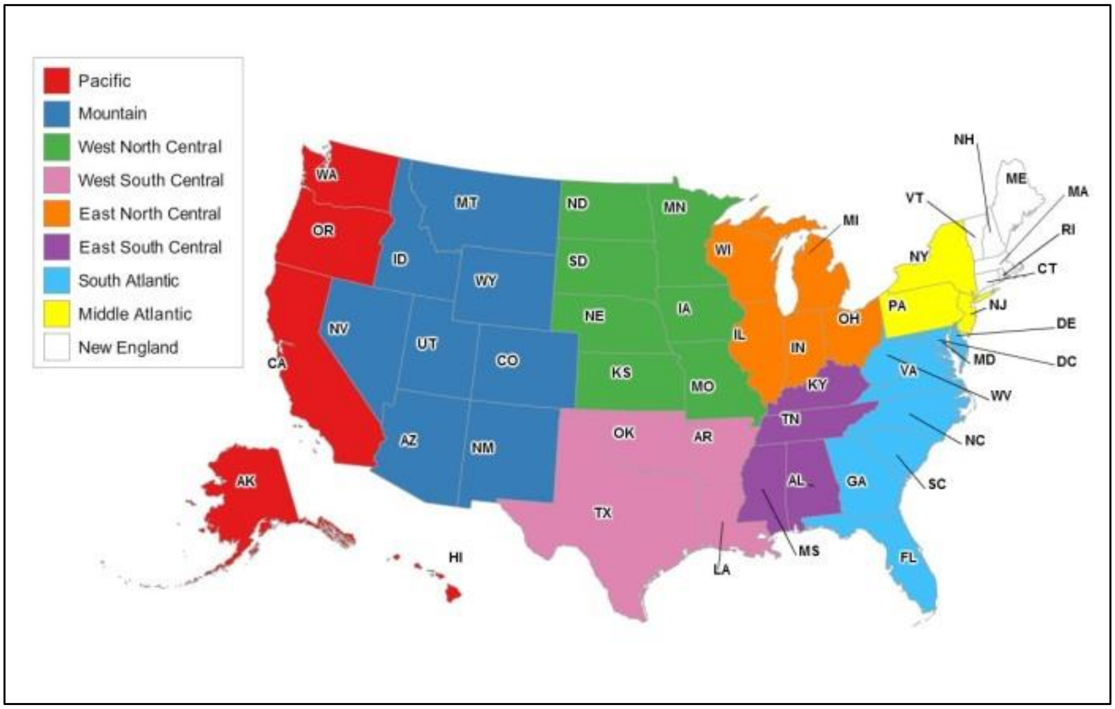

Figure 1-7: US Census Bureau Divisions

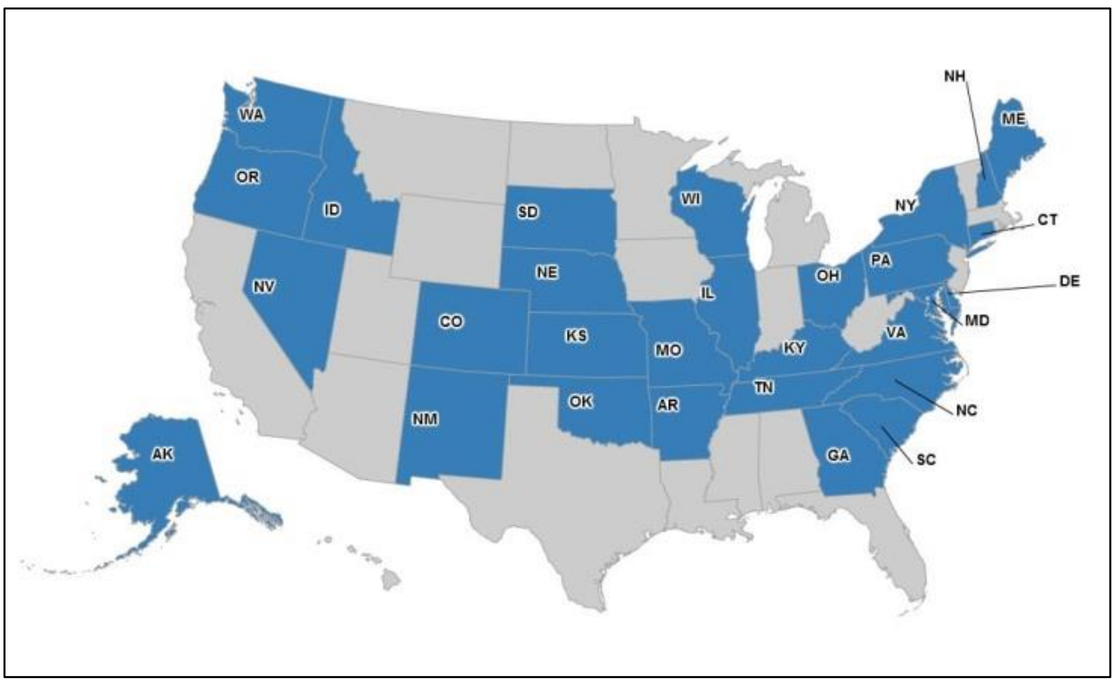

Figure 1-8: Randomly Selected States for the Survey

At least half of the states from each division were randomly chosen, and a total of 29 states were used in the study. The states selected for the survey were: Alaska, Arkansas, Colorado, Connecticut, Delaware, Georgia, Idaho, Illinois, Kansas, Kentucky, Maine, Maryland, Missouri, Nebraska, Nevada, New Hampshire, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, South Dakota, Tennessee, Virginia, Washington, and Wisconsin. A map of the US showing the selected states for the study is shown in Figure 1-8.

1.5.5.2 Owner Group Selection

The driving force in any construction project is the owner. The owner of any project is the entity that has a need to construct a project and the budget to facilitate that construction. Within that role it was decided to include owners as a focus group for this survey. There are various types of owners that construct buildings at any given time in the US. Some examples of owners could be:

- Individual persons wishing to construct a project,
- Firms or companies that construct several projects for their operations
- Public owners

Owner organizations in the US represent the interests of owners in construction projects some of these are: Building Owners and Managers Association (BOMA), Construction Owners Association of America (COAA), and the Construction Users Roundtable (CURT). Attempts were made to distribute the "owner survey" to these owner groups in the US, but the groups contacted did not allow the distribution of the survey to their members. This forced the research to concentrate on a particular type of owner. The owner group selected was the various colleges and universities in the US. The reason this group of owners was selected was primarily due to convenience. Contact information is readily available on the university websites and the surveys can be distributed to the appropriate individuals. Universities, though, have unique features that make them very interesting and suitable for this study. These features are:

- They construct diverse types of buildings. By observing the campus map of any university, it is clear that universities have buildings dedicated to a variety of functions such as educational buildings, office buildings, laboratories and research buildings, athletic facilities, medical facilities, civic buildings, retail facilities, power generating facilities, etc.
- They perform projects in a variety of contracting methods such as Design Build, Design-Bid-Build, Construction Management, Construction Management @ Risk, and sometimes they even self-perform small projects.
- Universities are both private and public and both types of universities were included in

the survey.

The individuals who were chosen to participate in the survey were representatives from the various facility services departments in each of the universities that had the responsibility for supervising and administering the various construction projects within their universities.

To identify the universities to contact for the research, the Peterson's Student Edge website (Peterson's 2011) was used to obtain a directory of all the universities in the US. Among other criteria, the universities in the directory are stratified according to their state and the size of their student body. The website separates universities into four different size categories:

- **Large Universities**: Universities with more than 15,000 students
- **Mid-Sized Universities**: Universities with between 5,000 and 15,000 students
- **Small Universities**: Universities with between 2,000 and 5,000 students
- **Very Small Universities**: Universities with a less than 2,000 students

For the purposes of this research "Very Small Universities" were not surveyed. For all other universities in the 29 selected states, a contact person within the office of facility services or any other university department that would be responsible for the supervision and management of construction contracts on their respective campus was identified. A total of 554 universities were identified in the sampled population, and personnel from 346 (62%) of these universities were contacted. A distribution of the number of universities contacted per state is shown in Table 1-3.

1.5.5.3 Contractor Group Selection

The membership directory of the Associated General Contractors of America (AGC) was used to identify the group of general contractors to be used in the survey. The website maintains a directory of construction companies and for the purposes of this investigation general contractors were selected that participate in building construction and they were selected from the AGC directory using the following filters from the options available on the site: commercial, healthcare, manufacturing, education, and lodging/multi-family residential projects (AGC 2011).

Through various internet searches, attempts were made to identify contact personnel within each construction firm to respond to the survey. Targeted participants were those who would have extensive construction experience and are a key management figure in their firm. There were 1,617 firms identified from the 29 selected states, and personnel from 937 (58%) of these were contacted. A distribution of the number of contractors contacted per state is shown in Table 1-3.

Table 1-3: Contacted Owners, Engineers, Architects and Contractors per State

	Owners	Engineers	Architects	Contractors
Alaska	3	12	19	28
Arkansas	4	23	40	10
Colorado	13	62	40	25
Connecticut	13	27	41	23
Delaware	2	12	35	4
Georgia	28	58	40	51
Idaho	4	25	44	20
Illinois	21	99	42	56
Kansas	7	33	39	25
Kentucky	9	55	40	34
Maryland	13	53	39	11
Missouri	9	63	40	43
Maine	4	23	40	13
North Carolina	17	90	40	86
Nebraska	4	30	22	26
New Hampshire	2	10	40	9
New Mexico	5	30	40	14
Nevada	3	10	40	22
New York	46	129	41	66
Ohio	19	41	40	28
Oklahoma	6	34	40	21
Oregon	9	36	24	34
Pennsylvania	37	52	40	31
South Carolina	10	37	40	37
South Dakota	5	29	30	17
Tennessee	11	71	40	34
Virginia	14	59	40	60
Washington	11	35	24	59
Wisconsin	17	53	40	50
Total	346	1291	1080	937

1.5.5.4 Designer Group Selection

The two major designer groups that are involved in the US construction industry are the architects and Engineers. Engineers were selected from the online directory of the American Council of Engineering Companies (ACEC 2011), while architects were selected from the online directory of the American Institute of Architects (AIA 2011).

The ACEC directory maintains a list of engineering companies practicing in the US and is stratified according to size and state. The directory also allows visitors to the website to filter the companies according to the market served. For this study the list was filtered according to the markets that are used in the construction of buildings, the main area of interest in the study, such as “Barracks”, Dormitories”, “Civil Buildings”, etc. The directory also separates engineering firms into six different sizes which are listed below:

- Small Firms: 1 – 30 employees,
- Medium Firms: 31 – 75 employees
- Medium Large Firms: 76 – 150 employees
- Large Firms: 151 – 499 employees
- Extra Large Firms: 500 – 999 employees
- Extremely Large Firms: more than 1000 employees

Through various online searches, a contact person was identified within each firm in each selected state who would be suitable to respond to the survey. A suitable person was identified to be someone who had extensive design experience and be a key management figure in their firm. There were 2,131 firms identified from the 29 selected states in all six firm sizes, and personnel from 1,291 (61%) of these were contacted. A distribution of the number of engineers contacted per state is shown in Table 1-3.

The AIA directory maintains a list of architects according to their state, and the information provided includes all contact information and email. Due to the large number of architects registered within the AIA directory, a random sample or architects was generated for each state and a survey was sent to each selected individual. A total of 1,080 architects were contacted from the 14,905 registered AIA architects in the US (7%). A distribution of the number of architects contacted per state is shown in Table 1-3.

1.5.6 Survey Distribution

The surveys were administered online using a survey tool called Limesurvey, which is freely distributed software (www.limesurvey.org) and is available on the Oregon State University College of Engineering servers. All of the survey responses were stored on University servers and downloaded for analysis. Identifying information from the participants was stripped during analysis of the data.

The distribution of the survey took place between June and December of 2011. The identified contacts were emailed the link to the survey and were subsequently reminded to complete the survey a total of three times. A reminder was sent every two weeks. If a person responded to the survey, their email was removed from the contact list and not contacted again.

1.6 Survey Results

Of the 3,654 individuals who were contacted for the various surveys, 765 responded. The response rate for all the surveys was 21.6%, and this information is shown in Table 1-4. The distributions of responses from each state and for each sampled group are shown on Table 1-5.

The response rate is attributed to a variety of reasons. Primarily, there was no incentive for the responders to participate and the research explained to them that their participation is voluntary. Also the topic of safety is not among the favorite topics to talk about amongst designer professionals.

Table 1-4: Summary of Responses and Response Rates

	Owners	Architects	Engineers	Contractors	Total
Responses	121	221	244	179	765
Contacted	346	1080	1291	937	3654
Response Rate	35.1%	20.9%	19.6%	20.1%	21.6%

The response to this survey was the largest from any of the surveys that were conducted on the topic of DCWS in the US. As of this date there has not been a survey conducted nationally in the US, nor with so many responses. Hinze et al. (1992) conducted a survey of design firms listed in 3 publications (ENR, Constructor and The Military Engineer) on the topics of designer involvement on safety and constructability reviews with 35 responses and a response rate of 18.2%. A survey by Toole (2002) investigated whether there is a common understanding of site safety responsibilities among designers, general contractors and subcontractors through phone and written surveys, with a participation of 54 design firms, 26 general contracting firms and 25 subcontractors, from Pennsylvania.

Gambatese (2011) conducted a survey and several focus group discussion on the effects of the CDM regulations in the UK. In total 258 participants responded to the survey and 110 participants were involved in the focus group discussions. The participants of the survey and the focus groups were architects, design engineers, facility owners/developers, constructors, manufacturers/suppliers, and health and safety professionals.

In other studies that were conducted, researchers performed focus groups on specific topics. Gambatese et al. (2008) performed an expert panel study with 18 participants on the topic of linking design to construction site fatalities. In a different investigation Gambatese et al. (2005) looked at the viability of designing for construction worker safety through in depth interviews of 19 professionals; 8 architects, 4 structural engineers, 3 civil engineers, 2 mechanical engineers and 2 electrical engineers.

As observed in Table 1-5, the participation in the survey was not equally distributed among the participating states, and the response of certain groups in several states was low. Examples of this include the complete absence of surveys from universities in Maine and South Dakota, the non-response of contractors from Oklahoma, and single responses from all industry groups; designers (Delaware, Maine), Universities (Delaware, Idaho, Nebraska, Nevada, New Hampshire, Oklahoma) and contractors (Arkansas, New Hampshire)

The low number of responses, or even non-responses, among industry groups, does not allow the results to be representative of the states surveyed, or even to represent a true national average. It is assumed though, that the responses represent an approximation of the national averages because of the following:

- The responses have a geographic diversity.
- The responses from engineering firm employees come from a variety of firm sizes as seen in Table 1-6.
- The responses from university facility services employees come from a variety of university sizes and both from private and public universities as seem in Table 1-7.
- The selection of architects from the AIA directory was random.

Table 1-5: Responses per State and Group

	Received Surveys per State and Group				
State	**Designers**	**Architects**	**Universities**	**Contractors**	**Total**
Alaska	3	8	3	2	16
Arkansas	2	7	2	1	12
Colorado	19	7	7	6	39
Connecticut	11	7	4	5	27
Delaware	1	6	1	2	10
Georgia	10	6	7	10	33
Idaho	7	9	1	7	24
Illinois	18	14	3	6	41
Kansas	7	6	2	5	20
Kentucky	8	3	4	4	19
Maine	1	6	0	2	9
Maryland	11	8	5	3	27
Missouri	12	12	7	5	36
Nebraska	6	7	1	7	21
Nevada	2	10	1	6	19
New Hampshire	3	9	1	1	14
New Mexico	8	8	2	2	20
New York	14	4	13	11	42
North Carolina	6	5	9	17	37
Ohio	4	4	8	10	26
Oklahoma	10	8	1	0	19
Oregon	8	8	5	15	36
Pennsylvania	13	8	13	3	37
South Carolina	8	6	2	8	24
South Dakota	6	10	0	2	18
Tennessee	10	10	3	9	32
Virginia	15	8	3	10	36
Washington	9	9	7	11	36
Wisconsin	12	8	6	9	35
Totals:	**244**	**221**	**121**	**179**	**765**

Table 1-6: Engineer responses according to the size of their firm

State	Size of Firm (employees)						Total
	Small (1 - 30)	Medium (31 - 75)	Medium / Large (76 - 150)	Large (151 - 499)	Extra Large (500 - 999)	Extremely Large (1000+)	
Alaska	1	0	0	0	0	2	3
Arkansas	2	0	0	0	0	0	2
Colorado	2	3	2	1	0	11	19
Connecticut	6	0	1	0	0	4	11
Delaware	0	0	1	0	0	0	1
Georgia	8	1	0	0	1	0	10
Idaho	3	1	0	2	0	1	7
Illinois	9	0	1	3	3	2	18
Kansas	2	2	0	0	1	2	7
Kentucky	2	1	2	0	2	1	8
Maine	0	1	0	0	0	0	1
Maryland	2	0	1	2	2	4	11
Missouri	4	1	0	4	0	3	12
Nebraska	3	1	0	0	0	2	6
Nevada	1	1	0	0	0	0	2
New Hamp.	1	0	1	0	0	1	3
New Mexico	2	1	0	2	0	3	8
New York	5	3	3	2	1	0	14
North Carol.	5	0	0	0	1	0	6
Ohio	1	0	0	0	0	3	4
Oklahoma	7	1	1	0	0	1	10
Oregon	2	0	2	2	2	0	8
Pennsylvania	4	0	2	3	2	2	13
South Carol.	5	0	0	1	0	2	8
South Dakota	3	1	0	1	1	0	6
Tennessee	6	1	0	1	1	1	10
Virginia	5	3	0	4	1	2	15
Washington	2	1	0	3	0	3	9
Wisconsin	5	3	2	2	0	0	12
Totals:	98	26	19	33	18	50	244

Table 1-7: Distribution of owner responses (Small/Med/Large & Public/Private)

State	Pub. Large	Pub. Med.	Pub. Small	Pri. Large	Pri. Med.	Pri. Small	Total	Public	Priv.	Large	Med.	Small
Alaska	1	1	1	0	0	0	3	3	0	1	1	1
Arkansas	0	2	0	0	0	0	2	2	0	0	2	0
Colorado	0	3	3	0	1	0	7	6	1	0	4	3
Connecticut	1	2	0	0	0	1	4	3	1	1	2	1
Delaware	1	0	0	0	0	0	1	1	0	1	0	0
Georgia	2	2	2	0	1	0	7	6	1	2	3	2
Idaho	1	0	0	0	0	0	1	1	0	1	0	0
Illinois	0	0	0	0	2	1	3	0	3	0	2	1
Kansas	0	1	1	0	0	0	2	2	0	0	1	1
Kentucky	1	1	1	0	0	1	4	3	1	1	1	2
Maine	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	1	0	4	0	0	0	5	5	0	1	0	4
Missouri	2	4	0	0	1	0	7	6	1	2	5	0
Nebraska	0	1	0	0	0	0	1	1	0	0	1	0
Nevada	0	1	0	0	0	0	1	1	0	0	1	0
New Hamp.	0	1	0	0	0	0	1	1	0	0	1	0
New Mexico	1	1	0	0	0	0	2	2	0	1	1	0
New York	1	4	0	0	4	4	13	5	8	1	8	4
North Carol.	1	5	1	0	2	0	9	7	2	1	7	1
Ohio	5	0	1	0	0	2	8	6	2	5	0	3
Oklahoma	0	1	0	0	0	0	1	1	0	0	1	0
Oregon	1	2	1	0	0	1	5	4	1	1	2	2
Pennsylvania	0	4	0	0	2	7	13	4	9	0	6	7
South Carol.	0	0	1	0	0	1	2	1	1	0	0	2
South Dakota	0	0	0	0	0	0	0	0	0	0	0	0
Tennessee	1	1	0	0	0	1	3	2	1	1	1	1
Virginia	2	1	0	0	0	0	3	3	0	2	1	0
Washington	2	2	1	0	0	2	7	5	2	2	2	3
Wisconsin	0	6	0	0	0	0	6	6	0	0	6	0
	24	46	17	0	13	21	121	87	34	24	59	38

1.6.1 Participants' experience

Construction industry experience was considered an important requirement for participants to provide insightful information for designer participation in DCWS. The responders from each particular firm contacted to participate were selected to be high ranking in their organization in positions such as president, vice-president, chief operations officer, etc.

That experience was captured successfully as observed in Table 1-8. Of the engineer participants, 73.0% of them had design experience of 20 years or more, 79.2% of architects had similar experience, and 81.1% of contractor participants had an equivalent experience in construction.

Table 1-8: Experience in Design and Construction by Survey Participants

	Engineers		Architects		Contractors			
	In Design		In Design		In Construction		Total	
NA	4	1.6%	3	1.4%	1	0.6%	8	1.2%
0 - 5 years	12	4.9%	7	3.2%	6	3.4%	25	3.9%
6 - 10 years	10	4.1%	5	2.3%	3	1.7%	18	2.8%
11 - 15 years	18	7.4%	12	5.4%	16	8.9%	46	7.1%
16 - 20 years	22	9.0%	19	8.6%	8	4.5%	49	7.6%
21 - 25 years	37	15.2%	34	15.4%	29	16.2%	100	15.5%
26 - 30 years	56	23.0%	39	17.6%	35	19.6%	130	20.2%
more than 30	85	34.8%	102	46.2%	81	45.3%	268	41.6%
	244	100.0%	221	100.0%	179	100.0%	644	100.0%

1.6.2 Type of buildings designed/constructed

The research also required that the survey participants have a diverse knowledge in designing and constructing a variety of buildings types. To verify this requirement, the project participants were asked to indicate the types of buildings that their firm/organization designs or constructs. As observed in Table 1-9, the participants had experience in all types of buildings specified by the survey. They were also asked to indicate any other types of buildings they construct or design. In addition to those listed, the types of buildings that were mentioned were healthcare and death care. Healthcare facilities included hospitals and other medical facilities, while death care facilities included funeral homes, mausoleums and other cemetery buildings. All of the owners specified that they construct educational facilities. This is a reasonable response since the owners surveyed were universities.

Table 1-9: Types of buildings constructed or designed by the participants' firms/organizations

	Engineers		Architects		Owners		Contractors	
Types of Buildings	n	%	n	%	n	%	n	%
Educational Buildings	103	42.2%	121	54.8%	121	100%	150	83.8%
Res., Multifamily, dorm.	72	29.5%	156	70.6%	111	91.7%	88	49.2%
Commercial	119	48.8%	178	80.5%	22	18.2%	167	93.3%
Industrial	103	42.2%	88	39.8%	13	10.7%	133	74.3%
Retail	69	28.3%	121	54.8%	26	21.5%	131	73.2%
Transp. Buildings	83	34.0%	34	15.4%	4	3.3%	81	45.3%
Civic	108	44.3%	129	58.4%	11	9.1%	138	77.1%
Athletic Facilities	78	32.0%	68	30.8%	110	90.9%	123	68.7%

1.6.3 Types of buildings systems designed

The survey participants are experienced in design various building systems, as observed in Table 1-10. The designers were asked to indicate the types of building systems their firms are involved in designing, and as observed, the designers from the firms surveyed had experience in design for most of the systems that are incorporated into the construction of a building.

Table 1-10: Types of Building Systems Designed

	Engineers		Architects	
	n	%	n	%
Architectural (drawings & documents)	76	31.1%	216	97.7%
Foundations (geotechnical)	137	56.1%	75	33.9%
Structural framing	134	54.9%	90	40.7%
Building Enc., T/M protect., wall systems, openings, finishes	67	27.5%	157	71.0%
Conveying systems/components	39	16.0%	79	35.7%
Electrical systems/components	80	32.8%	63	28.5%
Mechanical systems/components	89	36.5%	59	26.7%
Site utilities, excavations, paving, grading, site work	153	62.7%	91	41.2%

1.6.4 Types of project delivery methods practiced

The survey responders participated in several project delivery methods, as shown in Table 1-11. The survey asked all participants to state the types of project delivery methods that their firm/organization participated in, and as observed, almost all types of project delivery methods are represented in the responses.

Table 1-11: Types of project delivery methods used

	Engineers		Architects		Owners		Contractors	
Proj. Delivery Methods Used	n	%	n	%	n	%	n	%
DBB	224	91.8%	196	88.7%	103	85.1%	154	86.0%
DB	182	74.6%	147	66.5%	58	47.9%	139	77.7%
CM/GC or CM@Risk	114	46.7%	111	50.2%	85	70.2%	154	86.0%
DBOM	29	11.9%	11	5.0%	17	14.0%	22	12.3%
DBOT	15	6.1%	3	1.4%	5	4.1%	7	3.9%
Multiple Prime	38	15.6%	37	16.7%	33	27.3%	58	32.4%
Self-Performed	35	14.3%	65	29.4%	52	43.0%	47	26.3%

1.6.5 Participants' prior knowledge of DCWS and safety participation

To gauge the extent of prior knowledge of the DCWS concept and the type of participation in issues related to construction worker safety, the industry participants were asked the following questions:

- B1: Were you previously aware of the "Design for Construction Worker Safety" concept?
- B2: Is your firm currently actively practicing some form of DCWS?
- B3: Does your firm currently have guidelines for reviewing design for construction workers safety?
- B4: Has your firm ever been asked to address issues relating to construction worker safety?
- B5: Does your firm participate in constructability meetings with designers, where construction worker safety issues are discussed?

Engineers and architects were asked questions B1 through B4. Owners were asked questions B1 through B3, while contractors were asked questions B1 and B5.

The results showed that the survey participants had some prior knowledge of the DCWS concept (Question B1). Specifically, 20.5% of engineers, 5.4% of architects, 21.5% of owners, and 16.2% of contractors stated that they knew about DCWS prior to the survey.

When the designers (architects and engineers) were asked to state if their firm is practicing some form of DCWS (Question B2), only 19.3% of engineers and 5.4% of architects stated that their firm is practicing some form of DCWS. Examples of their efforts included: active practice of DCWS through focused project reviews and project hazard registers, and the use of construction personnel during the early design process to incorporate means and methods into the design.

For the same question, 72.5% of the owners stated that they practice some form of DCWS. This number appears to be impressive at first, but when they were asked to describe their efforts, the majority of the responders included comments about the facilities safety plans that are in place for their employees, and is not related to the DCWS concept.

When asked if their firm/organization has guidelines for reviewing their designs for construction worker safety (Question B3), 9.8% of engineers and 3.2% of architects stated that they did. Examples of their guidelines included constructability reviews, the review of construction safety plans, and the design of fall restrain systems.

For the same question, 15.7% of the owners stated that they have guidelines for reviewing designs for construction worker safety. When asked to describe their efforts, the owners described the review of the contractor’s safety plans.

The designers were also asked to state if their firm has been asked to address issues related to construction worker safety. Thirty-one percent of engineers and 10.4% of architects confirmed that their firm has been asked to address safety. Some examples of their efforts included the design of framing systems to reduce worker exposure to hazards, the development of phasing plans for construction, and the design of fall protection and anchorage systems.

In response to question B5, 46.9% of the contractors stated that they participate in constructability meetings with designers where safety issues are discussed. Items discussed during these meetings included rigging of equipment, issues relating to working in confined spaces, traffic control plans, temporary equipment access, fall protection systems, emergency evacuation, and excavation safety. A complete summary of the results of these questions is shown in Appendix D – Summary of Survey Results.

1.6.6 Opinions

The survey participants were asked to rate their level of agreement on various statements in order to gauge their understanding of safety within the construction industry, their perceived capabilities in participating in construction safety as well as for them to identify areas of obstacles or incentives to participate in construction safety.

1.6.6.1 Construction Industry Hazards Understanding

Two statements were given to the survey participants to rate the level of understanding designers and owners have on construction operations and procedures. These statements were:

- C1a: Designers know how construction operations and procedures take place, and
- C2a: Owners know how construction site operations and procedures take place

The level of agreement varied according to the industry group each survey respondent belonged to. The results are summarized in Table 1-12. The values in the table and the following tables in this section represent the percentage or participants that responded with "Strongly agree" and "Agree" to the statements.

Table 1-12: Agreement with level of construction operations and procedures understanding by designers and owners

	Engineers	Architects	Owners	Contractors
C1a Designers	70.1%	67.4%	43%	19.6%
C2a Owners	17.6%	9%	80.2%	14%

As observed, the majority of engineers and architects agreed with statement C1a (70.1% and 67.4% respectively). Only 43% of owners agreed with that statement while a mere 19.6% of contractors agreed with the statement. Similarly for the owners' level of understanding of construction operations and procedures (C2a), 80.2% of owners agreed with the statement. Only 17.6% of engineers, 9% of architects, and 14% of contractors agreed with the statement.

Regarding the level of understanding by designers and owners as to what constitutes a hazard to construction workers, the survey asked participants to state the level of understanding by responding to the following two statements:

- C1b: Designers have clear understanding of what constitutes a hazard to construction workers
- C2c: Owners have clear understanding of what constitutes a hazard to construction workers

The level of agreement varied again according to the industry group each survey respondent belonged to. The results are summarized in Table 1-13.

As observed, a substantial percentage of engineers (47.5%), architects (43%) and owners (33.9) agreed that designers have a clear understanding what constitutes a hazard to construction workers. By contrast, only 11.7% of contractors agreed with the statement. Similarly for the owners' level of understanding of what constitutes a hazard to construction workers, 73.6% of owners agreed with the statement, while only 13.9% of engineers, 4.6% of architects and 14% of contractors agreed with the statement.

Table 1-13: Agreement to understanding what constitutes a hazard to construction workers by designers and owners

	Engineers	Architects	Owners	Contractors
C1b Designers	47.5%	43%	33.9%	11.7%
C2c Owners	13.9%	4.6%	73.6%	14%

The survey participants were also asked whether owners and designers have the capabilities to be educated on the topic of construction worker safety through their agreement with the following statements:

- C1c: Designers have adequate capacity and opportunities to be educated in construction worker safety
- C2b: Owners have adequate capacity and opportunities to be educated in construction worker safety

Table 1-14: Agreement to the capabilities of owners and engineers to be educated on construction worker safety

	Engineers	Architects	Owners	Contractors
C1c Designers	43%	26.2%	43%	43.4%
C2b Owners	27%	14.5%	73.5%	43.5%

As observed in Table 1-14, a substantial amount of engineers (43%), owners (43%) and contractors (43.4%) believe that designers have the capabilities to be educated on construction worker safety. By contrast, only 26.2% of architects agreed with the statement.

Regarding the owners' capabilities to be educated on the topic, a substantial majority of the owners (73.5%) agreed with the statement, 43% of the contractors agreed with the statement while, 27% of the engineers and 14.5% of the architects agreed.

The survey participants were also asked if designers and owners should be involved in construction worker safety through their level of agreement with the following two statements:

- C1d: Designers should be involved and participate in construction worker safety through design decisions
- C2d: Owners should be involved and participate in construction worker safety

As seen in Table 1-15, support for designers to be involved in construction worker safety was 53.7% from engineers, 25.8% from architects, 45.4% from owners, and 79.9% from contractors. The support for owner involvement was 52.9% from engineers, 27.2% from architects, 59.5% from owners, and 65.4% from contractors. With the exception of the architect group, there seems to be significant support for more universal involvement of the project team members in construction safety.

Table 1-15: Agreement to designers and owners participating in construction worker safety

	Engineers	Architects	Owners	Contractors
C1d Designers	53.7%	25.8%	45.4%	79.9%
C2d Owners	52.9%	27.2%	59.5%	65.4%

Continuing, the survey participants were also asked whether the nature of construction contracting is an obstacle for designers and owners to participate in construction worker safety through their level of agreement with the following two statements:

- C1e: The nature of construction contracting does not allow designers to participate in construction worker safety
- C2e: The nature of construction contracting does not allow owners to participate in construction worker safety

Table 1-16: Agreement to nature of construction contracting being an obstacle for worker safety participation

	Engineers	Architects	Owners	Contractors
C1e Designers	41.4%	59.3%	33.1%	14%
C2e Owners	29.3%	55.2%	17.3%	25.7%

As observed in Table 1-16, the majority of the architects who responded agreed with both statements; 59.3% for designers and 55.2 for owners. The other groups though did not show a majority of agreement with the statements.

1.6.6.2 Construction Industry Hazards Involvement

In order to understand who the industry participants feel is currently involved in construction worker safety and if actions taken prior to construction affect worker safety, the industry participants were asked to rate their level of agreement with the following statements:

- C3a: The construction industry is a hazardous industry
- C3b: Only construction contractors are currently involved in reducing hazards to construction workers
- C3c: All construction site hazards to construction workers are taken care of by construction contractors
- C3d: Decisions made before the design of a project begins can help eliminate some construction hazards
- C3e: Decisions made during the design of a project can help eliminate some construction worker hazards
- C3f: Decisions made during the construction of a project can help eliminate some construction worker hazards.

The level of agreement to statements C3a, C3b and C3c is shown in Table 1-17. From the observed results, it is clear that the majority of professionals understand that the construction industry is a hazardous industry (C3a) since 75.8% of engineers, 81% of architects, 76.9% of owners, and 87.8% of contractors agreed with the statement.

Regarding the statement that only contractors are currently involved in reducing hazards to construction workers (C3b), the results did not show that any of the groups had a majority agreement. The highest agreement with the statement was shown from the architects with 47.6%.With statement C3c, there was again no clear majority, but the contractors had the highest agreement with 47.5% followed by the architects with 46.7%

Table 1-17: Level of agreement in statements C3a, C3b and C3c

	Engineers	Architects	Owners	Contractors
C3a-Construction is hazardous	75.8%	81%	76.9%	87.8%
C3b-Only contractors are involved in Safety	31.9%	47.6%	15.7%	34.6%
C3c-All hazards are tackled by contractors	28.3%	46.7%	30.6%	47.5%

A notable observation from the survey responses is that all of the industry participants recognize that decisions made in the project stages prior to the beginning of construction can affect the safety of workers during construction. This is supported by the following survey results:

Regarding their level of agreement with C3d regarding decisions made prior to design, 68.4% of the engineers, 47.5% of the architects, 59.5% of the owners, and 81.0% of the contractors stated that they agree with the statement.

In response to C3e regarding decisions made during design, 77.9% of the engineers, 52.5% of the architects, 66.2% of the owners, and 86.6% of the contractors stated that they agree with the statement.

Similarly in response to C3f regarding decisions made during construction, 86.5% of the engineers, 84.2% of the architects, 80.2% of the owners, and 92.2% of the contractors stated that they agree with the statement. A summary of the above results related to their opinion about construction worker safety is shown in Table 1-18.

Table 1-18: Opinions on whether decisions made during the various project phases affect construction worker safety

	Engineers	Architects	Owners	Contractors
C3d-Decisions made before design	68.4%	47.5%	59.5%	81.0%
C3e-Decisions made during design	77.9%	52.5%	66.2%	86.6%
C3f-Decisions made during construction	86.5%	84.2%	80.2%	92.2%

Even though the majority of industry professionals recognize that their design decisions influence construction site safety, willingness to support legislation similar to the CDM Regulations in the UK was not expressed in the survey. Specifically they were asked to state their agreement with the following statement:

- C4a: My firm/organization would be supportive of proposed legislation for designers to start practicing DCWS

Only 15.6% of engineers, 10.4% of architects, 11.6% of owners, and 38.0% of contractors responded that their firm/organization would be supportive.

It was hypothesized that a major obstacle for designers to practice DCWS is the fear of litigation. For that reason, the participants were asked to state their agreement with the following statement:

- C4b: My firm would be supportive of the DCWS concept if designers were legally protected from liability in practicing DCWS

The response for support of the DCWS concept was higher this time, with engineers agreeing with the statement with 53.3%, architects with 42.5% and owners with 21.5%. The level of agreement with the statement from contractors was lower by contrast with 31.8%.

1.6.6.3 Obstacles and Enablers

As mentioned previously the survey responders were asked to state their agreement with the existence of obstacles and enablers for DCWS implementation by designers in six different areas, Regulatory, Economic, Contractual, Legal, Ethical and Cultural.

The level of agreement for the existence of obstacles varied according to the group that the participants belonged to. A summary of the agreement about the existence of obstacles in these six areas is shown in Table 1-19. As observed the majority of engineers and architects agreed that there are Economic, Contractual and Legal obstacles. The owner responses did not show a majority for the agreement of the existence of any obstacles for designers to practice DCWS. The contractor responses showed with a majority that there are economic obstacles for designers to practice DCWS.

Table 1-19: Responses to agreement for the existence of obstacles for DCWS implantation by designers

	Engineers	Architects	Owners	Contractors
Regulatory	32.0%	46.6%	30.6%	19.6%
Economic	61.5%	61.5%	43.0%	50.3%
Contractual	62.7%	67.0%	45.5%	40.8%
Legal	55.3%	62.0%	37.2%	38.5%
Ethical	9.8%	22.6%	7.4%	9.5%
Cultural	36.5%	38.9%	27.3%	30.2%

The level of agreement for the existence of enablers did not show any clear majority among any of the groups surveyed. As observed in Table 1-20, none of the groups showed agreement greater than 50%.

Table 1-20: Responses to agreement for the existence of enablers for DCWS implantation by designers

	Engineers	Architects	Owners	Contractors
Regulatory	11.5%	9.5%	10.7%	10.6%
Economic	17.6%	13.6%	10.7%	20.7%
Contractual	18.0%	13.1%	11.6%	24.0%
Legal	16.8%	15.4%	11.6%	20.7%
Ethical	28.7%	27.6%	25.6%	36.9%
Cultural	13.9%	14.9%	10.7%	20.1%

1.6.6.4 Additional comments

The survey participants were also asked to add any comments and input to guide future implementation of the DCWS concept by the US construction industry. Several respondents commented on the need for more education on the DCWS concept, especially in the university environment. Some of the participants also stated that there is an increasing need for collaboration between designers, contractors, and owners, and once that is achieved then DCWS will be more easily accepted by designers. Alternative delivery methods such as design-build and CM/GC allow this increased collaboration between construction groups, and the practice of DCWS could be more easily implemented under such contracting arrangements.

The study participants also commented that increased government regulation and legislation would not be beneficial for the industry and that legislative efforts for DCWS will not get support from the industry. Designers in particular stated that an additional review of designs for safety will increase their costs and commented that owners would not be willing to pay for that increase. Some participants also stated that the highly litigious nature of the US construction industry does not encourage designers to participate in construction safety.

Lastly, several designers and owners indicated concern that design costs might increase if an additional review was added to the design process to account for construction worker safety. This concern is valid since that additional review is presently not covered in designer fees. They also feel that owners may not be willing to compensate them for that additional work.

1.7 Analysis

Since the majority of the questions on the survey were Likert-type questions, appropriate tests needed to be used to analyze the data.

1.7.1 Statistical tests

Through literature research, the following tests were chosen to analyze the results of the survey:

- Chi-squared tests for equality of odds
- Chi-squared test for the 95% confidence interval of the odds ratio
- Ordered 2 x k contingency tables

Descriptions of the tests as well as examples of calculations are included in this section.

1.7.1.1 Chi-squared Test for equality of odds

The Likert responses were simplified in 2X2 tables as shown in Figure 1-9. This simplification of the responses allows the comparison of two groups in relation to a response of interest, thus allowing the use of odds ratios to determine if the responses of two populations differ. This simplification is suggested in literature by Siegel et al. (1988).

	Response 1	Response 2
Group A	X_{A1}	X_{A2}
Group B	X_{B1}	X_{B2}

Figure 1-9: Simplified 2X2 table for Likert responses

The group comparisons that were considered during this analysis included the following:

- Architect Group vs. All Other Groups together
- Engineer Group vs. All Other Groups together
- Owner Group vs. All Other Groups together
- Contractor Groups vs. All Other Groups together
- Architect Group vs. Engineer Group
- Architect Group vs. Owner Group
- Architect Group vs. Contractor Group
- Engineer Group vs. Owner Group
- Engineer Group vs. Contractor Group
- Owner Group vs. Contractor Group

The responses of interest that were considered were:

- Affirmative/Negative responses to questions that required a Yes/No answer
- Strongly Agree & Agree vs. all other responses
- Strongly Disagree & Disagree vs. all other responses

The Likert responses were grouped in such a way to allow the comparison of agreement or disagreement among the various groups. If agreement was to be investigated, then the “strongly agree” and “agree” responses were grouped and compared to the “neutral”, “disagree” and “strongly disagree” responses. The “neutral” responses were always considered to belong to the “other” group in the analysis. For example, if agreement is investigated, the “other” responses would be the disagreement since neutral does not represent agreement.

Attempts to find differences in the responses were also conducted after accounting for the following variables:

- The size of the universities (owners) according to the classification of Small, Medium and Large discussed in 0,
- The ownership of the universities (owners); Public or Private,
- Difference in responses between professionals with experience with Design Build Operate Transfer (DBOT) and Design Build Operate Maintain (DBOM) vs. professionals who did not have experience in DBOT and DBOM,
- Difference in responses between professionals with experience in Construction Management General Contractor (CMGC) vs. professionals who did not have experience in CMGC, and
- Difference in responses between professionals with experience in Design Build (DB) vs. professionals who did not have experience in DB, and
- Differences in responses between professionals who had prior knowledge of DCWS

(Questions B1 to B5).

The method of calculating the Chi-squared test for the equality of odds was obtained from the statistics textbook by Ramsey & Schafer (2002) "The Statistical Sleuth".

- Example of calculations: Question B1 comparison between architect and engineer responses

Question B1 asked survey participants to respond if they were previously aware of the DCWS concept, and they have to answer with a Yes or a No. The results are summarized in the following table:

Table 1-21: Example Question B1 comparison between architects and engineers (Data)

Group	*No*	*Yes*	*Total*
Architect:	191	12	203
Engineer:	179	50	229
Total:	370	62	432

Step 1: Calculate the odds ($\hat{\omega}$) for each group:

$$\hat{\omega}_{Architect} = \frac{12}{191} = 0.0628, \qquad \hat{\omega}_{Engineer} = \frac{50}{179} = 0.2148$$

Step 2: Calculate the odds ratio ($\hat{\varphi}$) and its log:

$$\hat{\varphi} = \frac{\hat{\omega}_{Engineer}}{\hat{\omega}_{Architect}} = \frac{0.2148}{0.0628} = 4.446 \ , \qquad \log(\hat{\varphi}) = 1.492$$

Step 3: Calculate the proportion $\hat{\pi}_c$ from the combined sample:

$$\hat{\pi}_c = \frac{12 + 50}{191 + 179} = 0.1435$$

Step 4: Calculate the Standard Error (SE) for the log odds ratio estimate:

$$SE = \sqrt{\frac{1}{(203)(0.1435)(1 - 0.1435)} + \frac{1}{(229)(0.1435)(1 - 0.1435)}} = 0.275$$

Step 5: Calculate the z-statistic:

$$z = \frac{1.492}{0.275} = 5.4263$$

Step 6: Calculate the one sided p-value

$$\Pr(Z > 5.4263) = \sim 0$$

The above calculation suggests that there is enough evidence that the odds ratio ($\hat{\varphi}$) is different than 1, and that engineers are more likely to be aware of the DCWS concept.

1.7.1.2 Chi-squared test for the 95% confidence interval of the odds ratio

To calculate the 95% confidence interval for the odds, a Chi-squared test was used as described again in "The Statistical Sleuth" (Ramsey et al. 2002).

- Example of calculations (continued): Question B1 comparison between architect and engineer responses

In continuation of the example described in previously, the 95% Confidence Interval (C.I) for the difference between the two odds is calculated as follows:

Step 1: Use the odds ratio ($\hat{\varphi}$) and its log:

$$\hat{\varphi} = \frac{\widehat{\omega}_{Engineer}}{\widehat{\omega}_{Architect}} = \frac{0.2148}{0.0628} = 4.446 \ , \qquad \log(\hat{\varphi}) = 1.492$$

Step 2: Use the shortcut method for the calculation of the Standard Error of the log odds ratio

$$SE = \sqrt{\frac{1}{191} + \frac{1}{12} + \frac{1}{179} + \frac{1}{50}} = 0.337$$

Step 3: Find the 95% interval for the log odds ratio

$$\log(\hat{\varphi}) \pm (1.96)(SE) = 1.492 \pm (1.96)(0.337) = 0.8298 \text{ to } 2.1542$$

Step 4: Calculate the CI values by taking the exponent of the values calculated in step 4:

$$\exp(0.8298) \ \ to \ \ \exp(2.1542) \rightarrow \ 2.2928 \ to \ 8.6212$$

The tests summarized in 1.7.1.1 and 1.7.1.2 conclude the following about the comparison between the answers supplied by engineers and architects concerning question B1.

"Engineers are 4.446 times more likely to be aware of the DCWS concept, with a p-value ~0, and a 95% CI that the odds ratio is between 2.2928 and 8.6212"

1.7.1.3 Ordered 2 x k contingency tables

One additional test that was used to investigate the difference in answers among responders by taking into account the variables with an increasing magnitude, such as experience and size of firm, is the ordered 2xk contingency table, as it is described in the text by Le (1998). An example of a similar treatment of safety data was performed by López Arquillos et al. (2012) and by Camino López et al. (2008), where they used independent variables of increasing magnitude, such as the severity of an accident, to describe its influence on dependent variables. This test was used for the analysis of the following:

- The effect of years of experience in design and construction on the responses.
- The size of the engineering firms according to the classification small firms, medium firms, medium-large firms, large firms, extra-large firms, and extremely large firms as described in 1.5.5.4,

The data for such an analysis are organized as follows:

	Option A	*Option B*	*Total*
Level 1	a_1	b_1	n_1
Level 2	a_2	b_2	n_2
…	…	…	…
Level k	a_k	b_k	n_k
Totals	*A*	*B*	*N*

An example of the calculations is described below, for the data shown in Table 1-22.

Table 1-22: Example Question B1 comparison between engineers from various firm sizes (Data)

	Yes	*No*	*Total*
Size 1, *Small*:	17	75	92
Size 2, *Medium Firms*:	3	23	26
Size 3, *Medium Large Firms*:	3	15	18
Size 4, *Large Firms*:	6	24	30
Size 5, *Extralarge Firms*:	5	12	17
Size 6, *Extremely Large Firms*:	16	30	46
Totals:	50	179	229

Step 1: Calculate value C, "Concordances"

$$C = b_1(a_2 + \cdots + a_k) + b_2(a_3 + \cdots + a_k) + \cdots + b_{k-1}a_k$$
$$= 75(3 + 3 + 6 + 5 + 16) + 23(3 + 6 + 5 + 16) + \cdots + 12(16) = 4266$$

Step 2: Calculate value D, "Discordances"

$$D = a_1(b_2 + \cdots + b_k) + a_2(b_3 + \cdots + b_k) + \cdots + a_{k-1}b_k$$
$$= 17(23 + 15 + 24 + 12 + 30) + 3(15 + 24 + 12 + 30) + \cdots + 5(30)$$
$$= 2611$$

Step 3: Calculate the Statistic:

$$S = C - D = 4266 - 2611 = 1655$$

Step 4: Calculate the z statistic:

$$z = \frac{S - \mu_S}{\sigma_S}, where$$

$$\mu_S = 0\ , and$$

$$\sigma_S = \left\{\frac{AB}{3N(N-1)}\left[N^3 - n_1^3 - n_2^3 - \cdots - n_k^3\right]\right\}^{\frac{1}{2}}$$

$$= \left\{\frac{(50)(175)}{3(229)(229-1)}\left[229^3 - 92^3 - 26^3 - \cdots - 46^3\right]\right\}^{\frac{1}{2}} = 795.59$$

$$z = \frac{1655}{795.59} = 2.0802$$

Step 5: Calculate the one tailed p-value

$$\Pr(Z > 2.0802) = 0.0188$$

The above calculation suggests that there is enough evidence that engineers employed in larger firms were more likely to be aware of the DCWS concept with a p-value of 0.0188.

1.7.2 Results Concerning Previous Knowledge & Participation (B1 – B5)

1.7.2.1 Question B1

The first question of the survey asked participants about their previous knowledge of DCWS by asking if they were aware of DCWS. After performing the various tests that were describe previously, the following results were found to be significant:

- Architects were 4.18 times less likely to be aware of DCWS than all the other industry groups combined (p-value ~0, 95% CI 2.24 to 7.79).
- Engineers were 1.71 times more likely to be aware of the DCWS concept than all other industry participants combined (p-value 0.0064, 95% CI 1.14 to 2.57).
- Owners were 1.69 times more likely to be aware of the DCWS concept than all other industry participants combined (p-value 0.0286, 95% CI 1.0371 to 2.77).
- Engineers were 4.46 times more likely to be aware of the DCWS concept than architects (p-value ~0, 95% CI 2.29 to 8.62).
- Engineers employed in larger firms were more likely to be aware of the DCWS concept with a p value 0.0188.
- Engineers who were aware of DCWS were 2.04 times more likely to agree with statement C1c **"**Designers have adequate capacity and opportunities to be educated in construction worker safety" than engineers who did not have prior knowledge of DCWS" (p-value 0.0172, 95% CI 1.28 to 5.17).
- Owners who had prior knowledge of the DCWS concept were 2.14 times more likely to disagree with statement C3c **"**All construction site hazards to construction workers are taken care of by construction contractors" (p-value 0.0408, 95% CI 1.02 to 4.50).

1.7.2.2 Question B2

Question B2 of the survey asked participants to state if their firm is actively participating in some form of DCWS. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 16.11 times more likely to state that their firm is not actively participating in some form of DCWS. (p-value ~0, 95% CI 8.17 to 33.78)
- Engineers were 4.13 times more likely than architects to state that their firm is actively participating in some form of DCWS. (p-value ~0, 95% CI 3.11 to 13.92)
- Owners who participated in the DB contracting method were 2.98 times more likely to state that they are not practicing some form of DCWS compared to owners that do not participate in the DB contracting method. (p-value 0.0107, 95% CI 1.11 to 8.03)
- Engineers who work at a firm that actively practices DCWS were 4.66 times more likely to agree with statement C1c "Designers have adequate capacity and opportunities to be educated in construction worker safety" than engineers who did not have prior knowledge of DCWS". (p-value 0.0006, 95% CI 2.18 to 9.98)
- Engineers who work at a firm that actively practices DCWS were 2.66 times more likely

to agree with statement C1d “Designers should be involved and participate in construction worker safety through design decisions”. (p-value 0.0131, 95% CI 1.25 to 5.64)

- Engineers who work at a firm that actively practices DCWS were 2.92 times more likely to disagree with statement C1e “The nature of construction contracting does not allow designers to participate in construction worker safety”.(p-value 0.0461, 95% CI 1.41 to 6.04)
- Owners who work at an organization that actively practice DCWS were 4.25 times more likely to agree with statement C2b “Members in my organization have adequate capacity and opportunities to be educated in construction worker safety”. (p-value 0.0415, 95% CI 1.35 to 13.35)
- Owners who work at an organization that actively practices DCWS were 6.39 times more likely to agree with statement C2d “My organization should be involved and participate in construction worker safety”. (p-value 0.0204, 95% CI 2.15 to 18.96)
- Engineers who work at a firm that actively practices DCWS were 3.50 times more likely to disagree with statement C3b “Only construction contractors are currently involved in reducing hazards to construction workers”. (p-value 0.00035, 95% CI 1.63 to 7.51)
- Engineers who work at a firm that actively practices DCWS were 3.67 times more likely to disagree with statement C3c “All construction site hazards to construction workers are taken care of by construction contractors”. (p-value 0.0003, 95% CI 2.05 to 10.613)
- Engineers employed in larger firms were more likely to be working in a firm that participates in some form of DCWS with a p-value equal to 0.0003.

1.7.2.3 Question B3

Question B3 of the survey asked participants to state if their firm had guidelines for reviewing design for construction worker safety. After performing the various tests that were described previously, the following results were found to be significant:

- Engineers were 3.56 times more likely to state that their firm has guidelines for reviewing for construction worker safety than architects. (p-value 0.0003, 95% CI 1.49 to 8.47)
- Owners were 6.12 times more likely to state that their organization has guidelines for reviewing for construction worker safety than architects. (p-value ~0, 95% CI 2.47 to 15.134)
- Engineers who work at a firm that participates in DBOT and DBOM contracts were 3.62 times more likely to state that their firm has guidelines for reviewing for construction worker safety. (p-value 0.0354, 95% CI 1.24 to 10.50)
- Architects who work in a firm that has guidelines for reviewing designs for construction worker safety were 6.58 times more likely to agree with the statement “Owners should be involved and participate in construction worker safety”. (p-value 0.034, 95% CI 1.23 to 35.05)
- Engineers who work in a firm that has guidelines for reviewing designs for construction worker safety were 5.61 times more likely to agree with the statement “Owners should be involved and participate in construction worker safety”. (p-value 0.0002, 95% CI 1.61

to 19.56)

- Owners who work in an organization that has guidelines for reviewing designs for construction worker safety were 5.61 times more likely to agree with the statement "My organization should be involved and participate in construction worker safety". (p-value 0.0021, 95% CI 1.22 to 26.49)
- Architects who work in a firm that has guidelines for reviewing designs for construction worker safety were 14.13 times more likely to disagree with the statement "The nature of construction contracting does not allow owners to participate in construction worker safety". (p-value 0.0203, 95% CI 2.60 to 76.75)
- Engineers who work in a firm that has guidelines for reviewing designs for construction worker safety were 4.06 times more likely to disagree with the statement "The nature of construction contracting does not allow owners to participate in construction worker safety". (p-value 0.0064, 95% CI 1.5106 to 10.92)
- Owners who work in an organization that has guidelines for reviewing designs for construction worker safety were 5.27 times more likely to agree with the statement "The nature of construction contracting does not allow my organization to participate in construction worker safety". (p-value 0.0035, 95% CI 1.40 to 19.70)
- Engineers who work in a firm that has guidelines for reviewing designs for construction worker safety were 13.64 times more likely to disagree with the statement "Only construction contractors are currently involved in reducing hazards to construction workers". (p-value ~0, 95% CI 3.10 to 60.157)
- Owners who work in an organization that has guidelines for reviewing designs for construction worker safety were 4.94 times more likely to agree with the statement "Only construction contractors are currently involved in reducing hazards to construction workers". (p-value 0.0051, 95% CI 1.05 to 23.15)
- Engineers who work in a firm that has guidelines for reviewing designs for construction worker safety were 4.92 times more likely to disagree with the statement "All construction site hazards to construction workers are taken care of by construction contractors". (p-value 0.0009, 95% CI 1.60 to 15.09)
- Architects who work in a firm that has guidelines for reviewing designs for construction worker safety were 12.85 times more likely to disagree with the statement "All construction site hazards to construction workers are taken care of by construction contractors". (p-value 0.0024, 95% CI 1.51 to 109.35)
- Engineers who work in a firm that has guidelines for reviewing designs for construction worker safety were 5.35 times more likely to agree with the statement "There are ECONOMIC incentives that may enable designers to practice DCWS". (p-value 0.0278, 95% CI 1.93 to 14.80)
- Engineers employed in larger firms were more likely to be working in a firm that has guidelines for reviewing designs for construction worker safety (p-value ~0).

1.7.2.4 Question B4

Question B4 of the survey asked designer participants to state if their firm was asked to address issues relating to construction worker safety. After performing the various tests that were describe previously, the following results were found to be significant:

- Engineers were 4.43 times more likely to state that their firm was asked to address issues relating to construction worker safety than architects. (p-value ~0, 95% CI 2.63 to 7.43)
- Engineers who stated that their firm participates in DBOT and DCOM contracts were 5.6 times more likely to state that their firm was asked to address issues relating to construction worker safety than engineers who stated that their firm does not participate. (p-value 0.0001, 95% CI 2.08 to 15.03)
- Architects who stated that their firm was asked to address issues relating to construction worker safety were 9.15 times more likely to agree with the statement "Designers in my firm know how construction site operations and procedures take place" than architects whose firm does not address issues on construction worker safety. (p-value ~0, 95% CI 1.1987 to 69.90)
- Architects who stated that their firm was asked to address issues relating to construction worker safety were 3.65 times more likely to agree with the statement "Designers in my firm have a clear understanding of what constitutes a hazard to construction workers" than architects whose firm does not address issues on construction worker safety. (p-value 0.0099, 95% CI 1.29 to 9.82)
- Engineers who stated that their firm was asked to address issues relating to construction worker safety were 3.88 times more likely to agree with the statement "Designers in my firm have a clear understanding of what constitutes a hazard to construction workers" than engineers whose firm does not address issues on construction worker safety. (p-value 0.0002, 95% CI 2.06 to 7.33)
- Engineers who stated that their firm was asked to address issues relating to construction worker safety were 2.52 times more likely to agree with the statement "Owners should be involved and participate in construction worker safety**"** than engineers whose firm does not address issues on construction worker safety. (p-value 0.0076, 95% CI 1.34 to 4.71)
- Engineers who stated that their firm was asked to address issues relating to construction worker safety were 3.26 times more likely to disagree with the statement "Only construction contractors are currently involved in reducing hazards to construction workers" than engineers whose firm does not address issues on construction worker safety. (p-value 0.0019, 95% CI 1.78 to 5.96)
- Architects who stated that their firm was asked to address issues relating to construction worker safety were 3.95 times more likely to disagree with the statement "Only construction contractors are currently involved in reducing hazards to construction workers" than architects whose firm does not address issues on construction worker safety. (p-value 0.0176, 95% CI 1.60 to 9.77)
- Engineers who stated that their firm was asked to address issues relating to construction worker safety were 3.16 times more likely to disagree with the statement "All construction site hazards to construction workers are taken care of by construction contractors" than engineers whose firm does not address issues on construction worker safety. (p-value 0.0018, 95% CI 1.71 to 5.82)
- Engineers who stated that their firm was asked to address issues relating to construction worker safety were 3.34 times more likely to agree with the statement "Decisions made before the design of a project begins can help eliminate some construction worker hazards" than engineers whose firm does not address issues on

construction worker safety. (p-value 0.0009, 95% CI 1.50 to 7.39)

- Engineers from larger firms were more likely to state that their firm was asked to address issues relating to construction worker safety than engineers from smaller firms. (p-value 0.001)

1.7.2.5 Question B5

Question B5 of the survey asked contractor participants to state if their firm participates in constructability meetings with designers, where construction worker safety issues are discussed. After performing the various tests that were described previously, the following results were found to be significant:

- Contractors with more experience were more likely to be state that their firm has participated in constructability meetings with designers where construction worker safety issues are discussed. (p-value ~0.035)
- Contractors who stated that their firm has participated in constructability meetings with designers, where construction worker safety issues were discussed were 2.68 times more likely to agree with the statement "Designers should be involved and participate in construction worker safety through design decisions" than contractors whose firm does not participate. (p-value 0.0196, 95% CI 1.048 to 6.88)
- Contractors who stated that their firm has participated in constructability meetings with designers, where construction worker safety issues were discussed were 3.01 times more likely to agree with the statement "All construction site hazards to construction workers are taken care of by construction contractors" than contractors whose firm does not participate. (p-value 0.007, 95% CI 1.59 to 5.70)

1.7.3 Designer Group Industry Knowledge and Safety Participation (C1a-C1e)

1.7.3.1 Question C1a

Question C1a was stated as follows in the various surveys:

- *Contractor/Owner Survey: Designers know how construction site operations and procedures take place*
- *Designer Survey: Designers in my firm know how construction site operations and procedures take place*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were describe previously, the following results were found to be significant:

- Architects were 2.59 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.82 to 3.69)
- Engineers were 3.40 times more likely to agree with the statement than all the other

groups combined. (p-value ~0, 95% CI 2.39 to 4.85)

- Contractors were 6.84 times more likely to disagree with the statement than all the other groups combined. (p-value ~0, 95% CI 4.62 to 10.142)
- Architects were 10.491 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 6.48 to 16.98)
- Engineers were 12.48 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 7.71 to 20.195)
- Owners were 3.41 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 2.02 to 5.77)
- Contractors were 11.10 times more likely to disagree with the statement than engineers. (p-value ~0, 95% CI 6.03 to 19.57)
- Owners were 3.13 times more likely to disagree with the statement than engineers. (p-value 0.0005, 95% CI 1.62 to 6.06)
- Contractors were 6.95 times more likely to disagree with the statement than architects. (p-value ~0, 95% CI 4.19 to 11.62)
- Owners were 1.96 times more likely to disagree with the statement than architects. (p-value 0.0189, 95% CI 1.06 to 3.63)
- There is significant association between the experience of a contractor and a disagreement to the statement (p=0.0002); the more experienced the contractor, the more likely they would disagree.

1.7.3.2 Question C1b

Question C1b was stated as follows in the various surveys:

- *Contractor/Owner Survey: Designers have a clear understanding of what constitutes a hazard to construction workers*
- *Designer Survey: Designers in my firm have a clear understanding of what constitutes a hazard to construction workers*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 1.64 times more likely to agree with the statement than all the other groups combined. (p-value 0.0019, 95% CI 1.17 to 2.28)
- Engineers were 2.24 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.62 to 3.09)
- Contractors were 5.96 times more likely to disagree with the statement than all the other groups combined. (p-value ~0, 95% CI 4.12 to 8.62)
- Architects were 6.36 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 3.73 to 10.58)
- Engineers were 7.70 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 4.55 to 13.03)
- Owners were 4.17 times more likely to agree with the statement than contractors. (p-

value ~0, 95% CI 2.30 to 7.59)

- Contractors were 7.00 times more likely to disagree with the statement than engineers. (p-value ~0, 95% CI 4.46 to 11.00)
- Contractors were 6.15 times more likely to disagree with the statement than architects. (p-value ~0, 95% CI 3.90 to 9.69)
- There is significant association between the experience of a contractor and disagreement with the statement (p=0.0035); the more experienced the contractor, the more likely they disagree.

1.7.3.3 Question C1c

Question C1c was stated as follows in the various surveys:

- *Contractor/Owner Survey: Designers have adequate capacity and opportunities to be educated in construction worker safety*
- *Designer Survey: Designers in my firm have adequate capacity and opportunities to be educated in construction worker safety*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 1.58 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0056, 95% CI 1.12 to 2.25)
- Architects were 1.63 times more likely to disagree with the statement than engineers. (p-value 0.0098, 95% CI 1.07 to 2.46)
- Contractors were 2.11 times more likely to agree with the statement than architects. (p-value 0.0003, 95% CI 1.37 to 3.25)
- Engineers were 2.12 times more likely to agree with the statement than architects. (p-value ~0, 95% CI 1.42 to 3.18)
- Owners were 2.12 times more likely to agree with the statement than architects. (p-value ~0, 95% CI 1.31 to 3.44)
- There is moderate association between the size of the firm an engineer works for and agreement with the statement (p=0.0243); the larger the firm, the more likely they would agree.

1.7.3.4 Question C1d

Question C1d was stated as follows in the various surveys:

- *Designers should be involved and participate in construction worker safety through design decisions*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were

found to be significant:

- Architects were 3.71 times more likely to disagree with the statement than all the other groups combined. (p-value ~0, 95% CI 2.54 to 5.41)
- Contractors were 6.17 times more likely to agree with the statement than all other groups. (p-value ~0, 95% CI 3.98 to 9.58)
- Contractors were 3.58 times more likely to agree with the statement than engineers. (p-value ~0, 95% CI 2.20 to 5.82)
- Architects were 2.59 times more likely to disagree with the statement than engineers. (p-value ~0, 95% CI 1.67 to 4.00)
- Contractors were 13.17 times more likely to agree with the statement than architects. (p-value ~0, 95% CI 7.92 to 21.88)
- Engineers were 3.67 times more likely to agree with the statement than architects. (p-value ~0, 95% CI 2.44 to 5.50)
- Owners were 2.57 times more likely to agree with the statement than architects. (p-value ~0, 95% CI 1.59 to 4.18)
- Architects who participated in CMGC contracts were 2.00 times more likely to disagree with the statement than architects who do not participate in CMGC contracts. (p-value 0.03, 95% CI 1.12 to 3.55)
- There is significant association between the size of the firm an engineer works for and agreement with the statement (p=0.0001); the larger the firm, the more likely they agree.

1.7.3.5 Question C1e

Question C1e was stated as follows in the various surveys:

- *The nature of construction contracting does not allow designers to participate in construction worker safety*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 2.95 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 2.10 to 4.15)
- Contractors were 3.22 times more likely to disagree with the statement than all the other groups combined. (p-value ~0, 95% CI 2.26 to 4.61)
- Architects were 3.87 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 2.51 to 5.96)
- Engineers were 1.68 times more likely to agree with the statement than contractors. (p-value 0.0058, 95% CI 1.11 to 2.55)
- Architects were 2.29 times more likely to agree with the statement than engineers. (p-value ~0, 95% CI 1.55 to 3.29)

- Contractors were 2.44 times more likely to disagree with the statement than engineers. (p-value ~0, 95% CI 1.62 to 3.68)
- There is significant association between the size of the firm an engineer works for and disagreement with the statement (p=0.0005); the larger the firm, the more likely they would disagree.

1.7.4 Owner Group Industry Knowledge and Safety Participation (C2a – C2e)

1.7.4.1 Question C2a

Question C2a was stated as follows in the various surveys:

- Contractor/Designer Survey: Owners know how construction site operations and procedures take place
- Owner Survey: *My organization knows how construction site operations and procedures take place*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Owners were 42.7 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 22.95 to 79.56)
- Owners were 43.8 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 21.08 to 89.91)
- Owners were 30.19 times more likely to agree with the statement than engineers. (p-value ~0, 95% CI 15.47 to 58.9)
- Owners were 68.27 times more likely to agree with the statement than architects. (p-value ~0, 95% CI 32.56 to 143.15)
- There is significant association between the experience of an engineer and disagreement with the statement (p=0.0142); the more experienced the engineer, the more likely they disagree.

1.7.4.2 Question C2b

Question C2b was stated as follows in the various surveys:

- Contractor/Designer Survey: *Owners have adequate capacity and opportunities to be educated in construction worker safety*
- Owner Survey: *Members in my organization have adequate capacity and opportunities to be educated in construction worker safety*

The survey participants were asked to state their agreement or disagreement with the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Owners were 10.85 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 6.41 to 18.37)
- Contractors were 1.54 times more likely to agree with the statement than all the other groups combined. (p-value 0.0088, 95% CI 1.08 to 2.18)
- Architects were 2.82 times more likely to disagree with the statement than all other groups combined. (p-value ~0, 95% CI 2.01 to 3.96)
- Owners were 5.46 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 3.05 to 9.76)
- Architects were 2.29 times more likely to disagree with the statement than contractors. (p-value ~0, 95% CI 1.50 to 3.49)
- Owners were 10.71 times more likely to agree with the statement than engineers. (p-value ~0, 95% CI 6.03 to 19.01)
- Contractors were 1.96 times more likely to agree with the statement than engineers. (p-value 0.0007, 95% CI 1.29 to 2.98)
- Architects were 1.84 times more likely to disagree with the statement than engineers. (p-value 0.001, 95% CI 1.24 to 2.71)
- Owners were 24.29 times more likely to agree with the statement than architects. (p-value ~0, 95% CI 13.02 to 45.32)
- Contractors were 4.44 times more likely to agree with the statement than architects. (p-value ~0, 95% CI 2.73 to 7.21
- Designers were 2.26 times more likely to agree with the statement than architects. (p-value 0.0002, 95% CI 1.40 to 3.65
- There is moderate association between the experience of an architect and agreement with the statement (p=0.0434); the more experienced the architect, the more likely they agree
- There is significant association between the size of the firm an engineer works for and agreement with the statement (p=0.0096); the larger the firm, the more likely they agree

1.7.4.3 Question C2c

Question C2c was stated as follows in the various surveys:

- Contractor/Designer Survey: *Owners have a clear understanding of what constitutes a hazard to construction workers*
- Owner Survey: *Members of my organization have a clear understanding of what constitutes a hazard to construction workers*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Owners were 31.93 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 18.65 to 54.68)

- Architects were 3.37 times more likely to disagree with the statement than all other groups combined. (p-value ~0, 95% CI 2.34 to 4.86)
- Owners were 24.75 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 13.08 to 46.81)
- Architects were 2.09 times more likely to disagree with the statement than contractors. (p-value 0.0005, 95% CI 1.34 to 3.25)
- Owners were 22.81 times more likely to agree with the statement than engineers. (p-value ~0, 95% CI 12.51 to 41.56)
- Architects were 1.84 times more likely to disagree with the statement than engineers. (p-value ~0, 95% CI 1.43 to 3.31)
- Contractors who participated in DB contracts were 2.62 times more likely to disagree with the statement than contractors who did not participated in DB contracts. (p-value 0.032, 95% CI 1.24 to 5.53)
- There is significant association between the experience of an engineer and disagreement with the statement (p=0.0053); the more experienced the engineer, the more likely they disagree.
- There is significant association between the size of the firm an engineer work for and agreement with the statement (p=0.0015); the larger the firm, the more likely they agree.

1.7.4.4 Question C2d

Question C2d was stated as follows in the various surveys:

- Contractor/Designer Survey: *Owners should be involved and participate in construction worker safety*
- Owner Survey: *My organization should be involved and participate in construction worker safety*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Owners were 1.84 times more likely to agree with the statement than all the other groups combined. (p-value 0.0017, 95% CI 1.20 to 2.84)
- Engineers were 1.40 times more likely to agree with the statement than all the other groups combined. (p-value 0.0197, 95% CI 1.01 to 1.94)
- Contractors were 2.19 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.52 to 3.16)
- Architects were 3.98 times more likely to disagree with the statement than all other groups combined. (p-value ~0, 95% CI 2.76 to 5.73)
- Architects were 4.55 times more likely to disagree with the statement than contractors. (p-value ~0, 95% CI 2.74 to 7.56)
- Architects were 3.21 times more likely to disagree with the statement than engineers.

(p-value ~0, 95% CI 2.07 to 4.97)

- Owners were 4.76 times more likely to agree with the statement than architects. (p-value ~0, 95% CI 2.88 to 7.86)
- Architects who participated in DB contracts were 2.35 times more likely to agree with the statement than architects who do not participate in DB contracts. (p-value 0.012, 95% CI 1.14 to 4.82)
- There is significant association between the size of the firm an engineer works for and agreement with the statement (p=0.0008); the larger the firm, the more likely they agree.

1.7.4.5 Question C2e

Question C2e was stated as follows in the various surveys:

- Contractor/Designer Survey: *The nature of construction contracting does not allow designers to participate in construction worker safety*
- Owner Survey: *The nature of construction contracting does not allow my organization to participate in construction worker safety*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 4.19 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 2.95 to 5.94)
- Owners were 2.20 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0001, 95% CI 1.45 to 3.35)
- Contractors were 1.79 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0006, 95% CI 1.26 to 2.54)
- Architects were 4.48 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 2.87 to 6.98)
- Architects were 3.27 times more likely to agree with the statement than engineers. (p-value ~0, 95% CI 2.18 to 4.91)
- Owners were 1.63 times more likely to disagree with the statement than engineers. (p-value 0.0192, 95% CI 1.02 to 2.62)
- There is significant association between the size of the firm an engineer works for and disagreement with the statement (p=0.0044); the larger the firm, the more likely they disagree.

1.7.5 Construction Industry Hazards (C3a – C3f)

1.7.5.1 Question C3a

Question C3a was stated as follows in the various surveys:

- *The construction industry is a hazardous industry*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Contractors were 1.9 times more likely to agree with the statement than engineers. (p-value 0.0155, 95% CI 1.02 to 3.57)

1.7.5.2 Question C3b

Question C3b was stated as follows in the various surveys:

- *Only construction contractors are currently involved in reducing hazards to construction workers*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 2.38 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.70 to 3.33)
- Owners were 2.66 times more likely to disagree with the statement than all other groups combined. (p-value ~0, 95% CI 1.72 to 4.13)
- Architects were 1.99 times more likely to agree with the statement than contractors. (p-value 0.0005, 95% CI 1.31 to 3.05)
- Owners were 2.07 times more likely to disagree with the statement than contractors. (p-value 0.0017, 95% CI 1.25 to 3.43)
- Architects were 2.04 times more likely to agree with the statement than engineers. (p-value 0.0005, 95% CI 1.35 to 2.96)
- Owners were 2.10 times more likely to disagree with the statement than engineers. (p-value 0.0017, 95% CI 1.29 to 3.42)
- There is significant association between the size of the firm an engineer works for and disagreement with the statement (p= ~0); the larger the firm, the more likely they disagree.

1.7.5.3 Question C3c

Question C3c was stated as follows in the various surveys:

- *All construction site hazards to construction workers are taken care of by construction contractors*

The survey participants were asked to state their agreement or disagreement to the statement.

After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 1.68 times more likely to agree with the statement than all the other groups combined. (p-value 0.0011, 95% CI 1.20 to 2.34)
- Contractors were 1.46 times more likely to agree with the statement than all the other groups combined. (p-value 0.0162, 95% CI 1. 30 to 2.06)
- Engineers were 1.94 times more likely to disagree with the statement than all other groups combined. (p-value ~0, 95% CI 1.40 to 2.68)
- Owners were 1.86 times more likely to disagree with the statement than contractors. (p-value 0.006, 95% CI 1.14 to 3.04)
- Engineers were 2.08 times more likely to disagree with the statement than contractors. (p-value 0.0002, 95% CI 1.38 to 3.18)
- Architects were 2.26 times more likely to agree with the statement than engineers. (p-value ~0, 95% CI 1.51 to 3.36)
- Architects were 2.08 times more likely to agree with the statement than engineers. (p-value 0.0002, 95% CI 1.37 to 3.14)
- Owners were 2.23 times more likely to disagree with the statement than architects. (p-value 0.0005, 95% CI 1.38 to 3.62)
- There is moderate association between experience of an engineer and agreement with the statement (p= 0.023); the more experienced the engineer, the more likely they agree.
- There is moderate association between experience of an architects and disagreement with the statement (p= 0.013); the more experienced the architect, the more likely they disagree.
- There is significant association between the size of the firm an engineer works for and disagreement with the statement (p= 0.019); the larger the firm, the more likely they disagree.

1.7.5.4 Question C3d

Question C3d was stated as follows in the various surveys:

- *Decisions made before the design of a project begins can help eliminate some construction worker hazards*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 3.61 times more likely to disagree with the statement than all the other groups combined. (p-value ~0, 95% CI 2.04 to 6.39)
- Contractors were 1.89 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.81 to 4.44)

- Engineers were 1.64 times more likely to agree with the statement than all the other groups combined. (p-value 0.0025, 95% CI 1.14 to 2.38)
- Architects were 3.59 times more likely to disagree with the statement than contractors. (p-value 0.0002, 95% CI 1.60 to 8.07)
- Architects were 3.63 times more likely to disagree with the statement than engineers. (p-value ~0, 95% CI 1.72 to 7.64)
- There is moderate association between the size of the firm an engineer works for and agreement to the statement (p= 0.0365); the more experienced the engineer, the more likely they agree.

1.7.5.5 Question C3e

Question C3e was stated as follows in the various surveys:

- *Decisions made during the design of a project can help eliminate some construction worker hazards*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 5.78 times more likely to disagree with the statement than all the other groups combined. (p-value ~0, 95% CI 2.98 to 11.201)
- Contractors were 3.56 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 2.05 to 6.17)
- Engineers were 2.51 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.61 to 3.92)
- Architects were 6.99 times more likely to disagree with the statement than contractors. (p-value ~0, 95% CI 2.40 to 20.338)
- Architects were 5.05 times more likely to disagree with the statement than engineers. (p-value ~0, 95% CI 2.16 to 11.81)
- Architects were 2.11 times more likely to disagree with the statement than Owners. (p-value 0.0012, 95% CI 1.26 to 3.53)

1.7.5.6 Question C3f

Question C3f was stated as follows in the various surveys:

- *Decisions made during the construction of a project can help eliminate some construction worker hazards*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, it was discovered that there were no significant results.

1.7.6 Participation through Legislation (C4a – C4b)

1.7.6.1 Question C4a

Question C4a was stated as follows in the various surveys:

- *My firm/organization would be supportive of proposed legislation for designers to start practicing DCWS*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 2.46 times more likely to disagree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.75 to 3.46)
- Contractors were 3.91 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 2.64 to 5.81)
- Architects were 4.57 times more likely to disagree with the statement than contractors. (p-value ~0, 95% CI 2.88 to 7.25)
- Engineers were 3.02 times more likely to disagree with the statement than contractors. (p-value ~0, 95% CI 1.91 to 4.78)
- Contractors were 2.94 times more likely to agree with the statement than engineers. (p-value ~0, 95% CI 1.84 to 4.71)
- Contractors were 5.22 times more likely to agree with the statement than architects. (p-value ~0, 95% CI 3.06 to 8.90)
- There is moderate association between experience of an architects and disagreement with the statement (p= 0.0264); the more experienced the architect, the more likely they disagree.
- There is moderate association between experience of an engineers and disagreement with the statement (p= 0.0263); the more experienced the engineer, the more likely they disagree.

1.7.6.2 Question C4b

Question C4b was stated as follows in the various surveys:

- *My firm would be supportive of the DCWS concept if designers were legally protected from liability in practicing DCWS*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were

found to be significant:

- Engineers were 2.87 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 2.03 to 4.05)
- Contractors were 2.02 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0019, 95% CI 1.30 to 3.13)
- Architects were 1.69 times more likely to agree with the statement than contractors. (p-value 0.0068, 95% CI 1.10 to 2.59)
- Engineers were 3.35 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 2.18 to 5.17)
- Architects were 2.51 times more likely to disagree with the statement than engineers. (p-value 0.0011, 95% CI 1.34 to 4.70)
- Contractors were 3.78 times more likely to disagree with the statement than engineers. (p-value ~0, 95% CI 2.02 to 7.04)
- Owners were 2.58 times more likely to disagree with the statement than engineers. (p-value 0.0072, 95% CI 1.25 to 5.31)
- There is moderate association between experience of an architects and agreement with the statement (p= 0.0378); the more experienced the architect, the more likely they agree.

1.7.7 Obstacles (D1a – D1f)

1.7.7.1 Question D1a

Question D1a was stated as follows in the various surveys:

- *There are REGULATORY obstacles that may not allow designers to practice DCWS. (“Regulatory” refers to guidelines enforced by professional and governmental organizations)*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 2.38 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.66 to 3.42)
- Contractors were 2.50 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0004, 95% CI 1.54 to 4.06)
- Architects were 4.04 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 2.48 to 6.56)
- Engineers were 2.20 times more likely to agree with the statement than contractors. (p-value 0.0004, 95% CI 1.36 to 3.57)
- Owners were 2.01 times more likely to agree with the statement than contractors. (p-value 0.007, 95% CI 1.14 to 3.55)

1.7.7.2 Question D1b

Question D1bwas stated as follows in the various surveys:

- *There are ECONOMIC obstacles that may not allow designers to practice DCWS. ("Economic" obstacles refers to costs, direct and/or indirect, and insurance costs)*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Engineers were 1.72 times more likely to agree with the statement than all the other groups combined. (p-value 0.0013, 95% CI 1.18 to 2.50)
- Contractors were 2.85 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0004, 95% CI 1.66 to 4.87)
- Architects were 1.97 times more likely to agree with the statement than contractors. (p-value 0.013, 95% CI 1.26 to 3.09)
- Engineers were 2.22 times more likely to agree with the statement than contractors. (p-value 0.0002, 95% CI 1.42 to 3.47)
- There is moderate association between experience of an architects and agreement with the statement (p= 0.0291); the more experienced the architect, the more likely they agree.

1.7.7.3 Question D1c

Question D1c was stated as follows in the various surveys:

- *There are CONTRACTUAL obstacles that may not allow designers to practice DCWS. ("Contractual" refers to standard language used in contracts)*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 2.24 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.50 to 3.34)
- Engineers were 1.86 times more likely to agree with the statement than all the other groups combined. (p-value 0.0003, 95% CI 1.27 to 2.72)
- Contractors were 4.16 times more likely to disagree with the statement than all the other groups combined. (p-value ~0, 95% CI 2.47 to 7.00)
- Architects were 4.15 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 2.58 to 6.68)
- Engineers were 3.56 times more likely to agree with the statement than contractors. (p-

value ~0, 95% CI 2.26 to 5.62)

1.7.7.4 Question D1d

Question D1d was stated as follows in the various surveys:

- *There are LEGAL obstacles that may not allow designers to practice DCWS. ("Legal" refers to federal, state, and local statutes)*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 2.22 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.51 to 3.26)
- Engineers were 1.57 times more likely to agree with the statement than all the other groups combined. (p-value 0.0055, 95% CI 1.09 to 2.26)
- Contractors were 2.86 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0004, 95% CI 1.66 to 4.92)
- Architects were 3.40 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 2.14 to 5.42)
- Engineers were 2.61 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 1.67 to 4.08)

1.7.7.5 Question D1e

Question D1e was stated as follows in the various surveys:

- *There are ETHICAL obstacles that may not allow designers to practice DCWS. ("Ethical" refers to principles of conduct that are considered correct)*

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 3.01 times more likely to agree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.94 to 4.67)
- Contractors were 2.61 times more likely to disagree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.78 to 3.82)
- Architects were 3.03 times more likely to agree with the statement than contractors. (p-value ~0, 95% CI 1.66 to 5.52)
- Architects were 3.03 times more likely to agree with the statement than engineers. (p-value ~0, 95% CI 1.61 to 4.73)

- Contractors were 3.03 times more likely to disagree with the statement than engineers. (p-value 0.0007, 95% CI 1.29 to 3.09)
- There is significant association between experience of a contractors and disagreement with the statement (p= 0.0038); the more experienced the contractor, the more likely they disagree.
- Architects who participate in CMGC contracts were 2.51 times more likely to agree with the statement than architects who do not participate in CMGC contracts. (p-value 0.0094, 95% CI 1.26 to 4.99)
- Contractors who participate in DB contracts were 4.28 times more likely to disagree with the statement than contractors who do not participate in DB contracts. (p-value 0.009, 95% CI 1.83 to 9.99)

1.7.7.6 Question D1f

Question D1f was stated as follows in the various surveys:

- There are CULTURAL obstacles that may not allow designers to practice DCWS.

  ("Cultural" refers to standards of construction industry practice)

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 1.441 times more likely to agree with the statement than all the other groups combined. (p-value 0.0195, 95% CI 1.021 to 2.05)
- Contractors were 2.91 times more likely to disagree with the statement than all the other groups combined. (p-value ~0, 95% CI 1.97 to 4.30)
- Architects were 1.73 times more likely to agree with the statement than contractors. (p-value 0.0069, 95% CI 1.11 to 2.70)
- Contractors were 2.76 times more likely to disagree with the statement than engineers. (p-value ~0, 95% CI 1.73 to 4.38)

1.7.8 Enablers (D3a – D3f)

1.7.8.1 Question D3a

Question D3a was stated as follows in the various surveys:

- *There are REGULATORY incentives that may enable designers to practice DCWS.*

  ("Regulatory" refers to guidelines enforced by professional and governmental organizations)

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were

found to be significant:

- Architects were 1.76 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0015, 95% CI 1.21 to 2.55)
- Architects were 2.20 times more likely to disagree with the statement than contractors. (p-value 0.0005, 95% CI 1.35 to 3.60)
- Engineers were 1.74 times more likely to disagree with the statement than contractors. (p-value 0.0106, 95% CI 1.07 to 2.84)
- Owners who participate in DB contracts were 5.66 times more likely to agree with the statement than owners who do not participate in DB contracts. (p-value 0.0043, 95% CI 1.16 to 27.45)

1.7.8.2 Question D3b

Question D3a was stated as follows in the various surveys:

- There are ECONOMIC incentives that may enable designers to practice DCWS.

  (“Economic" refers to monetary benefits, direct and/or indirect, and insurance benefits)

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 1.94 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0002, 95% CI 1.35 to 2.78)
- Architects were 2.39 times more likely to disagree with the statement than contractors. (p-value ~0, 95% CI 1.49 to 3.84)

1.7.8.3 Question D3c

Question D3a was stated as follows in the various surveys:

- There are CONTRACTUAL incentives that may enable designers to practice DCWS.

  (“Contractual” refers to standard language used in contracts)

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Contractors were 1.84 times more likely to agree with the statement than all the other groups combined. (p-value 0.0045, 95% CI 1.19 to 2.83)
- Architects were 1.89 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0003, 95% CI 1.31 to 2.73)

- Architects were 2.23 times more likely to disagree with the statement than contractors. (p-value 0.0003, 95% CI 1.39 to 3.58)
- Owners who participate in CMGC contracts were 6.16 times more likely to disagree with the statement than owners who do not participate in CMGC contracts. (p-value 0.0012, 95% CI 1.31 to 28.88)
- Owners who participate in DB contracts were 6.75 times more likely to agree with the statement than owners who do not participate in DB contracts. (p-value 0.0016, 95% CI 1.40 to 32.47)

1.7.8.4 Question D3d

Question D3d was stated as follows in the various surveys:

- There are LEGAL incentives that may enable designers to practice DCWS. (“Legal” refers to federal, state, and local statutes)

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 1.92 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0003, 95% CI 1.33 to 2.77)
- Architects were 2.29 times more likely to disagree with the statement than contractors. (p-value 0.0002, 95% CI 1.42 to 3.67)
- There is moderate association between experience of a contractor and agreement with the statement (p= 0.0305); the more experienced the contractor, the more likely they agree.

1.7.8.5 Question D3e

Question D3e was stated as follows in the various surveys:

- There are ETHICAL incentives that may enable designers to practice DCWS. (“Ethical” refers to principles of conduct that are considered correct)

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Contractors were 1.62 times more likely to agree with the statement than all the other groups combined. (p-value 0.008, 95% CI 1.10 to 2.39)
- Architects were 1.78 times more likely to disagree with the statement than all the other groups combined. (p-value 0.0107, 95% CI 1.11 to 2.86)

1.7.8.6 Question D3f

Question D3f was stated as follows in the various surveys:

- There are CULTURAL incentives that may enable designers to practice DCWS. ("Cultural" refers to standards of construction industry practice)

The survey participants were asked to state their agreement or disagreement to the statement. After performing the various tests that were described previously, the following results were found to be significant:

- Architects were 1.87 times more likely to disagree with the statement than contractors. (p-value 0.0069, 95% CI 1.11 to 3.15)
- There is moderate association between experience of a contractor and agreement with the statement (p= 0.0377); the more experienced the contractor, the more likely they agree.

1.7.9 Results Summary

The previous analysis of the results showed some tendencies among the responses of the participants. These tendencies are summarized in this section of the report.

1.7.9.1 Prior Knowledge & Current Participation

It became very clear that DCWS is not known in the construction industry at the moment. This finding is observed by the low percentage of participants who answered positively in question B1; 20.5% of engineers, 21.5% of owners, 5.4% of architects, and 16.2 of contractors. The architect group of participants had the lowest percentage of positive responses and they were 4.18 times more likely to not have prior knowledge than all the other groups.

The analysis of question B1 shows that engineers who did have prior knowledge were more likely to also state that designers have opportunities to be educated in construction worker safety (C1c) and that construction hazards are not only taken care of by contractors alone (C3c).

Participation in some form of DCWS (B2) was even lower than prior knowledge; 19.3% for engineers and 4.1% for architects. In situations where engineering firms participate in DCWS, their employees were more likely to state that designers have opportunities to be educated in construction worker safety (C1c) and be involved and participate in construction worker safety (C1d). These engineers were also more likely to disagree with the statements that the nature of the industry does not allow them to participate in construction safety (C1e), that only construction contractors are currently involved in reducing construction hazards (C3b) and that all hazards are taken care of by construction contractors. The firms that were more likely to be practicing DCWS were also larger firms (p=0.0003).

The existence of formal guidelines for reviewing design for construction worker safety (B3) was even lower among the responses than participation in some form of DCWS; 9.8% from engineers and 3.2% from architects. The positive attitudes from engineers towards safety participation surfaced again in this question as in B2.These attitudes included agreement with owner's participation to worker safety (C2d), disagreement that the nature of the industry does not allow owners to participate in worker safety (C1e), disagreement with the statement that only construction contractors are involved in eliminating construction hazards (C3b), and their disagreement that only construction hazards are taken care of by contractors (C3c). Engineers from larger firms though were also likely to be working in firms that had guidelines for reviewing designs for DCWS. One result that stood out among the responses was that engineers who responded positively to question B3 also responded that there are ECONOMIC incentives that may enable designers to practice DCWS.

Engineers from firms that were asked to address issues relating to construction worker safety (B4) also showed positive attitudes towards participation in DCWS as in the previous two questions (B2 and B3).

1.7.9.2 Designer Industry Knowledge and Safety Participation (C1a-C1e)

The survey responses to statements C1a-C1e reinforced the identification of attitudes that designers have towards their knowledge of the construction industry and the possibility of designers participating in construction worker safety. The results are shown in detail in section 1.7.3.

Specifically, both of the designer groups greatly agreed that designers know how construction operations and procedures take place (C1a): architects were 2.59 times more likely than all other groups and engineers were 3.4 times more likely than all other groups. Both groups also agreed that they have a clear understanding of what constitutes a hazard to construction workers (C1b): architects are 1.64 times more likely than all other groups and engineers are 2.24

times more likely. Contractors though, tended to disagree with the statements. The contractors were 6.84 times more likely to disagree than all other groups combined with statement C1a, and 5.96 with C1b.

This attitude towards knowledge of the industry and its hazards to its workers was not equally reflected by both groups when they were asked about opportunities to learn about safety. Architects were 1.58 times more likely to disagree than all other groups combined that there are opportunities to learn about construction worker safety (C1c), while engineers were 2.12 times more likely to agree than architects. Contractors and owners were also more likely to agree than architects.

Architects were also more likely to be in disagreement with the idea of being involved in construction worker safety (C1d). Specifically, they were 3.71 times more likely to disagree than the other industry groups, while engineers were 3.67 times more likely to agree than architects, contractors were 3.58 times more likely to agree, and owners 2.57 times more likely to agree. Architects also perceive that the current nature of construction contracting does not allow them to participate in construction worker safety (C1e). Specifically architects responded that the nature of the industry is an obstacle 2.95 times more often than all the other groups of participants combined.

1.7.9.3 Owner Industry Knowledge and Safety Participation (C2a-C2e)

The owners were 42.7 times more likely to agree with the statement that owners know how construction site operations and procedures take place (C2a). This value seems quite extreme but that could be partly due to the nature of the owners who were surveyed. Facility services or other equivalent departments on university campuses are actively involved with the construction of their projects by supervising these projects with all the necessary experienced personnel.

When asked to specify if owners have the capability to be educated in construction worker safety (C2b), owners were 10.85 times more likely to agree. Architects were 1.82 times more likely to disagree with the statement than engineers, and 2.29 times more than contractors.

Architects were also likely to disagree that owners have a clear understanding of what constitutes a hazard to construction workers (C2c). They were 2.09 times more likely to disagree than contractors and 1.84 times more than engineers. Regarding owner involvement in construction safety (C2d), architects were again more likely to disagree; by 4.55 times more than contractors and 3.21 times more than engineers.

Concerning the nature of the construction industry being an obstacle for owner participation in construction worker safety (C2e), the architects responded similarly as in (C1e) regarding designers; by 3.27 more than engineers and 4.48 times more than contractors. Architects seemed again to have a negative attitude towards participation in construction safety, and they seem to feel that owners should also not participate in safety.

1.7.9.4 Construction Industry Hazards (C3a-C3f)

All groups agreed that the construction industry is a hazardous industry (C3a), and there were no significant differences among the various groups regarding this statement.

When asked the statement whether contractors are the only group that is currently involved in reducing construction site hazards to construction workers (C3b), the architects were 2.38 times more likely to agree with this statement than all other groups combined. A substantial number of the survey participants from the other groups disagreed with the statement, recognizing the current involvement of other participants in construction worker safety.

A similar attitude towards C3c “All construction site hazards to construction workers are taken care of by construction contractors” was displayed by the architects. They were 2.38 times more likely to agree than all other groups.

The survey participants showed some variability in their answers when asked to agree if decisions made prior to design can affect construction worker safety (C3d). In three groups (engineers, contractors and owners), more than 50% of all participants agreed with the statement, but architects were 3.61 times more likely to disagree. The architects’ agreement with the statement was 47.5%. Similarly for statement (C3e) regarding decisions made during design, architects had the lowest level of agreement with 52.5% and they were 5.78 times more likely to disagree. Regarding decisions made during construction, there were no significant differences among the responses of each group.

1.7.9.5 Participation through Legislation (C4a-C4b)

From the responses to questions C4a and C4b, it is clear that the group with the most support for legislation for DCWS was the contractor group. Their agreement with C4a was 38% which made them 3.91 times more likely to be in support of such legislation. Architects stated that their firm would have the least amount of support, with 10.4% of architects indicating support.

With legal protection from liability for designers (C4b), the support for such legislation increased in the engineer group by 37.6%, in the architect group by 15.9%, and in the owner group by 10%; the support in the contractor group decreased by 6.1%.

1.7.9.6 Obstacles (D1a-D1f)

The obstacle areas that were identified in previous research were considered to be of varying importance by the survey participants. Regarding regulatory obstacles, architects were 2.38 times more likely to agree that they are in place, when compared to all other groups combined. Contractors on the other hand were 2.50 times more likely to disagree that there are regulatory obstacles in place for designers to practice DCWS.

When the participants were asked about economic obstacles, the engineers appeared to be different that all the other groups, with 1.72 times more likely to agree.

The area of contractual obstacles was recognized by both engineers and architects as a concern. Specifically, architects were 2.24 times more likely to agree; while engineers were 1.86 times more likely to agree with statement D1c. Contractors on the other hand were 4.16 times more likely to disagree than contractual problems do not allow designers to practice DCWS.

Similarly, the legal area of obstacles was identified both by engineers and architects to be a concern. Architects were 2.22 more likely to agree, while engineers were 1.57 times more likely to agree. Contractors were 2.86 times more likely to disagree.

The ethical area of obstacles was surprisingly only different for architects. Even though only 22.6% of architects agreed that there are ethical obstacles in place, they were still 3.01 times more likely to agree with statement (D1e) than all the other groups combined. By contrast, contractors were 3.03 times more likely to disagree with statement D1e than all other groups combined.

The last area of obstacles, cultural obstacles, also showed some differences among the responding groups. Specifically, architects were 1.44 times more likely to agree with statement D1f, while contractors were 2.91 times more likely to disagree.

1.7.9.7 Enablers (D3a-D3f)

The same six areas that were considered as obstacles were used as possible areas for enablers. Architects disagreed that there are regulatory enablers that would allow them to practice DCWS. Their disagreement was 1.76 times more than all the other groups.

For the existence of economic enablers, architects disagreed more than everyone else again with an odds ratio of 1.94. Similarly for contractual enablers architects disagreed with a ratio of 1.89, for legal with a ratio of 1.92, for ethical with a ratio of 1.62, and for cultural enablers with a ratio of 1.87.

Architects showed the most disagreement compared to all the groups regarding the presence of any enablers for practicing DCWS.

1.8 Hypothesis Statement Conclusions

After the survey results were analyzed, the hypothesis statements that were stated earlier in the manuscript (Section 1.5.2) were revisited to determine whether adequate information was collected in order to answer them. The results are shown below:

H1: Design for Construction Worker Safety is not prevalent in the US

This hypothesis was answered by questions B1 and B2. B1 asked all survey participants to answer if they had prior knowledge of DCWS. Question B2 asked designers if their firm/organization practiced some form of DCWS.

The results from both of these questions showed that DCWS is not prevalent in the US. Of the professionals who responded to the survey, only 20.5% of the engineers responded that they had prior DCWS knowledge (5.4% of the architects, 21.5% of the owners, and 16.2% of the contractors).

Regarding DCWS practice, 19.3% of the engineers and 4.1% of architects stated that their firm practices some form of DCWS. As a conclusion to this hypothesis, it is confirmed that DCWS is not prevalent in the US.

H2: DCWS is not understood in the US.

In order to answer this hypothesis, the survey responders were asked question B1 concerning prior knowledge of DCWS. The results of the question are shown above for H1. From the survey there was not enough information to answer this hypothesis. In addition, the comments that responders provided in questions B2a; "What motivated your firm to start practicing DCWS", and B2b; "Please describe your firm's efforts in practicing DCWS", were not adequate to give an affirmative or negative answer that designers understood the DCWS concept in general.

As a conclusion, there was not enough information collected in the survey to answer this hypothesis.

H3: DCWS is rarely practiced in the US.

This hypothesis was answered affirmatively by questions B2 and B3. The results of question B2 are shown above for H1. Question B3 asked participants from design firms and owner organizations to answer if their firm/organization has guidelines for reviewing designs for construction worker safety. The results of the survey showed that only 9.8% of engineers, 3.2% of architects, and 15.7% of owners have guidelines for reviewing designs for construction worker safety.

As a conclusion to this hypothesis, it is confirmed that DCWS is rarely practiced in the US.

H4: Owner and Designer participation in safety has many obstacles

To answer this question, all of the participants were asked if the nature of construction contracting is such that it does not allow owners and designers to participate in construction worker safety. Question C1e concentrated on designers and question C2e concentrated on owners.

C1e showed that 41.4% of engineers, 59.3% of architects, 33.1% of owners, and 14% of contractors agreed that the nature of construction contracting does not allow designers to participate in construction worker safety. 29.5% of engineers, 12.7% of architects, 33.8% of owners, and 50.9% of contractors disagreed with the above statement.

C2e showed that 29.1% of engineers, 55.2% of architects, 17.3% of owners, and 25.7% of contractors agreed that the nature of construction contracting does not allow owners to participate in construction worker safety. 38.6% of engineers, 15.4% of architects, 49.6% of owners and 48.6% of contractors disagreed with the above statement.

H4 cannot be answered from the above questions since there is no clear consensus among the participants. From these responses it seems that at least half of the contractors believe that the nature of construction contracting does not have obstacles for designers to participate in construction worker safety and the majority of the architects believe that designers and owners cannot participate in construction worker safety due to the nature of the industry.

As a conclusion, it is not clear that the nature of the industry does not allow owners and designers to participate in construction worker safety.

H5: The obstacles to DCWS are not clear

As mentioned previously, the participants were asked to answer if there are obstacle areas that hinder designer participation in construction safety. These areas were: a) Regulatory, b) Economic, c) Contractual, d) Legal, e)Ethical, and f) Cultural, and the nature of construction contracting that was answered in H4. The questions asked were C1e, D1a, D1b, D1c, D1d, D1e and D1f, and the complete results of these questions are shown in Appendix D – Summary of Survey Results.

As observed in the results, at least 50% of the architects agreed that the nature of construction contracting does not allow designers to participate in construction safety. The majority of the engineers did not agree with the same statement.

At least 50% of the engineers and architects stated that there are economic, contractual and legal obstacles that do not allow designers to participate in construction worker safety. Regarding the regulatory, ethical and cultural areas, the responses did not show a majority among engineers and architects agreeing that in these areas there are obstacles that do not allow designers to participate in construction worker safety.

Contractors and owners did not see obstacles in any of these areas that would not allow designers to participate in construction worker safety.

As a conclusion, designers believe that economic, contractual and legal obstacles are in place that do not allow them to participate in construction worker safety.

H6: Incentives to implement DCWS are not clear

As mentioned previously, the participants were asked to answer if there are enabling areas that allow designer participation in construction safety. These areas were again: a) Regulatory, b) Economic, c) Contractual, d) Legal, e)Ethical, and f) Cultural, and the nature of construction contracting that was answered in H4. The questions asked were D3a, D3b, D3c, D3d, D3e and D3f, and the complete results of these questions are shown in Appendix D – Summary of Survey Results.

As shown in the results, in none of the areas was there a clear majority of responses that would indicate that there are incentives for designer participation in construction worker safety.

H7: Designers understand the dangerous nature of the construction sites

To tackle this hypothesis, the survey participants were asked to state their level of agreement with the statement “The construction industry is a hazardous industry” (Question C3a). The results showed that 75.8% of engineers and 81% of architects agreed with the statement, supporting the hypothesis that designers understand that construction sites have inherent hazards.

H8: Owners understand the dangerous nature of the construction site

As is H7 above, in the same question (C3a), 76.9% of the owners responded that they were in agreement with the statement “The construction industry is a hazardous industry”. This result supports the hypothesis that owners understand that construction sites have inherent hazards.

H9: Contractors understand the dangerous nature of the construction site

As is H7 above, in the same question (C3a), 87.8% of contractors responded that they were in agreement with the statement “The construction industry is a hazardous industry”. This result supports the hypothesis that contractors understand that construction sites have inherent hazards.

H10: Designers believe that all construction site hazards are taken care of by contractors

To answer this hypothesis, designers were asked to state their agreement with statement C3b, “Only construction contractors are currently involved in reducing hazards to construction workers”, and C3c, “All construction site hazards to construction workers are taken care of by construction contractors”.

In both of these statements engineers and architects did not indicate a majority in their agreement. After further analysis, there was some relationship between the level of agreement with both of these statements and the experience of the designers. Specifically engineers with less experience were more likely to agree with C3b ($p=0.0132$). With regards to statement C3c, both engineers and architects that had fewer years of experience were more likely to agree (engineers $p=0.0023$, architects $p=0.0134$).

H11: Owners believe that all construction site hazards associated with the design are taken care of by contractors

To answer this hypothesis, owners were asked to state their agreement with the statements that the designers were asked in H10 (C3b and C3c). In both of these statements, the owners did not indicate their agreement with a majority.

H12: Decisions made during the entire construction process affect construction site safety hazards

To answer this hypothesis, all the industry participants were asked to state their level of agreement with the following three statements:

- C3d: Decisions made before the design of a project begins can help eliminate some construction hazards
- C3e: Decisions made during the design of a project can help eliminate some construction worker hazards

- C3f: Decisions made during the construction of a project can help eliminate some construction worker hazards.

From the responses that are shown in Appendix D – Summary of Survey Results, it is evident that the majority of participants agree that decisions made during predesign, design, and construction affect construction safety.

H13: It is not clear if owners and designers should be involved with construction site safety

To answer this hypothesis, the participants were asked to state their agreement with two statements:

- C1d: Designers should be involved and participate in construction worker safety through design decisions
- C2d: Owners should be involved and participate in construction worker safety

From the responses that are shown in Appendix D – Summary of Survey Results, the only group that did not indicate with a majority their agreement with the statements was the architect group (25.8% for C1d and 27.2% for C2d).

The other three groups (engineers, owners, and contractors), indicated with a majority their agreement with both statements.

1.9 Conclusions

All industry participants understand that design decisions have an impact on construction safety as seen in the survey responses. For decisions made prior to design the level of agreement was 68.4% from engineers, 47.5% from architects, 59.5% from owners, and 81% from contractors. For decisions made during design, 77.9% of engineers, 52.5% of architects, 66.2% of owners, and 86.6% of contractors agreed. Nevertheless, that understanding is not enough for designers to start practicing DCWS. The engineers responded with 53.7% agreement that designers should participate in construction worker safety, while only 25.8% of architects agreed. Similar responses were obtained when designers were asked about the possibility for owner participation in construction safety, with 52.9% of engineers agreeing and 27.2% of architects agreeing.

Designers recognized that there are obstacles for DCWS implementation in three of the key areas: legal, economic, and contractual.

The US construction industry is highly litigious and that deters many designers from assuming additional responsibility and from considering construction worker safety in their designs. A future possible framework for implementation of DCWS within the construction industry should take into consideration legal concerns and protect designers from frivolous lawsuits.

The economic obstacle identified by designers was due to concerns that the cost of design increases if DCWS is implemented in design. The owner group surveyed did not recognize that there are economic obstacles, suggesting that there might be long term benefits to DCWS implementation that counteract the initial possible increases of design costs. With further research through a lifecycle cost analysis of projects costs, it might be possible to prove that the initial perceived cost increases can be counteracted by savings during construction, maintenance, and decommissioning.

The architect group with 59.3% agreement believes that current construction contracting does not allow designers to participate in construction safety. That percentage is 41.4% for engineers, 33.1% for owners, and 14% for contractors. Architects also agreed to the greatest extent that current construction contracting does not allow owners to participate in construction safety. Architects need an additional incentive for them to practice DCWS, and that might only be able to be provided by a direct instruction from the owner group which provides the designers monetary compensation.

It is also very interesting that the responses of engineers and contractors were so closely aligned in many of the responses to the survey. This alignment would suggest that engineers have an understanding of construction operations; much more than architects, which allows the engineers to have a more realistic view of the hazards and safety risks on construction sites.

Increased collaboration between project participants should be encouraged. Construction contractors have inherent knowledge regarding safety and constructability issues that can be shared through dialogue with owners and designers. Using alternative contracting methods that facilitate the flow of knowledge such as DB and CM/GC, designers can contribute to construction safety through increased collaboration with contractors during design.

Education of designers about DCWS is important. As observed in the survey results, the majority of the construction industry participants did not have any previous knowledge of the concept, or did not believe that designers and owners have adequate opportunities to be educated in construction safety. It is important that universities with civil engineering and architecture degree programs include courses in their curricula that address the issue of construction safety and the effect that design decisions have on construction worker safety. Additionally, practicing engineers and architects may be educated in the concept through seminars and professional development courses.

The following manuscript, Manuscript 2, discusses the results of an investigation through the use of a Delphi panel, the direction with which interest can be generated for DCWS. Industry experts from all groups (owners, designers, contractors) are asked to identify which industry group has the largest ability to influence interest in DCWS and identify which method each group can use to generate the most interest. Four possible directions were provided to the panel: the business case, legislation, industry standards, and education. A business case direction would address any economic obstacles that were identified by designers. The legislation direction would address the method that DCWS legislation can be set in place to require designers to practice DCWS. To address the contractual barriers, the industry standards direction would address the best way to generate industry standards for practicing DCWS and to incorporate the standards into current construction contracts. DCWS is not known in the industry as was observed in the survey. For that reason the education direction would find the best method to generate interest through education of industry participants. The Delphi panel was also given the opportunity to suggest additional methods in order to generate interest.

2.0 Manuscript 2 – The use of a Delphi Panel to Determine the Direction for DCWS Interest Generation

2.1 Preface

The first manuscript of this dissertation showed that Design for Construction Worker Safety (DCWS) is not widely practiced by designers and that it is not well known by design professionals. Designers who responded to the Manuscript 1 survey specified that there are obstacles in three different areas that inhibit them from considering design for construction worker safety. These areas are Legal, Economic and Contractual.

As observed in Manuscript 1 and through literature, the Legal area obstacle comes from a fear of litigation. Designers consider their possible involvement in construction safety as an increase in their exposure to third-party lawsuits and that would significantly limit their profitability and even their survival.

Designers see that economic obstacles arise because of the increased review process that designs would need to go through in order to consider construction worker safety. Designers' comments from Manuscript 1 showed that they believe owners would not be willing to pay for that increased work and that would limit their profitability if they were to incorporate an additional level of design review.

According to Manuscript 1, contractual obstacles arise because designers believe contracts do not allow them to practice construction safety. Alternative contracting methods though, such as DB and CM/GC place designers and contractors in close collaboration prior to or during design. Through constructability meetings safety considerations can be addressed without consideration of contractual obstacles.

This manuscript attempts to identify the best possible way of generating interest for DCWS and to remove the obstacles for DCWS implementation with the use of a Delphi panel. The panel was *asked to identify the construction industry group that is best equipped to generate that interest, and with which method.*

2.2 Introduction

As was discussed previously, the purpose of this manuscript is to identify a method with which to generate interest for DCWS within the US construction industry and to remove any obstacles that might exist for DCWS practice. Designers (architects and engineers) who participated in the survey analyzed in Manuscript 1 agreed with a majority of more than 50% that there are legal, economic and contractual obstacles for them to practice DCWS. These percentages can be observed in section 1.6.6.3. The highest level of obstacle identification came from the architect group who identified by a higher percentage than the other industry groups that there are obstacles in all the areas: Regulatory, Economic, Contractual, Legal, Ethical, and Cultural. In addition, designers did not identify with a clear majority any incentives for them to practice DCWS.

Further investigation is required in order to identify a method with which interest in DCWS practice can be generated. This manuscript describes the approach that was taken in order to identify the method to generate interest and which construction industry group should be targeted for that interest to become a reality.

In summary, the objectives of this manuscript are the following:

- Identify the construction industry group that can generate interest for wider DCWS implementation in the US construction industry,
- Identify an appropriate method with which that interest can be generated, and
- Identify the group that needs to be targeted with the method chosen.

2.3 Literature Review

A more extensive literature review of DCWS is provided in part of Manuscript 1. Manuscript 2 will not include additional literature on DCWS. It will only concentrate on the methodology for finding the direction to generate interest in DCWS in the US construction industry.

As was observed in Manuscript 1, designers (architects and engineers) identified obstacles in three problem areas for the implementation of DCWS. These were legal, economic, and contractual. The owners who responded to the survey also identified economic obstacles. In addition, due to the low percentage of knowledge of the DCWS concept among the industry participants, the author believes that an additional problem area needs to be addressed: education.

The economic obstacles arose because designers and owners considered DCWS to be costly since additional review of design is required to address safety concerns. To investigate this issue further, the author believes that a business case model needs to be developed to address any concerns of additional costs.

The legal obstacles exist because designers at the moment are not required to be involved in construction safety. If they were required by law or by owners to participate, then the legal obstacles would not be there. A possible area of concentration of DCWS efforts is to investigate the possibility of promoting DCWS legislation.

The contractual problems identified can be eliminated by including requirements in design contracts for designers to participate in DCWS. Such requirements could include standards and guidelines that instruct designers in the proper and acceptable methods with which to address construction safety in design. A possible area of concentration of DCWS efforts would be the possibility of generating such standards for designer adoption and use.

The concern for education can be eliminated by updated teaching techniques and methods that include DCWS instruction to design professionals either through formal university curricula or through continuing education courses.

The following sections describe and address the aforementioned areas of concentration

2.3.1 The Business Case Approach

One method for generating interest in DCWS and Prevention through Design (PtD) in general is through the business case. The term “business case” has several definitions, and a simple internet search of the term will generate a myriad of definitions. According to Biddle (2013), a research scientist working on developing PtD Business Case models for NIOSH, the term business case should answer the question: "What is it in for the company?". A business case model should therefore answer that question by providing evidence that the implementation of any idea or program, such as PtD and DCWS is more beneficial than all the potential costs of not implementing the idea or program. The author states that business case models can be based on economics, finance, and business management, but used the "value strategy" in her report to evaluate PtD solutions. The PtD solutions described were not from the construction industry but from Healthcare, Agriculture and Garment Cleaning. However there is a great potential to develop business case models in other industries, including construction.

One example of benefits that came from implementing design decisions during construction and planning comes from Kaiser Permanente (KP). Christine Malcolm (2008), KP senior Vice President for Hospital Strategy and National Development, states that KP has managed to keep construction costs of their facilities 13% lower than the industry average, the hospital worker injury rate saw a 37% reduction, a 42% reduction in worker compensation claims, and a 46% in patient handling claims. Malcolm attributes these gains in savings to the Safety in Design program at KP and by cooperating with many industry groups and organizations prior to construction of their facilities such as the Center for Disease Control (CDC), the American Institute of Architects, NIOSH, and others. The changes KP implemented in their designs, according to Malcolm (2008), "do not cost anything to implement", and a list of 150 solutions was developed that KP could share with the rest of the industry.

The above examples suggest that there is great potential to generate interest in DCWS through the use of a business model. A recommendation for the research of the relationship between PtD and construction project business measures was also presented in a recent study performed for NIOSH regarding the possible implementation of PtD in the US after observing the UK construction industries experiences in the UK and the CDM regulations (Gambatese 2013). The author recommends that representative case study models be prepared and presented to US construction industry stakeholders in order to encourage PtD and DCWS practice in the US.

2.3.2 The Education Approach

Another method for generating interest in and understanding of the DCWS process along with its benefits to the construction industry is the use of enhanced education practices that incorporate safety considerations in their curriculum. Countries that have incorporated some form of DCWS in engineering design, such as in Australia, have also developed several formal educational tools to be used for the education of engineers in tertiary institutions (Creaser 2008).

The US is lacking in this respect but educators have recognized that there is a need and opportunity to include safety education in engineering programs in the US. Toole et al. (2008) listed education as one of the trajectories for PtD in construction and commented that with recent developments in curricula it is possible to include instruction in construction safety. They do comment that since university instructors lack the necessary training and knowledge to instruct on construction safety, it would be necessary for instructional modules to be developed in order to assist them in the educational tasks. NIOSH has already started developing modules to be used in design classes with the help of university faculty versed in both design and safety. Examples of these include modules for Steel Design, Concrete Design, Architectural Design, and Mechanical/Electrical Design (NIOSH 2013). In the paper by Popov et al. (2013) the authors summarize the current inclusion of PtD in undergraduate curricula in three US universities: Purdue University, Virginia Tech, and University of Central Missouri. The authors also list 13 universities that have incorporated PtD in various courses, but believe that there is a need to increase that number by encouraging universities to conduct PtD research and by incorporating faculty in instruction who are professional engineers (PE), certified safety professional (CSP) and certified industrial hygienists (CIH).

Toole et al. (2008) also suggest that considerations for construction safety can also be included within exams for professional engineers that are administered by the various state examining boards. Some continuing education classes for engineers and architects have been developed by educators interested in PtD and DCWS. One example of this is a class that is administered by the Harvard School of Public Health and offered once a year in Boston (HSPH 2013).

Education of current professionals is also conducted by private firms that take it upon themselves to train their employees in DCWS. One example of such a firm is Washington Group International, where an internal program was developed to educate engineers that includes classes for practical issues for eliminating potential construction hazards and the instruction of OSHA-10 (Zagres et al. 2008).

With just these efforts described in this section, the actual knowledge of PtD and DCWS in the US construction industry is still not prevalent (Tymvios et al. 2012), suggesting that there is a need for increased involvement by educators and professionals interested in PtD to educate engineers and architects as well as the other construction industry professionals in DCWS and PtD.

2.3.3 The Legislation Approach

Legislation has been the method of choice in the European Union to demand the use of PtD and DCWS in construction and other industries (EEC 1989; EEC 1992). As mentioned in Manuscript 1, through a European Union directives each European Union member country enacted legislation that would address safety on construction sites through the design process, examples of which are the CDM regulations in the UK and Spain's Royal Decree 1627 (INSHT 1997; Government 2007). In the US though, as mentioned in manuscript 1, any attempts to implement some form of construction safety considerations during design have been defeated in the House, the Senate, as well as in state governments (Gambatese 2000a; Behm 2005).

Any future attempt to enact a form of legislation that would make the practice of DCWS compulsory by all designers would face very strong opposition and have to be extremely convincing in order to pass through both federal and state legislative bodies.

2.3.4 The Industry Standards Approach

Industry standards are developed by professional societies in order to guide their members in policies relevant to the profession they represent (Toole et al. 2013). Several US professional societies developed such policies to instruct their members in proper ways to practice PtD. Toole et al. (2013) include the following standards in their article as examples:

- ASSE Prevention Through Design Technical Report TR-Z790.001-2009,
- ANSI/ASSE Z590.3-2011, Prevention Through Design Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes,
- ANSI/AIHA/ASSE Z10-2012, Occupational Health and Safety Management Systems,
- SAE J2194, Rollover Protective Structures for Wheeled Agricultural Tractors (2011),
- ANSI B11.0-2010, Safety Standards for Machine Tools,
- ANSI B11.19-2010, Performance Requirements for Safeguarding,

- ISO 12100:2010, Safety of Machinery: General Principles for Design—Risk Assessment and Risk Reduction,
- ANSI/PMMI B155.1-2011, Safety Requirements for Packaging Machinery and Packaging-Related Converting Machinery,
- ASHRAE Technical Committee 9.11, Clean Spaces,
- ANSI B11, Safety Standards for Machine Tools,
- ISA 12, Electrical Equipment for Hazardous Locations,
- UL 2201, Portable Engine—Generator Assemblies,
- ANSI Z87, Safety Standards for Eye Protection,
- ANSI/AIHA Z9, Health and Safety Standards for Ventilation Systems,
- ANSI/ASSE A10 Accredited Standards Committee for Safety in Construction and Demolition Operations, and
- ANSI/ASHRAE 161-2009, Air Quality within Commercial Aircraft. (Toole et al. 2013)

None of the above guidelines though addresses construction specifically. There is a need for formal guidelines to be developed for designers to follow in order to address construction worker safety.

2.4 Methodology

In order to settle on the best method to use to generate interest in DCWS, further investigation is needed. The Delphi process was chosen as the research method for this manuscript to settle on a route to generate that interest in DCWS. A brief literature review on the process, advantages, disadvantages and the reasons for that choice is included in this section of the manuscript.

2.4.1 The Delphi Method

The Delphi Method was developed as a "spinoff" from research that was conducted for the Air Force by the Rand Corporation and their "Project Delphi" in the early 1950's. The name Delphi, derived from the ancient Greek oracle at Delphi, was used since it referred to the forecasting information that the project was seeking. The project aimed to find the best way to get consensus of opinions by a group of experts using a series of questionnaires with controlled opinion feedback. Because the initial studies were geared towards defense issues, it was very difficult for the Delphi Method to be transferred to other research areas, and that was partly due to the time required for the declassification of method by the US armed forces. The first non-defense research paper published in 1964 that used Delphi as its primary research method was published by Rand and it was titled "Report on a Long-Range Forecasting Study" (Lindstone et al. 1975; Landeta 2006). Since then thousands of studies have been conducted in many countries using the Delphi method in areas ranging from technological forecasting to the evaluation of social problems, academia, administration, agriculture, automotive, banking, criminal justice, health care, housing, etc. (Gupta et al. 1996; Landeta 2006).

There are four objectives that can be achieved through the use of a Delphi panel. These are:

- To gain accuracy from the knowledge of certified experts,
- To establish a degree of consensus among the responses the experts provide,
- To maintain anonymity among the panel participants to avoid bias, and
- To attempt to answer a question in cases where it is not possible to do with standard statistical procedures due to the nature of the question or the absence of objective data. (Hallowell 2008)

The Delphi Method is different from traditional survey methods because of the following reasons:

- The panel participants are certified experts,
- The panel experts are selected according to predetermined guidelines,
- Consensus is achieved through anonymous feedback to the panel participants that is provided by the panel moderator, and
- The format of the survey allows anonymous interaction among participants without the effects of judgment bias.(Hallowell 2008)

2.4.2 The Delphi process

The Delphi process consists of surveys, sent to a panel of experts, designed to answer specific questions of interest. The typical steps in the Delphi process are summarized in Figure 2-1. The figure, which was modified from Hallowell (2008), shows that the first step is the identification, selection, and validation of the Delphi panel experts.

The process then continues with the development of the first questionnaire, its distribution, and subsequent analysis. If consensus is reached, then the Delphi process ends and the results are reported. If no consensus is reached, then another round needs to be conducted and another questionnaire is developed. For this research project, and to reduce the amount of time that is required for the Delphi process, the validation of the Delphi panel occurred at the same time as the first questionnaire, as described in subsequent sections (2.4.9 and 2.5.1).

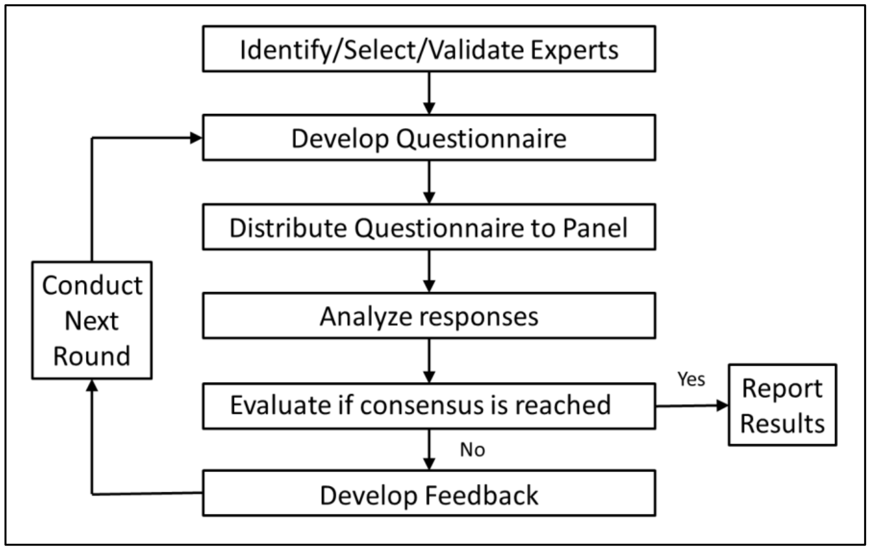

Figure 2-1: Typical Delphi Process (modified from Hallowell (2008))

2.4.3 Delphi Method Strengths

The Delphi process has survived as an acceptable research tool all these years because of the inherent advantages that are present. Some of these advantages are the following:

- As described in the report by Dalkey (1969), *"two heads are better than one"* and *"several heads are better than one"*. In other words, a group of knowledgeable individuals can provide the best possible answer when faced with an issue where the best information available is personal judgment.
- The Delphi method can be used to achieve consensus when there is a lack of empirical evidence (Murphy et al. 1998).
- Various issues can be eliminated, such as individual dominance, conflict of interest, and group pressures, that are inherent to face-to-face discussions (Murphy et al. 1998).
- The Delphi method is relatively inexpensive to organize and administer (Rowe et al. 1999).
- The Anonymity of the Delphi panel, leads to creative outcomes and richness of the generated information form the process (Okoli et al. 2004).
- The use of recent online tools for administering surveys and the use of email, significantly reduces the time required to conduct Delphi research (Rajendran 2006).
- Expert opinions from individuals is not limited by geography (Hallowell 2008).
- Bias that can arise through the process can be eliminated through controlled feedback and the careful analysis of the responses (Hallowell 2008).

2.4.4 Delphi Method Criticisms

Even though the Delphi process has been used in numerous research projects since its inception, there have been several criticisms concerning its validity as a research method. Some of the criticisms are listed here:

- The Delphi method has been described as unscientific (Sackman 1974).
- Some questions do not get asked at the beginning of a research project, since they are deemed unimportant. Since traditional Delphi does not add questions in subsequent rounds, when these questions become important they cannot be added, and this weakens the process considerably (Simmonds 1977).
- The abilities of the panel participants limit the quality of the Delphi research (Rajendran 2006)
- Even if consensus is reached in two or more rounds, it is not clear if that would actually increase the accuracy of the group's decision making (Murphy et al. 1998).
- Some participants might abandon the process if it takes too long to complete and have other commitments, leading to a low response rate (Adler et al. 1996).
- The results of the Delphi process can be limited by sloppy execution, questionnaires that are crudely designed, poor choice of panel experts, analysis of unreliable results, limited value of feedback and consensus, and instability of responses between consecutive rounds (Gupta et al. 1996).
- Bias might be developed in the Delphi process due to poorly worded or leading questions and selective interpretation of the results (Lang 1998).
- Depending on the panel members, the Delphi process can take a substantial amount of time to implement (Rajendran 2006).

2.4.5 Delphi Method Bias

A major concern that needs to be addressed when conducting survey research is the elimination of bias among the respondents.

Hallowell et al. (2010) identified eight types of bias that can potentially impact the results of a Delphi study in construction related research. These are described below:

- Collective unconscious – This refers to a situation where a consensus is reached unconsciously by panel participants through a need to conform to a popular trend. The authors refer to this as the "bandwagon effect". Panel participants reach this collective unconscious without considering the pros and cons of the decision they are conforming (Hallowell et al. 2010).
- Contrast Effect – In Delphi questionnaires where participants are asked to rate risks and factors, the sequence in which the items are presented and rated can affect the value they receive, especially when the items have substantially different values. The authors suggest that the Delphi questionnaire be structured in such a way that the contract between the rating systems be minimized (Hallowell et al. 2010).
- Neglect of Probability – This type of bias occurs when panelists ignore the likelihood of the rated item to be occurring when they make a decision under uncertainty (Hallowell et al. 2010).
- Von Restorff Effect – Extreme events are more easily remembered, and that causes participants to distort the perception of probability for certain items that are being rated (Hallowell et al. 2010).
- Myside Bias – This type of bias occurs when panel participants only generate arguments

for one side of the issue discussed (Hallowell et al. 2010).

- Recency Effect – Since more recent events are better remembered, panelists are more likely to rate items related to more recent events with a higher value. To redeem this problem participating panelists should not be chosen if they have recently experienced an event that would affect their responses to the survey (Hallowell et al. 2010).
- Primary Effect – This type of bias occurs when the first items rated receive a higher importance compared to subsequent items (Hallowell et al. 2010).
- Dominance – This type of bias occurs when one person on a Delphi panel is overly vocal and intimidating to the other members of the panel that affects their answers (Hallowell et al. 2010).

The authors continue in suggesting six different methods in which to minimize bias. These are:

- Randomizing the questions in the survey – The randomization of the questions would allow the researchers to minimize bias caused by the contrast effect, and the primacy effect.
- Include reasons in controlled feedback – This countermeasure would reduce the collective unconscious bias, the Von Rostorff effect, and the myside bias.
- Conduct multiple rounds and maintain anonymity – Multiple rounds can also help reduce the Von Rostoff effects, the recency effect, and the dominance effect.
- Require independent probability and severity ratings – This countermeasure eliminates the neglect of probability.
- Report medians – By reporting medians the contrast effect can be minimized, as well as the myside bias and the recency effect.
- Remove members who experienced recent events. This would eliminate the recency effect. (Hallowell et al. 2010)

For this research the abovementioned biases are tackled using the following methods:

- To eliminate collective unconscious, the panel members were asked to include feedback for their valued ratings.
- The contrast effect was tackled by randomizing questions where possible and by reporting the median after each round.
- The neglect of probability was not an issue in this research since the panel members were asked to rate the influence of each construction industry group and the best method with which each group can be targeted to generate that interest.
- The Von Restorff effect was eliminated using controlled feedback of responses and by conducting multiple rounds
- The myside bias was minimized by asking the participants to provide feedback for their ratings and by reporting the medians
- The recency effect was not considered to be a problem since the research did not deal with material that would be deemed tragic or catastrophic. To the best knowledge of this author, the participants were not involved in recent accidents and other tragic events
- The primacy effect was tackled by randomizing the questions for each panel member

where possible.

- Dominance was achieved by preserving anonymity among participants

2.4.6 Delphi Method Alternatives

The Delphi Method was designed to be used when objective data is not available or not easily obtained. Alternatives for use in similar situations exist and they are summarized in this section:

2.4.6.1 Staticized groups research method

Staticized groups research method is similar to the Delphi method with the exception that there is no feedback and iteration. In other words, the process only has one round and the outcome of the process includes the aggregate responses of the survey, without any further interaction between the experts participating. Staticized groups would be used in a situation where the panel members cannot reach a consensus, but according to Rowe et al. (1999) the use of the Delphi is the preferred method over the staticized groups with a ratio of 12 to 2.

2.4.6.2 Interacting Groups Method

Interacting groups is also known as “focus groups” and it involved the assembly of experts in one location by any means possible: physically, teleconferencing, or any other method where experts can communicate in real time. Anonymity is lost with interacting groups and consensus is reached when all panel members agree upon the solution to the question at hand. The Delphi method was considered to be the preferred method over the interacting groups method at a ratio of 5 to 1 (Rowe et al. 1999).

2.4.6.3 Nominal Group Technique (NGT)

The Nominal Group Technique is also known as “estimate-talk-estimate” or “Brainstorming NGT”. It is similar to the Delphi method with the exception that the interaction takes place in face-to-face meetings with additional discussions in between the various rounds. It is a very expedited method for data collection, but it is also very susceptible to biases and conformity (Erffmeyer et al. 1984).

2.4.6.4 Delphi Method relationship to alternatives

According to Hallowell (2008), the Delphi method is the preferred method for gathering information when objective data is not available over the NGT and the interacting groups because of two reasons:

1. Low Intensity of Researcher – Informant communication

2. Low Intensity of Informant – Informant communication

The NGT technique requires high intensity between informants and with the researcher. The interacting groups method requires high inter-informant communication and low researcher – informant communication. The need for low levels of communication allow the researcher great control over the data gathering process and as a result possible bias can be minimized (Hallowell 2008).

2.4.7 Appropriate Application of the Delphi Method

Rajendran (2006) and Hallowell (2008) identified through literature the criteria used to determine if the Delphi method is the appropriate research methodology. These criteria occur when:

- Disagreement exists among the experts to the extent that a referred communication process is desired,
- The opinion of a group is more desirable than the opinion of a single expert,
- It is desired that the psychological aspects of face-to-face confrontation be minimized,
- Questions to be answered by intuitive judgment supersede questions to be answered by concrete measurement,
- The problem does not lend itself to precise analytical techniques, but can benefit from subjective judgments on a collective basis,
- The individuals needed to contribute to the examination of a broad or complex problem have no history of adequate communication and may represent diverse backgrounds with respect to experience or expertise,
- More individuals are needed than can effectively interact in a face-to face exchange,
- Time and cost make frequent group meetings infeasible,
- The efficiency of face-to-face meetings can be increased by a supplemental group communication process,
- Disagreements among individuals are so severe or politically unpalatable that the communication process must be refereed and/or anonymity assured,
- The heterogeneity of the participants must be preserved to assure validity of the results, i.e., avoidance of domination by quantity or by strength of personality,
- Combining views to improve decision making is desired,
- Immediate confirmation of the results is not possible,
- The research is contributing to an incomplete state of knowledge, and
- There is a lack of empirical evidence.

Rajendran (2006) and Hallowell (2008) also identified the situations when the Delphi method is not appropriate. According to their literature, these are:

- The opinion of the real expert is diluted by the consensus of the group,

- Results are immediately verifiable by some other means,
- There is insufficient structure in the questionnaire implying that not enough information is available to the Delphi participants,
- Consensus may be gained by means other than intuitive judgment, and
- It is used for any purpose other than that of combining opinions of a selected group.

2.4.8 Delphi Process suitability for this research

The Delphi process is suited for this research since it involved the development of a direction for generating interest in DCWS and to identify the construction industry group that can generate that interest. Current literature does not include any quantified research regarding the two items in question and the lack of information led to the decision of implementing the Delphi process with the use of experts in the area of design and construction safety.

2.4.9 Panel Selection

The panel participants were selected according to their declared interest in DCWS and their experience in design and construction. Panelists were chosen from five different groups: architects, engineers, contractors, owners, and safety professionals. Hallowell et al. (2010) suggest that a Delphi panel should consist of 8 – 12 members, but since several groups of experts are to be included in the panel, the author concluded that a larger panel would be appropriate. Initially 35 individuals were identified that were contacted through email to participate on the panel. A brief explanation of the study and the required commitment was included with the email. Of the 35 individuals contacted, 17 agreed to proceed with the Delphi panel. The characteristics of the panel participants are shown in Table 2-1.

Specifically three architects participated (A1, A2 and A3), two engineers (E1 and E2), six contractors (C1 to C6), three participants from owner organizations (O1, O2 and O3) and three safety professionals (S1, S2 and S3). An important aspect of the panel is the vast amount of cumulative experience that they have in construction and construction safety. The participants also represent fourteen different states ensuring geographic diversity of the panel. The qualifications that the panel members have are as follows:

- The panelists have 417 years of cumulative experience. (average = 24.5 years)
- There is diversity in geographical regions represented
- Five of the participants have a PhD or an MS degree
- All, but one of the panelists have professional licensees in engineering, architecture, construction, sustainability, or safety, and 8 of the panelists have multiple licenses.

The various professional licenses that are listed in Table 2-1 are the following:

- AIA – American Institute of Architects
- ARM - Associate Risk Manager
- CDT – Construction Documents Technology
- CHCM – Certified Hazard Control Manager
- CHEM – Certified Healthcare Environmental Manager
- CIH – Certified Industrial Hygienist
- CPC – Certified Professional Contractor
- CRIS – Construction risk & Insurance Specialist
- CSP – Certified Safety professional
- LEED AP – Leadership in Energy and Environmental Design Associated Professional
- PE – Professional Engineer
- SE – Structural Engineer

Table 2-1: Delphi Panel Characteristics

ID	State	Terminal Degree	Academic Position	Peer Reviewed Journal Papers	Book or Book Chapters	Years Industry Experience	Licensure
A1	OH	BS	None	0	0	16	AIA, LEED AP, CDT
A2	CA	BS	None	0	0	24	AIA
A3	NC	MS	None	0	0	8	LEED AP
E1	OR	BS	None	0	0	30	PE
E2	FL	MS	None	21	3	31	CSP, CHCM
C1	IL	BS	None	0	0	31	None
C2	SC	BS	None	0	0	30	CPC
C3	OR	MS	None	0	0	20	CSP, ARM
C4	ID	BS	None	0	0	35	CSP
C5	NE	BS	None	0	0	27	PE, SE
C6	KS	MS	None	0	0	36	SE
O1	CA	BS	None	0	0	5	CIH, CHEM
O2	CA	BS	None	0	0	23	CSP, CIH
O3	AL	BS	None	0	0	45	SE
S1	WA	PhD	Assist. Prof.	10	0	6	LEED AP, CSP, CRIS
S2	MO	BS	None	0	0	15	LEED AP
S3	VA	BS	None	0	0	35	PE

Within the first Delphi survey, shown in Appendix E – Delphi Survey – Round 1, initial questions were asked to certify whether the participants were experts in the field of construction and construction safety. To determine if a participant was an expert, the rating system that is described by Hallowell et al. (2010), was used to rate their credentials. The point system described by the authors assigns the following points for the various credentials:

- Professional Registration → 3 points per registration
- 1 year of professional experience → 1 point per year
- Conference presentation → 0.5 point per presentation
- Member of committee → 1 point per committee
- Chair of committee → 3 points per committee
- Peer-reviewed journal article → 2 points per article
- Faculty member at an accredited university → 3 points
- Writer/editor of book → 4 points per book
- Writer of a book chapter → 2 points per book
- BS degree → 4 points per degree
- MS degree → 2 points per degree
- PhD degree → 4 points per degree

Table 2-2: Panel Expert Scores to determine Qualification for Delphi Panel

		Prof. Registr.	Years of Exp.	Conf. Present.	Memb. Comm.	Chair Comm.	Journal Articles	Faculty Member	Book author/editor	Author book chapter	BS degree	MS degree	PhD degree	Total Points
	Points per item	3	1	0.5	1	3	2	3	4	2	4	2	4	
A1	Exp	3	16	0	0	0	0	0	0	0	1	0	0	29
	Points	9	16	0	0	0	0	0	0	0	4	0	0	
A2	Exp	1	24	0	0	0	0	0	0	0	1	0	0	31
	Points	3	24	0	0	0	0	0	0	0	4	0	0	
A3	Exp	1	8	0	0	0	0	0	0	0	1	1	0	17
	Points	3	8	0	0	0	0	0	0	0	4	2	0	
E1	Exp	1	30	0	0	0	0	0	0	0	1	0	0	37
	Points	3	30	0	0	0	0	0	0	0	4	0	0	
E2	Exp	2	31	0	4	1	21	0	3	0	1	2	0	106
	Points	6	31	0	4	3	42	0	12	0	4	4	0	
C1	Exp	0	31	0	0	0	0	0	0	0	1	0	0	35
	Points	0	31	0	0	0	0	0	0	0	4	0	0	
C2	Exp	1	30	0	0	0	0	0	0	0	1	0	0	37
	Points	3	30	0	0	0	0	0	0	0	4	0	0	
C3	Exp	2	20	0	1	1	0	0	0	0	1	1	0	36
	Points	6	20	0	1	3	0	0	0	0	4	2	0	
C4	Exp	1	35	0	0	2	0	0	0	0	1	0	0	48
	Points	3	35	0	0	6	0	0	0	0	4	0	0	
C5	Exp	2	27	0	0	1	0	0	0	0	1	0	0	40
	Points	6	27	0	0	3	0	0	0	0	4	0	0	
C6	Exp	1	36	0	0	0	0	0	0	0	1	3	0	49
	Points	3	36	0	0	0	0	0	0	0	4	6	0	
O1	Exp	2	5	0	4	3	0	0	0	0	1	0	0	28
	Points	6	5	0	4	9	0	0	0	0	4	0	0	
O2	Exp	2	23	0	1	0	0	0	0	0	1	1	0	36
	Points	6	23	0	1	0	0	0	0	0	4	2	0	
O3	Exp	1	45	3	2	0	0	0	0	0	1	0	0	55.5
	Points	3	45	1.5	2	0	0	0	0	0	4	0	0	
S1	Exp	3	6	5	0	0	10	1	0	0	1	1	1	50.5
	Points	9	6	2.5	0	0	20	3	0	0	4	2	4	
S2	Exp	1	15	0	1	2	0	0	0	0	1	0	0	29
	Points	3	15	0	1	6	0	0	0	0	4	0	0	
S3	Exp	1	35	0	2	0	0	0	0	0	1	0	0	44
	Points	3	35	0	2	0	0	0	0	0	4	0	0	

The authors suggest that panelists should score at least one point in four different credentials and have a minimum of 11 total points for them to qualify for the panel. The points associated with each panel member are shown in Table 2-2. As observed, all the panelists satisfy the minimum score of 11 that is suggested by Hallowell et al. (2010). The second requirement that the panelists should score points in at least four different credential categories is not satisfied. This occurs for panelists A1, A2, E1, and C1. These panelists have extensive experience in the construction industry, and as a result it is in this author's belief that the requirement of four categories can be relaxed for these individuals.

2.5 Results

The Delphi panel was asked to participate in three rounds of surveys. The results of the surveys are presented in this section.

2.5.1 Delphi Round 1

2.5.1.1 Delphi Round 1 - Questions

The first survey aimed at gathering information about the potential panel members in order to validate them as experts to continue with the Delphi process. The survey is shown in Appendix E – Delphi Survey – Round 1. It was conducted using the online survey software "Limesurvey" that is administered by the College of Engineering at Oregon State University. The participants were asked to state their position towards the implementation of DCWS in terms of extent of implementation and method of implementation. The survey continued by asking the participants to state the methods with which interest in DCWS can be generated.

Four methods were stated in the survey and these were: 1) Business Case, 2) Education, 3) Legislation and 4) Industry Standards. Panel participants were also asked to provide additional methods with which to generate interest for DCWS.

The Business Case was described in the survey as follows: *To increase acceptance and interest in DCWS there is a need for the development of a "Business case" model, where investment in DCWS generates a reasonable return in the form of profit, reduction in losses, and cost avoidance*.

The Education method was described as follows: *To increase acceptance and interest in DCWS there is a need for increased education of practicing design professionals, owners, contractors,* *as well as university students enrolled in Design, Engineering, Architecture and Construction programs*.

The Legislation method was described as follows: *The implementation of DCWS in the US should be achieved by the use of legislation at the Federal or State level*.

The Industry Standards method was described as follows: *The implementation of DCWS in the US should be achieved by the development of an industry standard much like quality standards such as ISO 9001 for quality management*.

The survey continued by asking the participants to rate the level of influence construction industry groups have in generating interest in DCWS on a scale of 1 to 10, where 1 indicates the least influence and 10 represents the highest influence. The groups that were to be rated were: Contractors, Owners, Designers (Engineers), Designers (Architects), Politicians – Legislations, Insurance Companies, Trade Organizations, Labor Organizations, and Educators. Panel participants were also asked to explain their answers for their ratings.

The panel members were finally asked to rate the extent to which the construction industry groups should be targeted for the methods they identified previously on a scale of 1 to 10. A value of 1 indicates that the industry group should not be targeted, and a value of 10 indicates that the groups should definitely be targeted.

2.5.1.2 Delphi Round 1 – Results

An analysis of the responses collected in the first Delphi survey is shown in this section of the manuscript. All seventeen panelists responded in the first round of the Delphi.

When the panel members were asked if DCWS should be implemented widely in the US construction industry, 13 of the responders (76.5%) stated that DCWS should be implemented to the full extent, while 4 of them (23.5%) stated that it should be implemented with some limitations. None of the responders stated that DCWS should not be implemented.

In regards to the question of the method with which DCWS should be implemented, 8 of the participants (47.1%) stated that it should be implemented voluntarily, and another 8 stated that it should be implemented through certifications much like LEED. Only one participant stated that DCWS should be implemented through some form of legislation.

The panelists' answers to the above 2 questions, reveal that they are very much interested in DCWS being implemented in the US construction industry.

When asked to state the area of concentration to generate interest for DCWS in the US construction industry, the responses of the panel showed some variation. The answers are summarized in Table 2-3. As observed in the table, the majority of the responses (n=15, 88.2%) stated that the business case should be a method for generating interest for DCWS, followed by 11 (64.7%) for education method, and by 9 (52.9%) for industry standards. Only one panel participant stated that Legislation should be a method of generating interest for DCWS. The panel participants did not state any additional methods for generating interest.

Table 2-3: Responses for Method to Generate DCWS interest – Delphi Round 1

Method of generating interest	Number of responses	% of responses
Business Case	15	88.2
Education	11	64.7
Legislation	1	5.9
Industry Standards	9	52.9

For the question concerning the amount of influence construction groups have on generating interest for DCWS the responses are summarized in Figure 2-2 and in Table 2-4. In Figure 2-2, the graph depicts the spread of the panel answers through box plots. The diamonds in the figure mark the median values, while the boxes mark the 25th and 75th percentile values. The whiskers in the plot mark the minimum and maximum values.

As observed, the panelists believe with a median of 10 that the owners have the greatest power to generate interest for DCWS. The owners also had the least amount of spread concerning that influence with a minimum of 5 and a maximum of 10. All the other groups had a median value lower than 10 and a spread greater than the values of the owner group. The influence of legislators was seen to have the lowest influence with a median value of 3.

Table 2-4: Summary of Responses Concerning Influence for Generating Interest in DCWS – Delphi Round 1

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	8.0	10.0	8.0	7.0	3.0	8.0	7.0	6.0	6.0
Min	4.0	5.0	2.0	2.0	1.0	1.0	3.0	1.0	1.0
Max	10.0	10.0	10.0	10.0	10.0	10.0	9.0	9.0	10.0

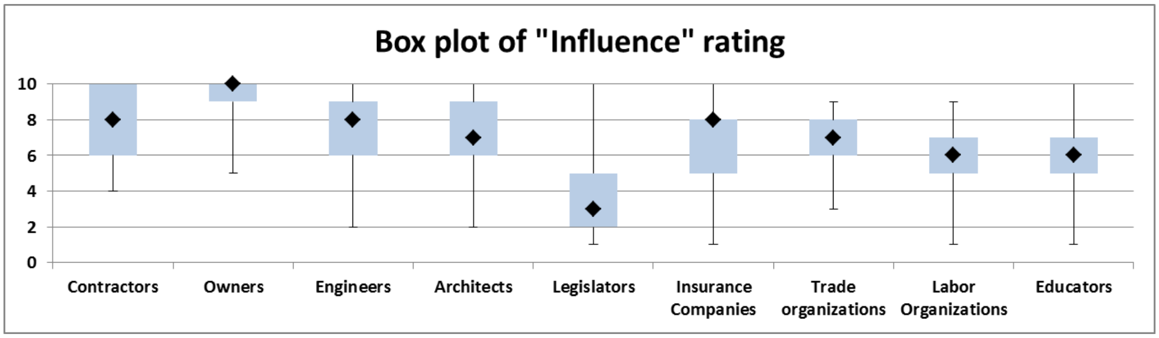

Figure 2-2: Distribution of Responses Concerning Influence for Generating Interest in DCWS – Delphi Round 1

In regards to the question concerning the business case, the responses of the 15 participants who stated this method should be an option for generating interest in DCWS and industry groups should be targeted to generate that interest, are summarized in Figure 2-3 and in Table 2-5. As observed, the panelists believe with a median of 10 that the owners and the contractors should be targeted with this method in order to generate interest in DCWS. The owners also had the least amount of spread concerning the business case with a minimum of 8 and a maximum of 10. All the other groups had a median value lower than 10 and a spread greater that the values of the owner group. Once again the legislator group had the lowest median value with 2.

Table 2-5: Summary of Responses Concerning Business Case – Delphi Round 1

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	10.0	10.0	7.0	8.0	2.0	8.0	7.0	6.0	6.0
Min	4.0	8.0	4.0	4.0	1.0	2.0	2.0	1.0	2.0
Max	10.0	10.0	10.0	10.0	7.0	10.0	10.0	10.0	10.0

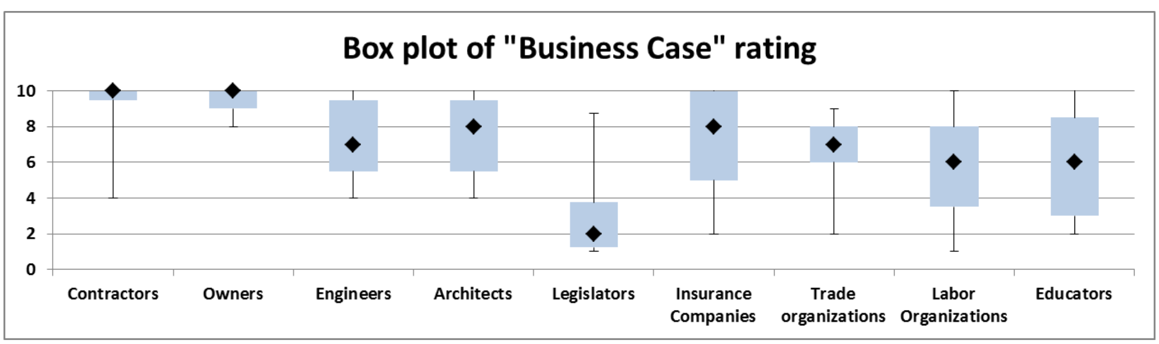

Figure 2-3: Distribution of Responses Concerning Business Case – Delphi Round 1

For the question concerning education, the responses of the 11 participants who stated this method to be an option for generating interest in DCWS and industry groups should be targeted to generate that interest, are summarized in Figure 2-4 and in Table 2-6. The panelists believe with a median of 10 the owners and contractors should be targeted with this method in order to generate interest in DCWS. All the other groups had a median value lower than 10. The educators had a median value of 9.5, while two other groups had a median value of 9; architects and engineers. Once again the legislator group had the lowest median value with 2.5.

Table 2-6: Summary of Responses Concerning Education – Delphi Round 1

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	10.0	10.0	9.0	9.0	2.5	8.5	8.0	7.0	9.5
Min	6.0	5.0	6.0	6.0	1.0	1.0	1.0	4.0	3.0
Max	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

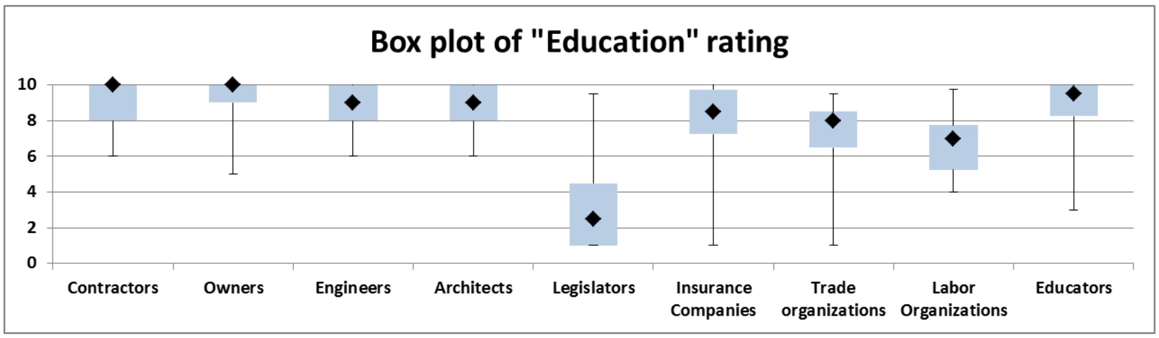

Figure 2-4: Distribution of Responses Concerning Education – Delphi Round 1

For the question concerning the industry standards, the responses of the 9 participants who stated this method to be an option for generating interest in DCWS and industry groups should be targeted to generate that interest, are summarized in Figure 2-5 and in Table 2-7. The panelists believe once again with a median of 10 that the owners have the greatest power to generate interest for DCWS with industry standards. This time the owners had a great spread of responses ranging from 2 to 10. All the other groups had a median value lower than 10. The influence of legislators was seen to have the lowest influence with a median value of 3.

Table 2-7: Summary of Responses Concerning Industry Standards – Delphi Round 1

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	9.5	10.0	9.0	9.0	3.0	9.0	8.5	7.0	8.0
Min	7.0	2.0	2.0	2.0	1.0	6.0	5.0	2.0	3.0
Max	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

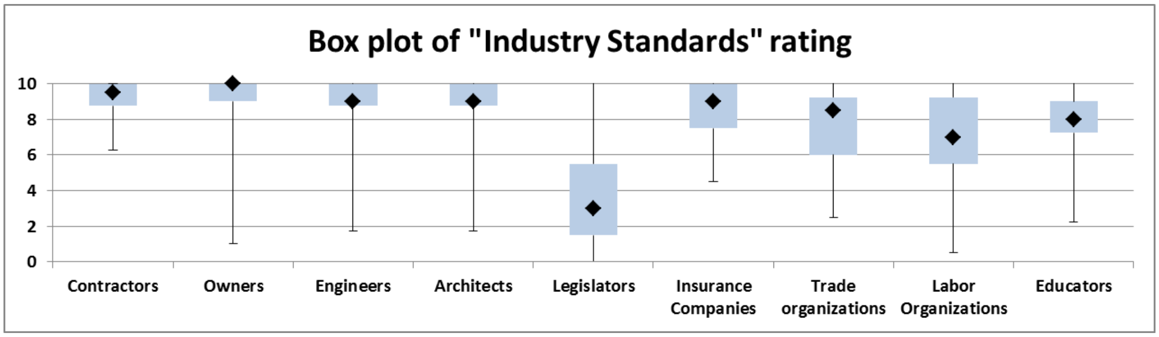

Figure 2-5: Distribution of Responses Concerning Industry Standards – Delphi Round 1

The results of the legislation option are not shown since only one of the panel participants stated that this was a method to generate interest in DCWS.

2.5.1.3 Delphi Round 1 – Analysis

In order to identify the group that should be targeted along with the method, the author used a weighted rating calculated as the product between the median response values of the influence of the group and the target method for each group. The results of these products are shown in Table 2-8. The last three columns of the table are shaded with various shades of red. The cells with the highest value have a darker shade of red. As observed, the combination of influence and method produced the highest values for the owner group in all three methods. The second highest values in all three methods were obtained for the contractor group. The legislator group had the lowest value for all three methods.

Table 2-8: Results of Influence X Target Method

	Influence	Method			Influence * Method		
		Business Case	Education	Industry Standards	Business Case	Education	Industry Standards
Contractors	8.0	10.0	10.0	9.5	80.0	80.0	76.0
Owners	10.0	10.0	10.0	10.0	100.0	100.0	100.0
Engineers	8.0	7.0	9.0	9.0	56.0	72.0	72.0
Architects	7.0	8.0	9.0	9.0	56.0	63.0	63.0
Legislators	3.0	2.0	2.5	3.0	6.0	7.5	9.0
Insurance Companies	8.0	8.0	8.5	9.0	64.0	68.0	72.0
Trade organizations	7.0	7.0	8.0	8.5	49.0	56.0	59.5
Labor Organizations	6.0	6.0	7.0	7.0	36.0	42.0	42.0
Educators	6.0	6.0	9.5	8.0	36.0	57.0	48.0

To determine whether the scores provided by the panel members for the influence and the target methods were similar in nature, the Kendal coefficient of concordance was used as described in the text by Siegel et al. (1988). This test determines whether there is a degree of association between several variables measured, in this case the various scores for the influence and the target methods for each industry group. The Kendal coefficient of concordance was only calculated for the influence rating and the business case method.

The coefficient of concordance is calculated using the following equation:

Equation 2-1

$$W = \frac{12\sum \bar{R}_i^2 - 3k^2N(N+1)^2}{k^2N(N^2-1) - k\sum T_j}$$

Where,

- k= number of sets of scores, i.e. the number of panel members providing their score
- N= number of items being scored, i.e., the industry groups. In this case there were 9 industry groups.
- $\bar{R}_i$ = the average of the rank assigned to the i^{th} item being ranked

Since the panel members could assign the same influence and target value to multiple industry groups, it was necessary to account for ties in the scores with the terms T_j, the correction factor for ties.

Equation 2-2

$$T_j = \sum_{i-1}^{g_j} \left(t_i^3 - t_i\right)$$

Where,

- t_i= is the number of tied scores in the i^{th} grouping of ties
- g_j= is the number of groups of ties in the j^{th} set of scores

After calculating the coefficient of concordance, a X^2 value can be generated using the following equation:

Equation 2-3

$$X^2 = k(N-1)W$$

The degrees of freedom associated with the above X^2 value is N-1, and with these two values, a probability can be calculate for the concordance of the items being scored.

The value of concordance for the influence values was 0.34, leading to a X^2 value of 45.53 and a p-value ~0. This small p-value suggests that *"with considerable confidence we can conclude that the agreement of the **17** respondents is higher than it would be by chance had the rankings been random or independent".* The very low probability under the hypothesis associated with the observed value of W enables us to reject the null hypothesis that the respondents' scores are unrelated to each other and conclude that there is good consensus among members concerning the influence each group has on promoting DCWS.

The value of concordance for the business case was 0.23, and with a X^2 value of 27.39 the p-value was 0.0006. Once again the p-value was very small and suggests that *"with considerable confidence we can conclude that the agreement of the **15** respondents is higher than it would be by chance had the rankings been random or independent".* The very low probability under the hypothesis associated with the observed value of W enables us to reject the null hypothesis that the respondents' scores are unrelated to each other and conclude that there is good consensus among members concerning the business case being a targeted method for each group.

The results of the first round did not reach a consensus regarding the method with which to generate interest in DCWS. Of the methods suggested to the Delphi panel, the business case showed the greatest support as a method to generate interest, with 15 of the 17 panel members choosing it. Consequently it was necessary to perform another round of survey to investigate whether all the panel participants would choose the business case.

2.5.2 Delphi Round 2

The second Delphi panel survey attempted to reach a consensus regarding the method with which to generate interest in DCWS, the target group for generating that interest, as well as identify the industry group that had the greatest influence in generating interest for DCWS.

2.5.2.1 Delphi Round 2 - Questions

The second survey presented the results of the first survey to the panel participants and gave them the option to change their answers if they wanted to. The survey is shown in Appendix F – Delphi Survey – Round 2. Each individual panel member received a unique survey in a MSWord document that depicted their answers and the summary of the answers of the panel. The panel members were asked to complete the survey and return it to the author.

The first question showed the panel the results of the question asked on the first survey regarding the methods with which interest can be generated. The panelists were asked to change their answer if they wished to do so. The four methods were once again, the business case, education, legislation, and industry standards. The panel members were then presented with their answers from the panel and the median answers for the ratings for influence and the methods of generating interest from the first round.

Because it was clear that the business case was chosen by the majority of the panel members, the survey continued by asking the panel participants to list the costs and benefits for practicing DCWS from the viewpoint of the major four construction industry participants: owners, architects, engineers, and contractors.

Monetary costs were defined for the panel members as *“additional costs to the construction industry stakeholder for practicing DCWS, such as increased insurance fees, design fees, construction costs, etc.”.*

Monetary benefits were defined as “*benefits to the construction industry stakeholder for practicing DCWS, such as decreased construction costs, savings due to innovations, etc.”.*

Non-monetary costs and benefits were defined as *“items that do not have a monetary value but can have an effect on the operations of the construction industry stakeholder who practices DCWS. Such costs/benefits could be increased market share, decreased competitiveness, etc.”*.

All the responses were once again gathered and summarized.

2.5.2.2 Delphi Round 2 – Results

An analysis of the responses collected in the second Delphi survey is shown in this section of the manuscript. Thirteen of the panel members submitted a response in this round. The panelists who did not respond were Owner 1 (O1), Owner 2 (O2), Architect 3 (A3) and Contractor 1 (C1).

Some of the panel members changed their answers regarding the area of concentration for DCWS. These answers are shown in Table 2-9. As observed, all panel members chose the business case as a method of generating interest for DCWS. The panel member who chose legislation decided to reject that answer and chose the business case instead. The number of panel members who chose industry standards increased by 1 to a total of 10.

Table 2-9: Responses for Method to Generate DCWS interest – Delphi Round 2

Method of generating interest	Number of responses Round 1	Number of responses Round 2	% of responses Round 2
Business Case	15	17	100%
Education	11	11	64.7%
Legislation	1	0	0%
Industry Standards	9	10	58.8%

In the question concerning the amount of influence construction groups have on generating interest in DCWS the responses are summarized in Figure 2-6 and Table 2-10. In Figure 2-6, as shown for the first Delphi survey, the box plots depict the range of the responses and the median value. When compared to Figure 2-2, the range of values for the influence has decreased for the majority of the industry groups and that is observed by the reduced size of the "box" in the box plots. The owners were seen again to have the highest value of influence with a median of 10. The range of the influence values for the owners was between 8 and 10. Three groups had influence with value of 8: contractors, engineers and insurance companies. Legislators were identified as having the lowest influence with a value of 3.

Table 2-10: Summary of Responses Concerning Influence for Generating Interest in DCWS – Delphi Round 2

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	8.0	10.0	8.0	7.0	3.0	8.0	7.0	6.0	6.0
Min	4.0	8.0	2.0	2.0	1.0	1.0	4.0	2.0	1.0
Max	10.0	10.0	10.0	10.0	8.0	10.0	8.0	8.0	10.0

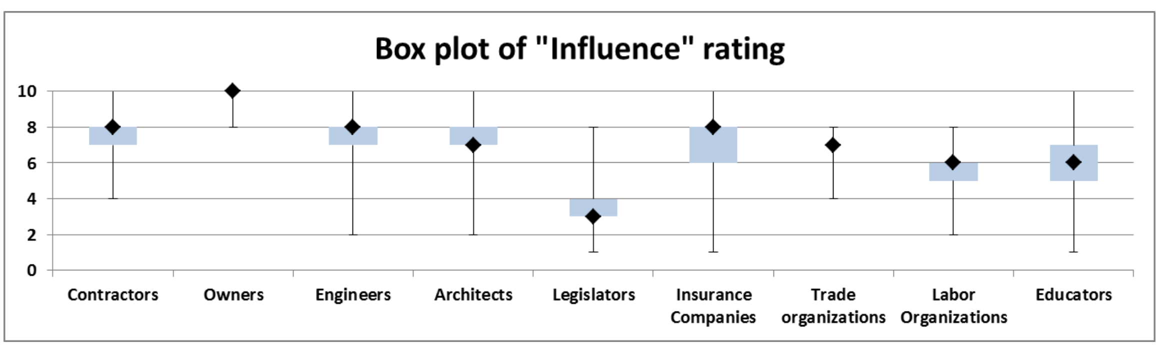

Figure 2-6: Distribution of Responses Concerning Influence for Generating Interest in DCWS – Delphi Round 2

In regards to the question concerning the business case, the responses of the 17 participants who stated this method to be an option for generating interest in DCWS and industry groups should be targeted to generate that interest, are summarized in Figure 2-7 and in Table 2-11. In Figure 2-7, the graph once again depicts the spread of the panel answers through box plots.

As observed, the panelists believe with a median of 10 that the owners and the contractors should be targeted with this method in order to generate interest in DCWS. The owners also had the least amount of spread concerning the business case with a minimum of 7 and a maximum of 10. All the other groups had a median value lower than 10 and a spread greater that the values of the owner group. Once again the Legislator group had the lowest median value with 2.

Table 2-11: Summary of Responses Concerning Business Case – Delphi Round 2

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	10.0	10.0	7.0	8.0	2.0	8.0	7.0	6.0	6.0
Min	4.0	7.0	4.0	4.0	1.0	2.0	2.0	1.0	2.0
Max	10.0	10.0	10.0	10.0	7.0	10.0	10.0	10.0	10.0

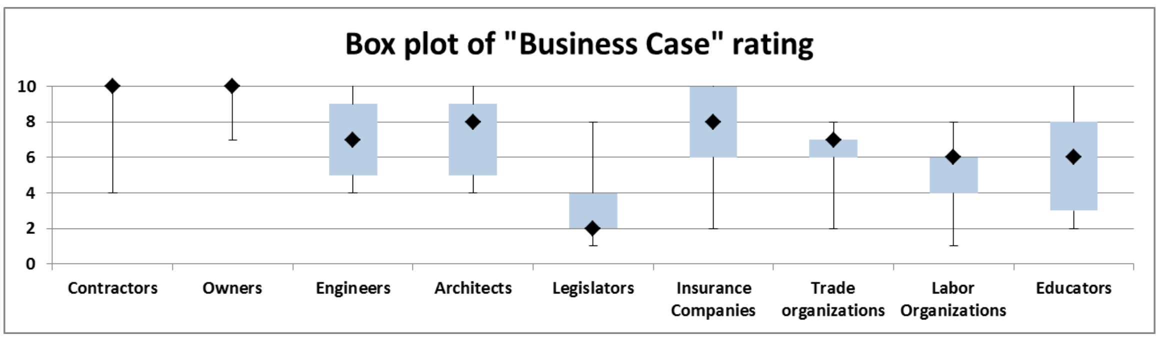

Figure 2-7: Distribution of Responses Concerning Business Case – Delphi Round 2

For the question concerning education, the responses of the 11 participants who stated this method should be an option for generating interest in DCWS and the industry groups who should be targeted to generate that interest, are summarized in Figure 2-8 and in Table 2-12.

Table 2-12: Summary of Responses Concerning Education – Delphi Round 2

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	10.0	10.0	9.0	9.0	1.5	8.5	8.0	7.0	9.5
Min	6.0	8.0	8.0	8.0	1.0	1.0	1.0	4.0	5.0
Max	10.0	10.0	10.0	10.0	5.0	10.0	9.0	9.0	10.0

The panelists believe with a median of 10 that the owners and contractors should be targeted with this method in order to generate interest in DCWS. All the other groups had a median value lower than 10. The educators had a median value of 9.5, while two other groups had a median value of 9: architects and engineers. Once again the legislator group had the lowest median value with 1.5.

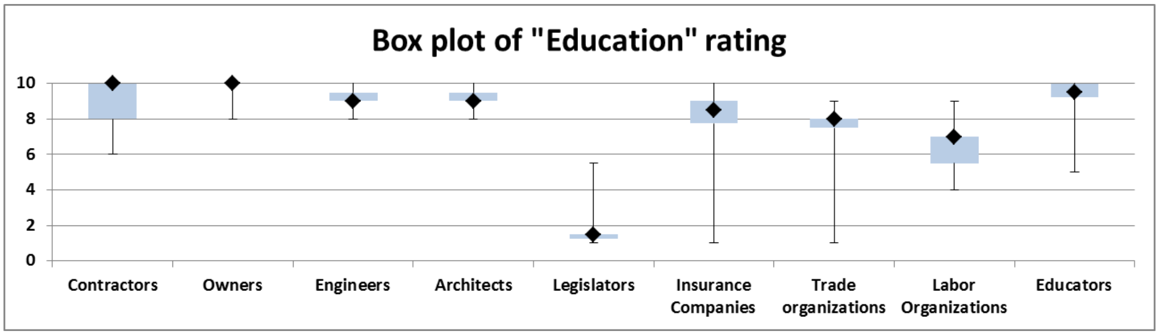

Figure 2-8: Distribution of Responses Concerning Education – Delphi Round 2

In regards to the question concerning the industry standards, the responses of the 10 participants who stated this method to be an option for generating interest in DCWS and the industry groups who should be targeted to generate that interest, are summarized in Figure 2-9 and in Table 2-13.

The panelists believe once again with a median of 10 that the owners have the greatest power to generate interest in DCWS with industry standards. In the second round they also gave a value of 10 to the contractors. This time the owners had once again a great spread of responses, ranging from 2 to 10. All the other groups had a median value lower than 10. The influence of legislators was seen to have the lowest influence with a median value of 3.

The results of the legislation option are not shown since none of the panelists chose that option in the second round.

The final questions of the survey asked the panel participants to list items that would be included in a cost/benefit analysis for implementing DCWS. The panel members were asked to list costs and benefits from the viewpoints of the owners, designers, and contractors, and consider both monetary and non-monetary costs and benefits. These items will be used as line items in a cost/benefit analysis.

A consolidated list of the panelist responses is provided below. A more extensive list is shown in Appendix H – Identified Costs and Benefits.

Table 2-13: Summary of Responses Concerning Industry Standards – Delphi Round 2

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	10.0	10.0	9.0	9.0	3.0	9.0	8.5	8.0	8.0
Min	7.0	2.0	2.0	2.0	1.0	6.0	6.0	2.0	8.0
Max	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

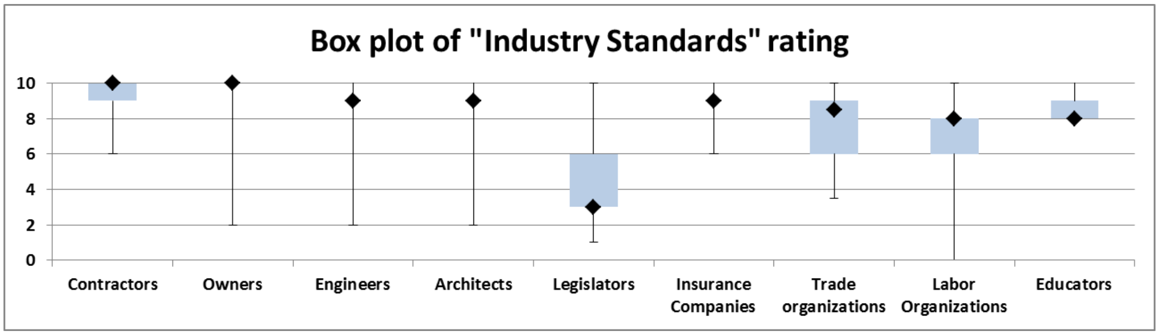

Figure 2-9: Distribution of Responses Concerning Industry Standards – Delphi Round 2

2.5.2.2.1 Engineer Costs & Benefits

Monetary Costs

A. Costs to design
B. Cost associated with hiring new employees that would be used to implement DCWS
C. Cost for coordinating with all other parties (Owner, Architect, Contractor, Subcontractors)
D. Cost associated with training
E. Cost associated with implementing the DCWS plan.
F. Cost associated with changes in contract documents
G. Costs associated with insurance/litigation/risk

Monetary Benefits

A. Benefits associated with decreased insurance costs
B. Benefits from reduced post design involvement (RFI and change orders)
C. Reduced potential for litigation

Non-monetary Costs

A. Increased Liability

Non-monetary Benefits

A. Market Specialization advantage(Niche Market)
B. Marketing advantage
C. Market differentiation
D. Reputation improvement

E. Improved relationships with industry participants (owners, contractors)
F. Ethical/Moral benefits
G. Potential for repeat business
H. Gained knowledge from understanding how things are build and construction safety knowledge
I. Improved Quality of construction documents

2.5.2.2.2 Architect Costs & Benefits

Monetary Costs

A. Costs to design
B. Cost associated with hiring new employees that would be used to implement DCWS
C. Cost for coordinating with all other parties (Owner, Architect, Contractor, Subcontractors)
D. Cost associated with training
E. Cost associated with implementing the DCWS plan.
F. Cost associated with changes in contract documents
G. Costs associated with insurance/litigation/risk

Monetary Benefits

A. Benefits associated with decreased insurance costs
B. Benefits from reduced post design involvement (RFI and change orders)
C. Reduced potential for litigation

Non-monetary Costs

A. Increased Liability

Non-monetary Benefits

A. Market Specialization advantage(Niche Market)
B. Marketing advantage
C. Market differentiation
D. Reputation improvement
E. Improved relationships with industry participants (owners, contractors)
F. Ethical/Moral benefits
G. Potential for repeat business
H. Gained knowledge from understanding how things are build and construction safety knowledge
I. Improved Quality of construction documents

2.5.2.2.3 Owner Costs & Benefits

Monetary Costs

A. Project Costs (Design, Construction, Cost tracking)
B. Cost associated with hiring new employees that would be used to implement DCWS
C. Training Costs
D. Time Requirements
E. Construction
F. RFI – Change Orders

Monetary Benefits

A. Insurance Cost reductions
B. Construction Costs (This also appeared in costs)
C. Construction Schedule
D. Organization
E. Project Life Cycle
F. Quality
G. RFI- Change orders (This also appeared in costs)
H. Litigations

Non-monetary Costs

A. Personal time and energy spent changing the momentum of the current owner / designer / contractor relationship model to one that would be more open to DCWS
B. Reduced competitiveness
C. Liability discrepancies
D. Increased complexity of contracts

Non-monetary Benefits

A. Safety
B. Efficiency
C. Image – Competitiveness
D. Sustainability
E. Workforce
F. Increased morale for construction crews and plant workers
G. Relationships

2.5.2.2.4 Contractor Costs & Benefits

Monetary Costs

A. Construction costs
B. Design costs (in cases of Design-Build)
C. Cost of hiring new employees
D. Cost of increased initial involvement
E. Possibility for increased project schedule
F. Possibility for increased change orders
G. Increased cost for coordination

H. Increased liability risk
I. Education & Training
J. Possible impact on schedule

Monetary Benefits

A. Insurance
B. Schedule
C. Productivity
D. Labor
E. Benefits from reduced post design involvement
F. Savings in maintenance costs
G. Safety

Non-monetary Costs

A. Reduced competitiveness
B. Possibility for increased conflict between project participants
C. There is a need to rework scope and contract issues with subcontractors

Non-monetary Benefits

A. Improved relationships
B. Potential for repeat business
C. Possibility for a niche market
D. Marketing opportunities
E. Increase competitive advantage
F. Improved reputation
G. Ethical/Moral benefits
H. Increased morale
I. Better understand designs through improved communication
J. Retention of employees
K. Attract high-caliber new hires

2.5.2.3 Delphi Round 2 – Analysis

An analysis of the influence and methods of generating interest scores was perform after round 2 similar to the analysis shown in section 2.5.1.3. The product between the median of the panelists' responses for the influence of the various group and the target methods is shown in Table 2-14. As observed, the product between the influence and method was again highest for the owners in all three methods analyzed. The second highest values were observed for the contractors in all three methods. The legislator group had the lowest value for all three methods once again.

Table 2-14: Results of Influence X Target Method

	Influence	Method			Influence * Method		
		Business Case	Education	Industry Standards	Business Case	Education	Industry Standards
Contractors	8.0	10.0	10.0	10.0	80.0	80.0	80.0
Owners	10.0	10.0	10.0	10.0	100.0	100.0	100.0
Engineers	8.0	7.0	9.0	9.0	56.0	72.0	72.0
Architects	7.0	8.0	9.0	9.0	56.0	63.0	63.0
Legislators	3.0	2.0	1.5	3.0	6.0	4.5	9.0
Insurance Companies	8.0	8.0	8.5	9.0	64.0	68.0	72.0
Trade organizations	7.0	7.0	8.0	8.5	49.0	56.0	59.5
Labor Organizations	6.0	6.0	7.0	8.0	36.0	42.0	48.0
Educators	6.0	6.0	9.5	8.0	36.0	57.0	48.0

The Kendal Coefficient of Concordance was calculated for the influence and the business case method in the same way that was performed after the first survey.

The value of concordance for the influence values was 0.57, leading to a X^2 value of 77.993 and a p-value ~0. This small p-value suggests that *"with considerable confidence we can conclude that the agreement of the **17** respondents is higher than it would be by chance had the rankings been random or independent".* The very low probability under the hypothesis associated with the observed value of W enables us to reject the null hypothesis that the respondents' scores are unrelated to each other and conclude that there is good consensus among members concerning the influence each group has on promoting DCWS.

The value of concordance for the business case was 0.57, and with a X^2 value of 77.55 the p-value was ~0. Once again the p-value was very small and it suggests that *"with considerable confidence we can conclude that the agreement of the **17** respondents is higher than it would be by chance had the rankings been random or independent".* The very low probability under the hypothesis associated with the observed value of W enables us to reject the null hypothesis that the respondents' scores are unrelated to each other and conclude that there is good consensus among members concerning the business case being a targeted method for each group.

The results of the second round reached a consensus regarding the method with which to generate interest in DCWS. The business case showed total support from all the Delphi panel members. In addition the influence rating was the highest for the owners, with a median value of 10 and a range between 8 and 10 making it clear that owners have the greatest influence from all construction industry groups. Within the scores for the business case, the owners and contractors had the greatest median with a value of 10, but the owner group had the least amount of spread in scores, from 7 to 10.

2.5.3 Delphi Round 3

The third round of the Delphi survey attempted to figure out if the line items for the business case model identified in round 2 could be applied to multiple projects or for just one project.

2.5.3.1 Delphi Round 3 - Questions

The third round of the Delphi process was administered using the “Limesurvey” software. The panel members received the link and were asked to complete the survey questions online. A copy of the survey is included in Appendix G – Delphi Survey – Round 3.

With the introduction of the survey, the participants were presented with the results of the previous rounds in the form of “box plots” and the median, minimum, and maximum values for the influence and the three methods for generating interest.

The panel participants were then presented with the list of items that was consolidated after the second round and were asked to identify if the line items could be applied to a single project or to multiple projects (i.e., across projects). This distinction between single and multiple projects would have allowed the generation of a benefit/cost model that compares between alternatives using a method similar to money-time relationships for the distribution of the costs and benefits over the lifecycle of a firm of organization. The participants were once again given the option of adding more line items to be considered in a cost/benefit analysis.

All the responses were once again gathered and summarized, and the results are shown in the following section

2.5.3.2 Delphi Round 3 – Results

Fourteen of the participants responded in the last round of the Delphi panel survey, and their responses are summarized below in Table 2-15, Table 2-16, Table 2-17, Table 2-18, Table 2-19, Table 2-20, Table 2-21, and Table 2-22. Highlighted are the line items for which the panel members who responded unanimously reached consensus. The “One” label on the tables refers to a line item being considered for a single project, while the “Multiple” label refers to a line item being considered for multiple projects.

Table 2-15: Distribution of Responses for Line Items Involving Design

Design	One	Multiple	One %	Mult. %
Additional costs (excluding time) to design DCWS solutions.	5	9	35.7	64.3
Cost of additional time to design DCWS solutions.	5	9	35.7	64.3
Cost of coordination between Owner/Designers/Contractors.	11	3	78.6	21.4
Cost of coordination among designers working in a particular firm	5	9	35.7	64.3

Table 2-16: Distribution of Responses for Line Items Involving Personnel

Personnel	One	Multiple	One %	Mult. %
Cost of hiring of additional employees to implement DCWS by DESIGNERS.	2	12	14.3	85.7
Cost of hiring external personnel to facilitate implementation of DCWS by DESIGNERS.	5	9	35.7	64.3
Cost of training of existing employees in office and on-site for DESIGNERS.	1	13	7.1	92.9
Cost of hiring of additional employees to implement DCWS by OWNERS.	5	9	35.7	64.3
Cost of hiring external personnel to facilitate implementation of DCWS by OWNERS.	6	8	42.9	57.1
Cost of training of existing employees in office and on-site for OWNERS.	5	9	35.7	64.3
Cost of hiring of additional employees to implement DCWS by CONTRACTORS.	3	11	21.4	78.6
Cost of hiring external personnel to facilitate implementation of DCWS by CONTRACTORS.	6	8	42.9	57.1
Cost of training of existing employees in office and on-site for CONTRACTORS.	3	11	21.4	78.6
Possible reduction of cost from training and replacing injured workers.	3	11	21.4	78.6
Increased morale for construction crews and plant workers.	3	11	21.4	78.6
Retention of employees.	1	12	7.7	92.3
Attraction of higher caliber employees	0	14	0.0	100.0

Table 2-17: Distribution of Responses for Line Items Involving Construction

Construction	One	Multiple	One %	Mult. %
Coordination costs for CONTRACTORS relating DCWS.	7	7	50.0	50.0
Increase/Decrease of construction costs related to DCWS solutions.	9	5	64.3	35.7
Cost of submitting and managing RFI by CONTRACTORS.	13	1	92.9	7.1
Cost of responding to RFI by DESIGNERS and OWNERS.	13	1	92.9	7.1
Possible reduction of RFI requests.	10	4	71.4	28.6
Possible reduction of Change Orders.	10	4	71.4	28.6
On-site presence requirements (meetings, supervision, etc.) by OWNERS.	11	3	78.6	21.4
On-site presence requirements (meetings, supervision, etc.) by DESIGNERS.	11	3	78.6	21.4
Cost/Benefit from possible increase/decrease of field labor by CONTRACTORS.	9	5	64.3	35.7
Cost/Benefit from the reduction/increase of safety equipment needs.	7	7	50.0	50.0
Possible reduction of missed work by CONSTRUCTION CREWS from injuries.	3	10	23.1	76.9
Cost/Benefit from possible increase/decrease of construction schedule.	11	3	78.6	21.4
Better/Worse understanding of designs by CONTRACTORS.	9	5	64.3	35.7
Improved/Worsen Constructability.	7	7	50.0	50.0

Table 2-18: Distribution of Responses for Line Items Involving Management Issues

Management	One	Multiple	One %	Mult. %
Cost of managing a DCWS plan.	5	9	35.7	64.3
Cost of setting up a quality assurance program.	3	11	21.4	78.6
Cost of additional quality assurance requirements.	3	11	21.4	78.6
Labor and cost for tracking metrics to assemble case histories for DCWS solutions.	2	12	14.3	85.7
Cost of time and energy spent in changing the momentum of the current owner/designer/contractor relationship model to one that would be more open to DCWS.	4	10	28.6	71.4
Possibility for increased conflict among project participants.	7	7	50.0	50.0
Increase/Decrease in understanding of construction site operations and processes.	5	9	35.7	64.3

Table 2-19: Distribution of Responses for Line Items Involving Post-Construction

Post-Construction	One	Multiple	One %	Mult. %
Possible reduced/increased maintenance/operation costs.	5	9	35.7	64.3
Possible increase/decrease life cycle of capital assets.	4	10	28.6	71.4
Potential for a better/worse quality project.	9	5	64.3	35.7
Possible increase/decrease in sustainability of final capital assets.	6	7	46.2	53.8

Table 2-20: Distribution of Responses for Line Items Involving Marketability

Market	One	Multiple	One %	Mult.%
Possible reduction/increase in Marketability (for Designers).	0	14	0.0	100.0
Possible reduction/increase in Marketability (for Contractors).	0	14	0.0	100.0
Potential for repeat business (for Designers).	0	14	0.0	100.0
Potential for repeat business (for Contractors).	0	14	0.0	100.0
Potential for attraction of more mature contractors and workers.	0	14	0.0	100.0
Market specialization advantage.	0	13	0.0	100.0
Reputation improvement/Improved image to the public.	0	14	0.0	100.0
Potential for decrease/increase in competitiveness (for Designers).	0	14	0.0	100.0
Potential for decrease/increase in competitiveness (for Contractors).	1	12	7.7	92.3
Ethical and Moral Benefits/Costs.	0	14	0.0	100.0
Opportunities for innovation in construction methods and design solutions.	1	13	7.1	92.9

Table 2-21: Distribution of Responses for Line Items Involving Contracts

Contracts	One	Multiple	One %	Mult. %
Improved quality of construction documents.	4	10	28.6	71.4
Cost of making modifications to contract/construction documents.	7	7	50.0	50.0
Increased/Decreased complexity in the process of bidding/awarding/managing contracts.	6	8	42.9	57.1
Harder/Easier to assign responsibility to project issues.	7	7	50.0	50.0
Increase/Decrease in need to rework contracts with subcontractors.	8	6	57.1	42.9

Table 2-22: Distribution of Responses for Line Items Involving Insurance & Liability

Insurance & Liability	One	Multiple	One %	Mult. %
Cost of obtaining liability insurance (Error and Omissions) for designers.	3	10	23.1	76.9
Possible reduction of insurance costs (Errors and Omissions) for designers.	4	9	30.8	69.2
Possible reduction in OWNER furnished insurance costs.	6	7	46.2	53.8
Potential for reduction in Worker's Compensation.	2	12	14.3	85.7
Potential for reduction in EMR (Experience Modification Rate)	2	11	15.4	84.6
Possible Increase/Decrease in liability for Designers.	4	9	30.8	69.2
Possible Increase/Decrease in liability for Owners.	6	8	42.9	57.1

As observed from the above tables the panel participants did not reach consensus in all but a few line items, the majority of which were in the marketability section of line items. The results of this survey showed that there is not a clear distinction between the line items and whether they could be applied for only one project or on multiple projects. A different method of conducting a cost benefit analysis needed to be developed. The line items specified by the panelists are very subjective and can be dependent on a project's characteristics, making it difficult to distinguish them in such a binary method: one project and multiple projects. The development of such a method is shown in Manuscript 3.

2.6 Conclusions

Several conclusions can be developed after the three rounds of the Delphi process that was described in this manuscript. The primary objective of the Delphi process was to identify the industry group that has the most influence to generate interest in DCWS. After two rounds it was identified that owners have the greatest influence in generating interest since the panel members gave owners a median score of 10 and the spread of their answers was between 8 and 10. All the other industry groups had lower median values and the variability in the values provided by the panel members was much wider.

The second objective was to identify the method with which interest was to be generated, and that was also achieved, since all 17 of the panel members identified that the "Business case" should be the method to generate that interest. Two other methods were also identified, "Education" with 11 panel participants supporting it, and "Industry Standards" with 10 of the participants supporting it. It was very interesting to see that the "Legislation" option generated no support.

The third objective of this manuscript was to identify the group with which the "business case" was to target. The panel members concluded that owners should be targeted since they received a median score of 10, while the spread of the answers varied from 7 to 10. The contractor group was also scored with a median of 10, but the spread of the answers was from 4 to 10. With such a wide variability in answers for the contractor group, it was concluded that the owners should be the group to be targeted for the business case.

The manuscript also identified line items to be used in a business case model, from the viewpoint of the four major construction industry participants: owners, contractors, architects and engineers. These line items will be used in the development of the “Business Case Model” in Manuscript 3.

3.0 Manuscript 3 – Benefit/Cost Model for evaluating DCWS solutions

3.1 Preface

The research conducted for the first manuscript concluded that the designers, architects and engineers, view that there are economic, legal and contractual obstacles for them to practice DCWS. In addition the owner group that was surveyed also identified economic obstacles that inhibit designer participation in DCWS.

Using these results, Manuscript 2 continued with a Delphi process to identify the best course of action in order to generate interest in DCWS and which group to be targeted to generate that interest. After three rounds, the panel participating in the Delphi process identified owners to be the group with the highest influence for generating interest in DCWS. All of the panelists recognized that the business case should be a method for generating interest and that owners should be targeted with that method. The other three methods of generating interest were not chosen by all of the panel members. The panel also identified line items that should be used to create that business case model in order to compare solutions that use DCWS and traditional construction solutions.

This Manuscript will describe the development of the business case model, and examine how two DCWS solutions fared over traditional construction solutions. The test cases were evaluated with the help of professionals who were involved during the construction of these solutions, and with the use of multi-criteria analysis (MCA).

3.2 Introduction

As discussed earlier, the purpose of this manuscript is to develop a business case model to evaluate a DCWS construction solution with respect to a traditional construction solution. Since the owner group was chosen by the Delphi panel to have the greatest influence to generate interest in DCWS and to be targeted for the business case, the line items used for the model will be those identified by the Delphi panel as being of interest to owners. A comprehensive list of the items is included in Appendix H – Identified Costs and Benefits.

The line items identified cannot be compared one-to-one since they include both tangible and intangible items. The tangible items include monetary costs and benefits which can be measured in the form of a currency. Intangible items, such as marketability and improved safety, are difficult to be directly measured in the form of currency, or in any other form of tangible unit. For such a comparison to take place the model needs to incorporate some form of multi-criteria analysis (MCA).

In summary, this manuscript will:

- Identify a MCA method to use for the comparison of the various solutions
- Develop a model for comparing DCWS solutions using the MCA method
- Conduct case studies of real DCWS solutions using the model

3.3 Literature Review

A more extensive literature review of DCWS is provided in part of Manuscript 1, and an extensive literature review concerning the Delphi method is included in Manuscript 2. Manuscript 3 will not include additional material on these two topics but will only concentrate on the methodology of developing the business case model for comparing two construction solutions when considering DCWS, using a multi-criteria decision making. This section of the manuscript will investigate the various MCDM methods and provide reasoning for the choice of MCDM method used in the development of the model.

3.3.1 Multi-Criteria Decision Making

On a daily basis, people make decisions and compare alternatives that range from the daily routine items such as the route to work, to important financial investments and business decisions. For the daily routine items, decisions seem to be seamless, but that apparent ease was developed through experience and a frequent repetition of the same tasks. The need for complex decisions does not occur every day and methodology is needed to help the decision-making process.

The amount of literature that exists on decision making is tremendous and continuously increasing, but a perfect model for decision making still remains unattainable. Multi-criteria decision-making (MCDM) is one of the most widely known branches of decision making. The number of MCDM methods is quite extensive, but most of these methods have common notions of alternatives and attributes. The term “alternatives” refers to the different choices available for the person making the various decisions, and the term “attributes” represent the various dimensions from which the alternatives are viewed. Attributes can also be referred to as either “goals” or “decision criteria” (Triantaphyllou 2000).

A clear distinction between the MCDM methods is their division into two types, the discrete and the continuous. Continuous methods require mathematical programming with multiple objective functions, while discrete methods use a set of decision alternatives that has been predetermined (Triantaphyllou 2000). Because of the complexity of the continuous methods, a model for the decision analysis between DCWS alternatives will use a discrete MCDM method which is more practical in nature.

Three steps are needed to identify which decision making technique involving numerical analysis of alternatives is optimal. These are (Triantaphyllou 2000):

1) Determine the relevant criteria and alternatives.
2) Attach numerical measures to the relative importance of the criteria and to the impacts of the alternatives of these criteria.
3) Process the numerical values to determine a ranking of each alternative.

MCDM methods are in general similar in their approach to the first two steps, and differ in the way they approach the third step.

As defined by Triantaphyllou (2000), all MCDM methods can be compressed into a matrix format as shown in Figure 3-1. This format is used to explain the various types of MCDM in the following sections. As observed, the set of “A” values from 1 to m refers to the decision alternatives to be evaluated; the set of “C” values from 1 to n refers to the decision criteria used to evaluate the various alternatives. Each criterion is associated with a weight of importance that is shown in the Figure 3-1 with “w” ranging also from 1 to n. In MCDM methods, it is assumed that the “weight of importance” values are already determined by the person performing the evaluation (Triantaphyllou 2000; Triantaphyllou et al. 2005).

CRITERIA

$$\begin{array}{c|cccc} & C1 & C2 & \cdots & C_n \\ Alt. & w_1 & w_2 & \cdots & w_n \\ \hline A_1 & a_{11} & a_{12} & \cdots & a_{1n} \\ A_2 & a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & a_{m1} & a_{m2} & \cdots & a_{mn} \end{array}$$

Figure 3-1: Typical Decision Matrix for MCDM methods

A description of the most prominent MCDM methods is included in the following sections, for the purpose of deciding which method is most suitable for the development of the DCWS model.

3.3.1.1 Weighted Sum Method (WSM)

WSM is the most widely used approach for conducting MCDM analysis especially for analyses that only have one dimension such as money, time, length etc. In other words, the performance of each alternative is measurable and it is the same unit for all alternatives and all criteria. The alternative with the highest value is the one to choose. The sum for each alternative, as shown in Figure 3-1, is calculated with Equation 3-1 (Triantaphyllou 2000).

Equation 3-1: WSM calculation

$$A_i = \sum_{j=1}^{n} a_{ij} w_j$$

The use of this method is simple, but it becomes more complicated when it is applied to multi-dimensional evaluations. With the introduction of a ranking system for the dimensions, instead of the actual units, the problem can be avoided (Garber et al. 2002).

3.3.1.2 Weighted Product Method (WPM)

The WPM is similar to the WSM, with the difference that instead of addition within the model, there is multiplication. In this method, each alternative is compared with the others by multiplying together the ratios of the criteria for each method, and each ratio is raised to the power equivalent to the relative weight of the corresponding criterion. This is summarized in Equation 3-2 where two generic alternatives are compared, K and L, using again the matrix definitions in Figure 3-1 (Triantaphyllou 2000).

Equation 3-2: WPM product calculation (with ratio)

$$R\left(\frac{A_K}{A_L}\right) = \prod_{j=1}^{n}\left(\frac{a_{Kj}}{a_{Lj}}\right)^{w_j}$$

If the term $R(A_K/A_L)$ is greater than 1, then alternative A_K is more desirable than alternative A_L. When comparing multiple alternatives, the best alternative is the one that is better or at least equal to all other alternatives. WPM is also called a dimensionless analysis because the ratio eliminates the units of the various criteria (Triantaphyllou 2000).

The WPM can also be used without ratios, as shown in Equation 3-3 for a generic alternative A_K. This approach allows the alternatives to be compared according to their performance value and not their relative value (Triantaphyllou 2000).

Equation 3-3: WPM product calculation (without ratio)

$$R(A_K) = \prod_{j=1}^{n}\left(a_{Kj}\right)^{w_j}$$

There has been criticism of the weighted WPM method since the use of the weights as a power factor causes heterogeneous criteria to cancel each other out and result in false ranking (Mogharreban 2006).

3.3.1.3 Analytic Hierarchy Process (AHP)

AHP, developed by in the early 1980's by Saaty (1980), decomposes a complex MCDM problem into a system of hierarchies. The method is similar to the WSM method, with the difference that each criteria value for the alternatives is normalized by dividing it by the sum of each criterion as shown in Figure 3-2 (Triantaphyllou 2000).

CRITERIA

$Alt.$	$C1$ w_1	$C2$ w_2	… …	C_n w_n
A_1	$a_{11}/\sum_1^m a_{i1}$	$a_{12}/\sum_1^m a_{i2}$	…	$a_{1n}/\sum_1^m a_{in}$
A_2	$a_{21}/\sum_1^m a_{i1}$	$a_{22}/\sum_1^m a_{i2}$	…	$a_{2n}/\sum_1^m a_{in}$
⋮	⋮	⋮	⋱	⋮
A_m	$a_{m1}/\sum_1^m a_{i1}$	$a_{m2}/\sum_1^m a_{i2}$	…	$a_{mn}/\sum_1^m a_{in}$

Figure 3-2: Decision Matrix for AHP

The best alternative is then determined as in the WSM method with the best alternative having the highest value. This similarity with the WSM allows it to be used in both single- and multi-dimensional decision making (Triantaphyllou 2000). The AHP has been a widely used method and, since its inception, it has been cited in over 1,000 journal articles (Saaty 2000). One reason for its popularity is that it provides a dimensionless analysis without the concerns associated with the WPM method where the weight for each criterion is used as a power factor. It is also easy to implement and there are various software programs available online that can use it.

The AHP method has faced some criticism since ranking inconsistencies were observed due to the sum of each criterion adding up to 1, which is particularly obvious when two identical alternatives are compared. A revised version of the method was developed, discussed in the following section, this tackles that problem (Belton et al. 1983; Triantaphyllou 2000). The developer of the original method agreed with the issues mentioned by its critics and that the Revised AHP was a better method (Triantaphyllou et al. 2005).

3.3.1.4 Revised Analytic Hierarchy Process (RAHP)

As mentioned earlier, the RAHP was developed by Belton et al. (1983) and it involves a similar approach to the AHP. The difference between RAHP and AHP is that with RAHP the value of the alternative criterion is divided by the maximum of the criterion as shown in Figure 3-3 instead of the sum of the criterion (Belton et al. 1983; Triantaphyllou 2000).

CRITERIA

	$C1$	$C2$	…	C_n
$Alt.$	w_1	w_2	…	w_n
A_1	$a_{11}/\max(a_{i1})$	$a_{12}/\max(a_{i2})$	…	$a_{1n}/\max(a_{in})$
A_2	$a_{21}/\max(a_{i1})$	$a_{22}/\max(a_{i2})$	…	$a_{2n}/\max(a_{in})$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
A_m	$a_{m1}/\max(a_{i1})$	$a_{m2}/\max(a_{i2})$	…	$a_{mn}/\max(a_{in})$

Figure 3-3: Decision Matrix for RAHP

The best alternative is then determined as in the WSM and AHP methods with the best alternative having the highest value. Again this similarity with the WSM allows it to be used in both single- and multi-dimensional decision making (Triantaphyllou 2000). The RAHP has so far been only criticized by Saaty (1990), claiming that identical alternatives should not be considered in a decision process. However Triantaphyllou et al. (1989) also proved that there were inconsistencies with AHP with other examples not just in the cases where identical alternatives were considered.

The RAHP can also be modified and used similarly to WPM with Equation 3-2 and Equation 3-3 applied to the decision matrix for RAHP (Figure 3-3), in the same way as applied to the decision matrix for MCDM methods (Figure 3-1). That method is called Multiplicative Analytic Hierarchy Process (Multiplicative AHP) and is discussed in detail by Triantaphyllou (2000) and by Barzilai et al. (1997)

3.3.1.5 Other MCDM Methods

In his text, Triantaphyllou (2000) describes two additional methods for MCDM, namely the “Elimination and Choice Translating Reality” or ELECTRE method, and the “Technique for Order Preference by Similarity to the Ideal Solution” or TOPSIS. Both of these methods are extremely complex. They require monetary or physical inputs from the decision maker and the introduction of threshold levels for the differences between the alternatives depending on the preferences he/she might have (Triantaphyllou 2000). These approaches are beyond the scope of this manuscript. The criteria or line items that were identified by the Delphi panel at the end of Manuscript 2 do not have any physical quantities, with the exception of the construction/design costs. Also, the introduction of additional input requirements beyond initial weights and criteria values at the initial stage of the development of a business case model for DCWS would limit its use. This author believes that a complex model at this initial stage of the benefit/cost model should be simple to use, otherwise its implementation would be deterred by its complexity. Further iterations of the business case model and with the evaluation of additional case studies, the use of more complex MCDM methods might be possible.

A discussion on the MCDM methods is included in the Model Development section of the manuscript

3.4 Model Development

From Manuscript 2, the Delphi panel identified the various line items that should be considered for the creation of a business case model for DCWS solutions. The owner group was chosen to be the one with the highest influence and the target group for the business case. For that reason the line items used in the Benefit/Cost model were those identified for the owner group. The line items are listed in Appendix H – Identified Costs and Benefits.

The model developed should compare the implementation of a DCWS design solution against traditional means of construction.

3.4.1 Line Items

The line items identified for the owner's point of view were grouped together in categories for uniformity and ease. Since the panel members identified the line items as either positive or negative, the line items were turned into neutral statements as in the example that follows:

Line item identified by Delphi panel:

"Potential for increased amount of RFI requests"

Neutral line item used in the model:

"Number of RFI requests (Increase/Decrease)"

Table 3-1 shows the categories and line items as they were placed in the Model. Furthermore, these items refer to the equivalent criteria (C_1 to C_n) shown in the dimension matrix in Figure 3-1.

Table 3-1: Line items entered in model

Design & Construction Costs
Design Costs
Construction Costs
Personnel
Need for Owner Personnel Training
Need of hiring additional personnel
Quality of recruited workforce
Staff Retention
Owner Time Commitments
Owner commitment for meetings & coord. (Increase/Decrease)
Owner commitment for site visits (Increase/Decrease)
Owner time for drawing/specs reviews (Increase/Decrease)
Construction/Design Time
Design Time (Increase/Decrease)
Construction Time (Increase/Decrease)
Project Issues
Number of RFI requests (Increase/Decrease)
Complexity of Bidding contract (Increase/Decrease)
Complexity of awarding contract (Increase/Decrease)
Complex. of manag. Constr. contract (Increase/Decrease)
Maturity of contractors & workers
Worksite productivity
Relationships between Designers and Contractors
Worksite Organization
Safety
Overall Construction Safety
Number of workers on site
Costs/Savings from safety concerns
Litigation/Insurance
Potential for litigation
Potential for workers' compensation
Owner furnished insurance costs
Owner inherent liability via designers (Increase/Decrease)
Blurs of lines between "Design" and "Build"
Post Construction
Sustainability of final capital assets (Improved/Worsened)
Overall potential of project quality (Better/Worse)
Life cycle of capital assets (Increase/Decrease)
Maintenance/operation costs
Ease of facility operations with safety in mind
Marketability
Morale of construction crews
Owner image to the general public
Number of bidding contractors (Increase/Decrease)

3.4.2 Impact and Importance Factors

As observed in Table 3-1, many of the line items identified, such as “Potential for litigation” and “Number of RFI request”, are future speculations which are difficult to estimate. Furthermore, items such as “Morale of construction crews” and “Quality of recruited workforce” are abstract terms with no tangible dimension attached to them.

To account for these intangible characteristics, the line items are to be evaluated according to the “Impact” they would have on the project when compared to a traditional non-DCWS solution. This impact is termed as “Impact Factor”. The range of the impact factor was defined with a seven point scale, ranging from -3 to 3. An impact value of 3 suggests that the line item for the DCWS solution is extremely favorable when compared to the line item of the traditional solution. An impact value of -3 suggests that the line item for the DCWS solution is extremely unfavorable when compared to the line item of the traditional solution. Finally a 0 value suggests that the line item for the DCWS solution has the same impact when compared to the traditional solution.

This scale facilitates the comparison targeted in the model. Because each DCWS solution to be implemented on a project is compared to traditional measures, a negative impact factor suggests that the DCWS solution affects the project negatively when compared with traditional means and methods of construction. A positive impact factor suggests that the DCWS solution affects the project in a positive way. The impact factors are equivalent to the a_{ij} values in the dimension matrix in Figure 3-1. The impact factors for each item are subjective and the end users of the model would have to use their best judgment and experience for determining these values. The use of the impact factor facilitates converting all of the various criteria dimensions into one.

The line items for design and construction costs were combined together and their impact value was calculated according to Table 3-2. Design and construction costs represent a dimension that can be easily compared or estimated: monetary costs. As observed the cut off points are in 50% increments, but these can always be changed by the end user of model.

The equivalent to the weight of importance “w” shown in Figure 3-1 is the “Importance factor”. The range of the importance factor was defined with a five point scale ranging from 1 to 5, where a value of 1 has little importance and 5 has great importance for the owner.

Table 3-2: Impact value calculations for Design & Construction costs

Percentage in savings from more expensive option	Impact Factor
Greater than 200% in savings	5
Savings between 150% and 200%	4
Savings between 100% and 150%	3
Savings between 50% and 100%	2
Savings between 0% and 50%	1
No savings	0

3.4.3 Choice of MCDM method to use

By reducing the criteria into one dimension it is possible to use a simple method for the model and avoid the use of a method such as ELECTRE and TOPSIS. The use of a product methodology such as the WPM and the Multiplicative AHP is difficult to perform, since the DCWS solutions are compared with a baseline “traditional” solution which has a zero impact value. That comparison creates a situation where impact values of the DCWS solution are divided by the zero “baseline” values of the traditional solution. Similarly, use of the AHP and the RAHP methods causes some concerns, since these methods require that the individual impact values be divided by the sum or the maximum value of each criterion respectively. This creates a situation where one option has a series of “1” values for impact scores, eliminating the differentiation of a criterion having a greater impact than others.

With all the other methods eliminated, the only method left to use is the Weighted Sum Method (WSM), which is the most widely used method in multi criteria analyses. The only limitation of the WSM that was identified in the literature is that it can only be applied to single-dimensional problems. In order to avoid this limitation it is suggested that the dimensions be replaced by equivalent ranking values (Triantaphyllou 2000). The overall score for the solutions was calculated using Equation 3-1.

A model was therefore created using the WSM method. The steps used in the model are summarized in Figure 3-4, and the model was completed using a spreadsheet that is shown in Table 3-3. The solutions are first identified, and an estimate for the design and construction costs is developed. For each of the solutions and for each line item the impact factors are rated, followed by the influence factors. The total score is calculated automatically and the solution with the highest score is the one to choose.

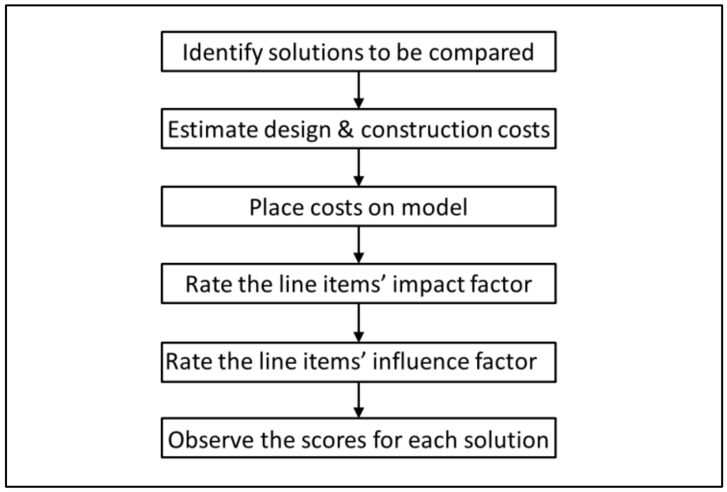

Figure 3-4: Steps for completing the model

3.4.4 Model Instructions

The model contained instructions for the users to fill the spreadsheet, and facilitate in making decisions for the implementation of a DCWS solution in their proposed projects. The instructions explain that the model can compare a DCWS option against a traditional construction/design solution, through a decision spreadsheet that allows them to score costs and benefits in various items that include design, construction personnel, time commitments, etc.

The spreadsheet cells that needed user input were highlighted in green. These included the values for the monetary cost for design and construction, the impact factors and the importance factors. The scores for the two options were then calculated automatically as the user enters these values. The instructions as they were presented to the users are shown in Appendix I – Benefit Cost Model. The model also contained the definitions for the various line items, in order to facilitate the users, and they are also contained in Appendix I. After the instructions, the spreadsheet contained the Benefit/Cost model, a blank version of which is shown in Table 3-3. The results of the model are summarized in the

The scores for each solution are shown at the end of the table. As mentioned, before these are calculated automatically with the use of the WSM method. The solution with the higher value should be the one considered.

Table 3-3: Blank Benefit/Cost Spreadsheet

This is a Benefit/Cost analysis for the Owner to decide whether to proceed with a DCWS solution			
Option A: Option B:			
	Option A DCWS solution A Impact Factor	**Option B** Traditional Solution Impact Factor	**Importance** **Factor**
Design& Construction Costs			
Design Costs	$ 1.00	$ 1.00	1
Construction Costs	$ -	$ -	
	$ 1.00	$ 1.00	
	% Difference	% Difference	
	0%	0%	
Personnel			
Need for Owner Personnel Training	0	0	1
Need of hiring additional personnel	0	0	1
Quality of recruited workforce	0	0	1
Staff Retention	0	0	1
Owner Time Commitments			
Owner commitment for meetings & coord. (Increase/Decrease)	0	0	1
Owner commitment for site visits (Increase/Decrease)	0	0	1
Owner time for drawing/specs reviews (Increase/Decrease)	0	0	1
Construction/Design Time			
Design Time (Increase/Decrease)	0	0	1
Construction Time (Increase/Decrease)	0	0	1
Project Issues			
Number of RFI requests (Increase/Decrease)	0	0	1
Complexity of Bidding contract (Increase/Decrease)	0	0	1
Complexity of awarding contract (Increase/Decrease)	0	0	1
Complex. of manag. Constr. contract (Increase/Decrease)	0	0	1
Maturity of contractors & workers	0	0	1
Worksite productivity	0	0	1
Relationships between Designers and Contractors	0	0	1
Worksite Organization	0	0	1
Safety			
Overall Construction Safety	0	0	1
Number of workers on site	0	0	1
Costs/Savings from safety concerns	0	0	1
Litigation/Insurance			
Potential for litigation	0	0	1
Potential for workers' compensation	0	0	1
Owner furnished insurance costs	0	0	1
Owner inherent liability via designers (Increase/Decrease)	0	0	1
Blurs of lines between "Design" and "Build"	0	0	1
Post Construction			
Sustainability of final capital assets (Improved/Worsened)	0	0	1
Overall potential of project quality (Better/Worse)	0	0	1
Life cycle of capital assets (Increase/Decrease)	0	0	1
Maintenance/operation costs	0	0	1
Ease of facility operations with safety in mind	0	0	1
Marketability			
Morale for construction crews	0	0	1
Owner image to the general public	0	0	1
Number of bidding contractors (Increase/Decrease)	0	0	1

	Option A	**Option B**
Total =	**0**	**0**

3.5 Case Studies

To test the functionality of the model, two case studies were identified. The first case study involved a real project in a Detroit plant where a DCWS solution was implemented, and the other involved a building construction project in Portland where the DCWS solution was not implemented.

3.5.1 Case Study 1 – Pre-assembled cable trays

The first case study involved the benefit/cost analysis of cable tray assemblies at the Detroit Edison Monroe Power Plant (PP) Flue Gas Desulfurization (FGD) Units 1 and 2. The assemblies were part of work for the retrofit of the aging PP that involved the replacement of the FGD system to provide increased reliability and sulfur removal efficiency. The cable trays were necessary to support the system and carry all the ductwork that was necessary for its operation. Babcock & Wilcox power generation and URS Corp provided the engineering, procurement, and construction of the FGD system and URS provided the engineering, procurement and construction of the absorber buildings (URS Corp 2011; B&W 2012). A picture of a cable tray being lifted into place is shown in Figure 3-5.

Figure 3-5: A cable tray being listed in place at the Monroe Power Plant (Case Study 1) (Picture provided by URS Corp.)

URS designed and constructed the cable trays in the case study and the design personnel considered alternatives to the traditional (stick built) on site cable trays. The personnel came up with the solution of preassembled cable trays that were transported to the site and lifted into place. URS Corp developed a detailed estimate for the stick built solution, and tracked the engineering and construction costs for the preassembled solution (URS Corp 2012).

Shown in Table 3-4, is a summary of the comparison of the direct costs of the two solutions, which was provided by URS Corp. The workforce that was required for the preassembly included electricians and ironworkers. The engineering cost involved the design and layout of the trays, and no additional design cost was included for the stick built solution since the designs were replicated from other similar buildings in the facility. The material costs were about the same, with the preassembled trays needing some additional material for fastening the trays to the overhead beams.

Table 3-4: Cost comparison for alternatives (Case Study 1)

Cost category	Preassembly	Stick built	Difference
Craft hours	1300	7910	6610
Craft related costs	$79,812	$477,391	$397,579
Material and assembly costs	$142,408	$132,389	($10,019)
Engineering hours	743 (to develop design of trays)	0 (original design based on typical details)	($743)
Engineering costs	$92,292	0	($92,291)
Total costs	$314,511	$609,780	$295,269

The above table only includes design and construction costs and does not consider any of the other line items that were identified to be used in the benefit/cost model. Designers working for URS were contacted and asked to fill out the spreadsheet from the viewpoint of the owner. Their responses are shown in Table 3-5. All impact factors for option B are zero in this case because option B is the traditional solution.

The monetary costs were vital to the project and given an importance factor of 5. Within the personnel list of line items, only two items were scored in terms of impact: owner personnel training and hiring of additional personnel. Their importance was relatively low and they were given an importance factor of 1. None of the line items within the “owner time commitments” received any impact value. Both construction and design time received a value of 5 for importance, but they differed in the impact value. Design time received a value of -2, while construction time received a value of 3. The design impact factor was negative due to the increased time for design, while the construction time value was positive because of the reduced construction time.

The items under the category project issues received a variety of impact and importance values. The most notable item was the importance factor value for worker productivity (5). The designers rated that item with a high value since construction time for the project was critical. The DCWS solution received an impact value of 2, suggesting that there were gains associated with the solution and the productivity of the crews. All the line items under the safety category received a positive value for impact, suggesting that there were gains in safety with the DCWS solution. The importance factors for the safety line items were between 4 and 5, values that imply safety concerns were important on the project.

All the items under litigation/insurance received a positive value for impact, except the item “owner furnished insurance” which was given a value of 0. The importance factor given for all of these items ranged from 1 to 3. The items under the “Post Construction” category received impact values ranging from 0 to 2 while their importance factors were between 1 and 3. The items under the marketability category received 0 for impact except “number of bidding contractors” which received a -1. The marketability category importance factors were between 1 and 3.

The overall score for Option A, the DCWS solution, was calculated using the method discussed earlier and received a score of 78. The traditional solution received no points. This score suggests that the DCWS solution was the best choice between the two. With such a big difference between the two solutions, it is clear that the DCWS option is the best solution. If the score for Option A was negative, then the DCWS would not have been favorable. In cases where the scores for the two options are equal, then both solutions are ideal. In such cases the user would need to decide based on other factors that are not listed on the model.

Table 3-5: Benefit/Cost analysis (Case Study 1)

This is a Benefit/Cost analysis for the Owner to decide whether to proceed with a DCWS solution			
Option A: Cable Trays - Preassembly - DCWS Solution A Option B: Cable Trays - Stick Build - Traditional Solution			
	Option A DCWS solution A Impact Factor	**Option B** Traditional Solution Impact Factor	**Importance** **Factor**
Design& Construction Costs			5
Design Costs	$ 92,291.00	$ -	
Construction Costs	$ 222,220.00	$ 609,780.00	
	$ 314,511.00	$ 609,780.00	
	% Difference	% Difference	
	-94%	94%	
Personnel			
Need for Owner Personnel Training	1	0	1
Need of hiring additional personnel	1	0	1
Quality of recruited workforce	0	0	1
Staff Retention	0	0	1
Owner Time Commitments			
Owner commitment for meetings & coord. (Increase/Decrease)	0	0	2
Owner commitment for site visits (Increase/Decrease)	0	0	2
Owner time for drawing/specs reviews (Increase/Decrease)	0	0	3
Construction/Design Time			
Design Time (Increase/Decrease)	-2	0	5
Construction Time (Increase/Decrease)	3	0	5
Project Issues			
Number of RFI requests (Increase/Decrease)	2	0	3
Complexity of Bidding contract (Increase/Decrease)	-1	0	3
Complexity of awarding contract (Increase/Decrease)	-1	0	2
Complex. of manag. Constr. contract (Increase/Decrease)	2	0	3
Maturity of contractors & workers	0	0	1
Worksite productivity	2	0	5
Relationships between Designers and Contractors	1	0	1
Worksite Organization	1	0	1
Safety			
Overall Construction Safety	3	0	5
Number of workers on site	1	0	4
Costs/Savings from safety concerns	1	0	4
Litigation/Insurance			
Potential for litigation	1	0	1
Potential for workers' compensation	2	0	3
Owner furnished insurance costs	0	0	1
Owner inherent liability via designers (Increase/Decrease)	1	0	2
Blurs of lines between "Design" and "Build"	1	0	1
Post Construction			
Sustainability of final capital assets (Improved/Worsened)	1	0	3
Overall potential of project quality (Better/Worse)	2	0	3
Life cycle of capital assets (Increase/Decrease)	0	0	1
Maintenance/operation costs	1	0	3
Ease of facility operations with safety in mind	0	0	3
Marketability			
Morale for construction crews	0	0	1
Owner image to the general public	0	0	3
Number of bidding contractors (Increase/Decrease)	-1	0	3

	Option A	**Option B**
Total =	**78**	**0**

3.5.2 Case Study 2 – Increased Parapet Height

The second case study involved the benefit/cost analysis of constructing two types of parapets at the edge of a roof under construction. The two parapets had a height of 30.5 cm (12in) and 99 cm (39in) respectively. In this case the 39in parapet is the DCWS solution, while the 12in parapet is the traditional solution. A height of 39 in is the minimum OSHA requirement for any work to be performed without the use of a temporary protection barrier. The roof had an area of 929 m^2 (10,000 ft^2).

Information for this case study was collected from an article by Rajendran et al. (2013) and through personal communications with Dr. Sathy Rajendran who worked as a safety supervisor for the contractor on the project. Dr. Rajendran currently holds the position of Assistant Professor at Central Washington University in the Department of Engineering Technologies, Safety and Construction Management.

The construction project was located in the Portland Metro area and was a physical plant building, part of a medical facility that housed an emergency power room, a normal power room, a chiller room, a boiler room, and a control room (Rajendran et al. 2013). The 12in parapet was designed for the building, while the possibility for the 39in parapet was only considered by the authors.

Information about the two options was gathered from the subcontractors involved in the project through Requests for Information (RFI). The three subcontractors were the walls and ceilings contractor, the roofing contractor, and the exterior skin contractor. Because a shorter parapet requires the installation of permanent roof anchors on the roof, information for the cost of these anchors was collected from the firm that produces the anchors and the contractor that installs them (Rajendran et al. 2013).

Construction personnel were interviewed to determine time and effort requirements for the installation of the temporary fall protection equipment. The material cost for these fall protection measures was obtained through vendors that rent them. The labor cost for the workers necessary to install the equipment was obtained from the specific contractors involved. The authors also accounted for delivery costs, hoisting, and any necessary training needed for the protective measures on site (Rajendran et al. 2013).

The authors also asked the facility's designer whether there would be additional cost for the design of a taller parapet. The designers indicated that there would be no difference in design costs between the two parapet heights (Rajendran et al. 2013). Table 3-6 shows the completed spreadsheet for the case study as completed by Dr. Rajendran. He was asked to complete the spreadsheet from the viewpoint of the owner, and because of the close working relationship that he had with the owner organization, he was able to do so.

Table 3-6: Benefit/Cost analysis (Case Study 2)

This is a Benefit/Cost analysis for the Owner to decide whether to proceed with a DCWS solution			
Option A: DCWS solution 39in Parapet Option B: Traditional solution 12in parapet			
	Option A DCWS solution A Impact Factor	**Option B** Traditional Solution Impact Factor	**Importance** **Factor**
Design& Construction Costs			
Design Costs	$ -	$ -	5
Construction Costs	$ 44,028.00	$ 5,025.00	
	$ 44,028.00	$ 5,025.00	
	% Difference	% Difference	
	776%	-776%	
Personnel			
Need for Owner Personnel Training	3	0	5
Need of hiring additional personnel	3	0	4
Quality of recruited workforce	0	0	4
Staff Retention	0	0	3
Owner Time Commitments			
Owner commitment for meetings & coord. (Increase/Decrease)	0	0	1
Owner commitment for site visits (Increase/Decrease)	0	0	1
Owner time for drawing/specs reviews (Increase/Decrease)	0	0	1
Construction/Design Time			
Design Time (Increase/Decrease)	0	0	1
Construction Time (Increase/Decrease)	-3	0	1
Project Issues			
Number of RFI requests (Increase/Decrease)	0	0	1
Complexity of Bidding contract (Increase/Decrease)	0	0	1
Complexity of awarding contract (Increase/Decrease)	0	0	1
Complex. of manag. Constr. contract (Increase/Decrease)	0	0	1
Maturity of contractors & workers	0	0	1
Worksite productivity	3	0	1
Relationships between Designers and Contractors	0	0	1
Worksite Organization	2	0	1
Safety			
Overall Construction Safety	3	0	1
Number of workers on site	0	0	1
Costs/Savings from safety concerns	3	0	1
Litigation/Insurance			
Potential for litigation	0	0	1
Potential for workers' compensation	0	0	1
Owner furnished insurance costs	0	0	1
Owner inherent liability via designers (Increase/Decrease)	0	0	1
Blurs of lines between "Design" and "Build"	0	0	1
Post Construction			
Sustainability of final capital assets (Improved/Worsened)	0	0	1
Overall potential of project quality (Better/Worse)	0	0	1
Life cycle of capital assets (Increase/Decrease)	0	0	1
Maintenance/operation costs	2	0	1
Ease of facility operations with safety in mind	2	0	1
Marketability			
Morale for construction crews	3	0	1
Owner image to the general public	0	0	1
Number of bidding contractors (Increase/Decrease)	0	0	1

	Option A	**Option B**
Total =	**42**	**25**

All impact factors for option B are zero in this case because option B is the traditional solution.

As observed in Table 3-6 option A, the DCWS solution, had a considerably higher cost at $44,028. Option B, the traditional solution, was only $5,025. The importance factor that was given for the cost was 5.

In the personnel category, the need for hiring additional owner personnel and owner personnel training received an impact factor of 3 and had importance factors of 5 and 4, respectively. All of the items in the owner time commitments category received a value of zero for the impact factor. The construction timeline item received an impact factor of -3, since the construction of a taller parapet requires more time. Under the project issues category, the only items that received an impact factor were “worksite productivity” with 3 and “worksite organization” with 2. Their importance factor was 1.

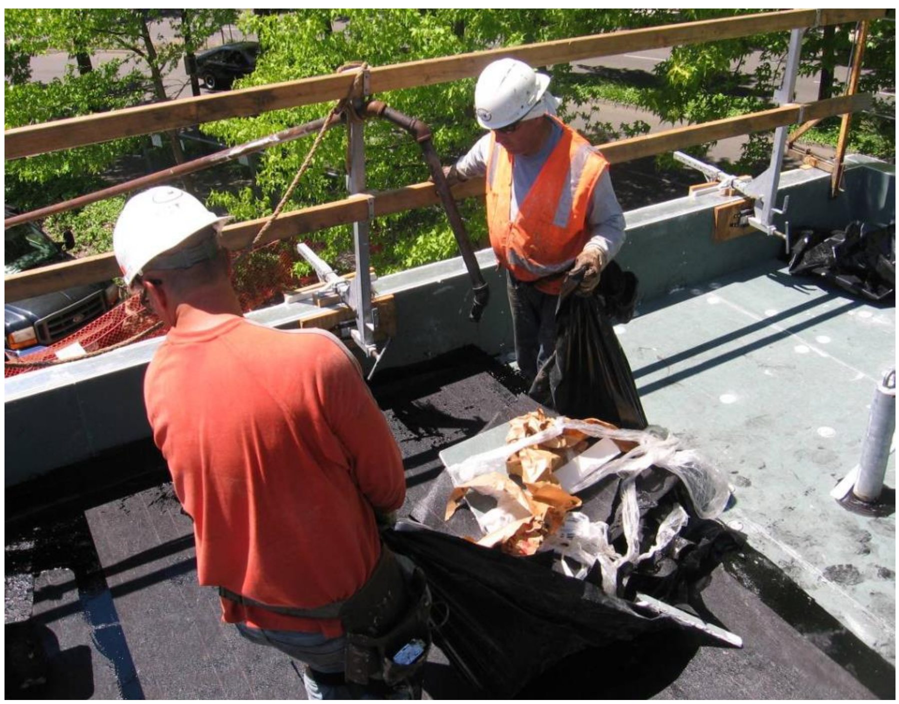

Figure 3-6: Construction workers placing insulation on the roof (Case Study 2) (Rajendran et al. 2013)

Under the category safety, the “overall construction safety” and “cost/savings from safety concerns” items each received an impact factor of 3 and an importance factor of 1. Continuing with the post-construction category, “maintenance/operations costs” and “ease of facility operations with safety in mind” received impact factor of 2 and importance factors of 1. Lastly under marketability, the “morale” line item received an impact factor of 3 and an importance factor of 1.

The overall score for the DCWS solution was 42, while the score for the traditional solution was 25. The traditional solution received a lower score because it was less expensive than the DCWS solution and the model assigned a positive impact factor to the least expensive solution. At the time of construction the owner only considered monetary cost in the decision for the parapet height, and as a result the shorter parapet was constructed. In addition the taller parapet was not considered during design. A picture of construction workers placing roof insulation on the project is shown in Figure 3-6.

3.6 Conclusions and Limitations

The benefit/cost model that was developed in this manuscript favored both DCWS solutions that were evaluated. In the first case study, URS engineers designed and supervised construction of the cable trays with construction safety in mind. URS has a DCWS program and promotes construction worker safety during design (Zagres et al. 2008). As a result the DCWS solution was evaluated after it had been designed and constructed. The second DCWS solution was the result of an independent study of construction methods at a Portland area construction site, where the author was supervising construction safety for the contractor. The DCWS solution was not constructed because it was not designed in the building in the first place (Rajendran et al. 2013).

Only two solutions have been evaluated with the decision spreadsheet as part of this research. The model requires validation for it to be used confidently in a professional setting. It is suggested that more DCWS projects be added to the evaluation in order to make sure that the model is adequate and correct in assessing the various solutions to be implemented in a construction project. In addition there is a possibility that some bias was contained in the case studies discussed in the manuscript, since they were evaluated by personnel that are champions in the field of PtD.

These additional evaluations would help determine if the line items adequately address the concerns for DCWS costs and carefully assess the benefits. It is expected that many of the line items would have similar impact values for various projects and with subsequent evaluations these would be identified and grouped together thus reducing the amount of input required by the users of the model.

It is also possible that more items can be added to the model. The Delphi panel that identified the items listed might have overlooked items that could be identified only after subsequent use, implementation and evaluation of the model by multiple individuals.

For the validation of the model this author suggests that sensitivity analysis be conducted, once more projects are evaluated with the model.

4.0 Conclusions, Limitations and Recommendations

4.1 Introduction

The purpose of this section is to summarize the findings that were developed in the three manuscripts and to determine whether the objectives described in the introductory chapter have been achieved. Included in this section is a discussion on the limitations of the research as well as suggestions for future possible research projects on the topic.

This dissertation successfully resulted in determining the state of practice regarding DCWS in the US construction industry. Through the national survey, the various viewpoints regarding DCWS from the industry groups were revealed. In addition, through the Delphi panel's contribution, the industry group capable of generating the greatest interest for DCWS was identified.

The overall objective of this research was to develop a possible framework for the implementation of DCWS in the US. That goal was achieved through the research described within the manuscripts in this dissertation and in particular in Manuscript 3, where an initial benefit/cost model was produced. The model can be used by owner organizations to evaluate and distinguish between DCWS solutions and traditional design solutions using an array of line items that extend beyond the monetary costs and benefits. Owners have the driving capability for the conception of a project and their needs guide the design requirements. The owner's decision to implement DCWS will also instruct designers to practice DCWS, since the concerns that designers have on DCWS would be compensated.

4.2 Conclusions

As mentioned previously, the main objective of the dissertation was achieved, and along the way several key questions were answered. To recall, the questions that were presented in the introductory chapter are the following:

- What is the extent of DCWS knowledge and practice in the US?
- What are the obstacles and enablers for designers to practice DCWS?
- Which construction industry group can generate interest for DCWS implementation in the US construction industry?
- Which is the best method to generate interest for DCWS implementation?
- What is the best framework to generate that interest?

The answers to the above questions are summarized in the following sections.

4.2.1 What is the extent of DCWS knowledge and practice in the US?

Through the nationwide survey that was conducted as part of the first manuscript, it became clear that DCWS is not known in the construction industry. Only 20.5% of engineers, 21.5% of owners, 5.4% of architects, and 16.2% of contractors who were surveyed answered affirmatively that they were aware of the DCWS concept. These numbers were surprisingly low when the concept was first introduced in the US in 1955 (Gambatese et al. 1997) and there were several attempts for its introduction in the form of legislation in the House and Senate (Gambatese 2000a; Behm 2005). As expected, the percentage of designer DCWS participation is even lower than the percentage of designer DCWS knowledge. Specifically 19.3% of engineers and 4.1% of architects stated that their firm participates in some form of DCWS.

The practice of DCWS at the moment is limited to larger firms, as observed from the survey analysis where the engineering firms that were more likely to be practicing DCWS were also larger firms ($p=0.0003$). The author believes that larger firms have the resources to experiment with methods and procedures. The availability of resources allows firms to be more proactive. In addition, larger firms are more likely to have additional personnel and experience in a variety of projects. Larger firms also participate in various forms of project delivery methods (DB, DBOT, etc.). This diversity enables firms to work with contractors during the design phase, thus incorporating contractor input in the design. In addition larger firms are more likely to be hired by sophisticated owner organizations that embrace DCWS.

It can be concluded that DCWS knowledge is very limited at the moment in the US. Availability of formal education of design professionals on DCWS is very limited. The concept is taught in only a limited number of universities and continuing education classes (Toole et al. 2008; NIOSH 2013; Popov et al. 2013). Furthermore, professional organizations, such as ASCE, have rejected the concept and do not consider it a viable option for engineers (Toole 2011). Even though the

Delphi panel chose the business case as the possible method for generating interest, the author believes that due to the extreme lack of knowledge of DCWS, it is important that education on the concept continue and be enhanced with additional programs and methods both in college and through continuing education.

4.2.2 What are the obstacles and enablers for designers to practice DCWS?

The survey that was administered also helped to identify the possible obstacles and enablers that might be present in practicing DCWS. Three areas were identified by both engineers and architects as being obstacles. These were economic, contractual, and legal obstacles. Owners identified the economic obstacles only. This finding was indicated by more than 50% agreement with statements that these obstacles exist from the various participating groups. The participating groups did not identify with a majority any enablers for designers to practice DCWS. Architects showed the most disagreement compared to all the groups regarding the presence of any enablers.

What was surprising though was that engineers who responded that their firms have formal guidelines for reviewing for construction worker safety were 5.35 times more likely to respond that there are ECONOMIC incentives that may enable designers to practice DCWS (p-value 0.0278, 95% CI 1.93 to 14.80). This suggests that firms which practice DCWS observe some financial benefits in doing so. It is important that these benefits be identified to provide additional proof that DCWS participation makes economic sense.

4.2.3 Which construction industry group can generate interest for DCWS implementation in the US construction industry?

The three rounds of the Delphi process showed that owners are the group that has the highest ability to generate interest in DCWS. This was evident with the high median value (10) and the least amount of variation (8 to 10) in the panel members' responses to the question on influence. The author believes that this was expected since owners make all the financial decisions on construction projects and it is necessary for them to be on-board with any innovative idea, such as the implementation of DCWS, for it to be implemented on a project.

Even though the owner group was found to be the most influential in generating interest, the group's effect on the perceived obstacles was not investigated. Such effect could be the complete removal of an obstacle or even the acceleration of DCWS implementation within the industry.

4.2.4 Which is the best method to generate interest for DCWS implementation?

The objective to identify the method with which interest should be generated for DCWS produced the business case solution. The response was overwhelming for the business case after two rounds. Fifteen participants chose the business case in the first round of the Delphi process and 17 participants chose that option in the second round. The other methods received far weaker support, with 11 for education, and 10 for industry standards. It was also very interesting to see that the "Legislation" option generated no support, with the one Delphi panel participant choosing that option in the first round, and changing his opinion in the second round. The lack of interest in legislation is not surprising since it most likely represents the nature of the US construction industry and the US in general where there is resistance to any form of legislation. This also suggests that implementation of DCWS is the US in the form of legislation such as the CDM regulations in the UK will meet tremendous opposition and would likely fail. The business case seems to be the optimum method for the US, since profit seems to be generating change in the majority of the US economy, including construction.

4.2.5 What is the best application for the identified method?

The third round of the Delphi process asked participants to identify line items to be used in a benefit/cost analysis in order to make comparisons between DCWS solutions and traditional design solutions. The panel members identified both monetary and non-monetary items. A comparison of monetary and non-monetary items is complicated and a multi-criteria analysis method was used to generate a benefit/cost model. This model was used to investigate two case studies where both DCWS solutions were evaluated to be beneficial for use in the projects.

This model is at its initial development stage. With the evaluation of additional projects, the model can be modified and improved to be more accurate.

4.3 Limitations

Several aspects of the dissertation suggest that there are limitations that were generated by the methodology and the data collected. These limitations can be attributed to several factors, some of which are discussed here.

It can be argued that the information gathered from the survey is not very accurate since the overall response rate was 21.6%. Such a response rate is reflective of the industry and online surveys in general. Cook et al. (2000) investigated several studies where online surveys were used to gather information where the average response rate was 39.6% with a standard deviation of that rate equal to 19.6%. The survey participants in this dissertation did not have any incentive to participate and they were not required by their professional associations to provide any answers to the survey.

In addition, the random selection of states in the survey excluded several states that have a construction industry sector much larger than those states selected. Examples of these states are Texas and California. Some researchers might argue that the absence of these states might skew the results to a particular direction. A future survey could possibly include all 50 states and the difference in the results be investigated.

The owner group that was selected in the survey might be viewed as not representative of all owners. Because university campuses construct almost all types of buildings and participate in a variety of project delivery methods, their experience was valuable to the research. To improve the quality of responses, a future research study should include other types of owners that would add variety to the project delivery methods and types of building, as well as the innate interests of the owners.

Since only two case studies have been performed using the model developed, the model requires validation for it to be used confidently in a professional setting. It is suggested that more DCWS projects be added to the evaluation in order to make sure that the model is adequate and correct in assessing the various solutions to be implemented in a construction project. Additional evaluations can determine if the line items are adequate for a complete and formal evaluation of DCWS solutions and accurately assess the benefits of such solutions. A validation of the model is also required using sensitivity analysis.

4.4 Recommendations for Future Research

The investigation performed in this dissertation is only one step in the direction of an industry-wide implementation on DCWS in the US. Future research is required to increase that interest and to promote DCWS among owners and designers. Some ideas for possible future directions for DCWS research are mentioned here.

4.4.1 Investigation of benefits from current DCWS practice

Several design firms currently practice some form of DCWS. These firms can be considered as very progressive since they started a DCWS program when there were no external incentives for them to do so. As mentioned earlier, some firms mentioned that there are some economic incentives for them to practice DCWS. A possible research project can investigate the lessons learned from that practice and can identify the benefits that these firms have gained after starting their DCWS program.

4.4.2 Investigation of additional projects with DCWS solutions

To gain more confidence in the model that was developed, additional case studies need to be investigated. Such an attempt would strengthen the validity and with the use of a sensitivity analysis, the model can be streamlined and be used in multiple construction types and settings. As is, the model would not be ideal for use in a professional setting and that can only be achieved after the model's validation. Additional line items might need to be added to the model, and some of the existing items might need to be eliminated.

4.4.3 Investigation of DCWS in horizontal construction

This dissertation concentrated only on building construction. A future research project might look at the possible inclusion of DCWS in horizontal construction and the investigation of current DCWS practices in these settings.

4.4.4 Investigation of the impact of culture on DCWS

This dissertation did not concentrate on the cultural aspects of the implementation of DCWS. A further study can be conducted to investigate the cultural characteristics present in design firms that inhibit the practice of DCWS by designers. In addition, the culture present in design firms that already practice DCWS can be evaluated to determine their characteristics and methods in order to transfer them to the rest of the industry.

4.4.5 Long term benefits to maintenance operations

Within the benefit/cost model, the line item for DCWS benefits or costs to future maintenance had an impact value that was very subjective and based on the opinion of the person preparing the model. A future study could analyze the true long-term benefits or costs to the lifecycle of a project that implemented DCWS solutions in its construction.

4.4.6 Effect of the owner group on the perceived obstacles

Since the effects of the owner group on the perceived obstacles were not investigated, a future research project could study how owners influence these obstacles. Owners could have the potential to eliminate obstacles and allow designers to practice DCWS on their own, or eliminate obstacles and at the same time accelerate DCWS implementation.

4.4.7 The determination of the importance factors of various owner groups

As observed in Manuscript 3, the model required user input for both the importance and the impact factors. The various owners that participate in building construction are most likely to have different criteria in selecting solutions for their buildings, and would also be likely to have the line items rated with different importance factors. It is possible, though, that owners from the same industry would likely rate the importance factors of these line items similarly. For example, all education facility owners might rate one line item with the same value. A research project could be established to determine the influence values of the various owner types in an effort to reduce the amount of input the users of the model are required to provide.

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APPENDICES

Appendix A – Contractor Survey

Contractor Views on the Design for Construction Worker Safety (DCWS) Concept

* Intro: Project Name: Owner, Designer, and Construction Contractor Views on Design for Construction Worker Safety (DCWS)

Principal Investigator: John Gambatese / Oregon State University

Student Investigator: Nicholas Tymvios/Oregon State University

Why am I being invited to take part in this study?

You are being asked to take part in this study because your organization is actively involved in the construction industry in at least one of three roles, either as a project owner and/or a member of a national organization of project owners, a designer (Architect/Engineer), or a construction contractor, and your name is listed as a contact person in your organization or the national organization.

What is the purpose of this study?

Researchers at Oregon State University are conducting academic research on Design for Construction Worker Safety (DCWS), a process in which architects and engineers explicitly consider the safety and health of construction workers as they make design decisions on the permanent features of the facility. Promoters of DCWS believe that it offers tremendous potential for making construction sites inherently safe and less unhealthy. They believe the earlier safety is considered in a project, the easier it is to achieve a safer site. The goal of this study is to increase our understanding of project participants' attitudes, experience, and perspectives regarding DCWS and to create documents that will facilitate participants' use of DCWS on their projects. We would very much appreciate hearing about your attitudes, experiences, and perspective regarding DCWS. The results of this study will be published in practical guidelines, research papers, and conference proceedings.

The concept of DCWS can also be found in literature as Prevention through Design (PtD), Design for Safety (DfS), Safety through Design (StD), and Safety in Design (SiD).

Design for Construction Worker Safety (DCWS) is a concept that:

- Explicitly considers the safety of construction workers during the design of a project.
- Asks designers to be conscious of and value the safety of construction workers when performing design.
- Suggests making design decisions based in part on how a project's inherent risk to construction workers may be affected.
- Includes worker safety considerations in the constructability review process.

Design for Construction Worker Safety (DCWS) is not:

- Having designers take a role in construction safety DURING construction.
- An endorsement of future legislation mandating that designers design for construction safety.
- An endorsement of the principle that designers can or should be held partially responsible for construction accidents.
- Implying that the vast majority of U.S. design professionals are currently equipped to design for construction safety.

What will happen during this study and how long will it take?

Within the survey you will be asked to answer short answer questions, multiple choice questions, and questions that rate your agreement or disagreement to various statements

It is expected that it will take approximately 10-15 minutes to complete the survey.

What are the risks of this study to the participants?

Breach of Confidentiality: There is a risk that we could accidentally disclose information that identifies you; however this risk is extremely low.

Internet: The security and confidentiality of information collected from you online cannot be guaranteed. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

What are the benefits of this study to the participants?

There are no direct benefits to the participants except for the value of being involved in a national research study on a contemporary topic. It is anticipated that the information gained by being a participant will provide you with knowledge of and an appreciation for the DCWS concept. The benefit of conducting the overall research is to contribute to the body of knowledge in this field of study and improve construction site safety and health. This will benefit the engineering and construction industry as a whole.

Will I be paid for participating?

Participants will not be paid or otherwise compensated for their involvement in the study.

Who will see the information I give?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

If the results of this project are published your identity will not be made public.

Do I have a choice to be in the study?

Participation in the study is voluntary. Anyone who agrees to participate in this research may change his/her mind at any time. Participants may refuse to answer any questions and/or may withdraw from the study at any time.

What if I have questions?

Participants are encouraged to ask any questions at any time about the study and its procedures, or his/her rights as a participant. The Investigator' names and contact information are included below so that the participant may ask questions and report any study-related problems. The investigators will do everything possible to prevent or reduce discomfort and risk, but it is not possible to predict everything that might occur. If a participant has unexpected discomfort or thinks something unusual or unexpected is occurring s/he should contact:

- John Gambatese, Civil and Construction Engineering, Oregon State University, 220 Owen Hall, Corvallis, OR 97331, Tel.: (541) 737-8913, john.gambatese@oregonstate.edu

- Nicholas Tymvios, Civil and Construction Engineering, Oregon State University, 220 Owen Hall Corvallis, OR 97331, Tel.: (541) 908-6473, tymviosn@onid.orst.edu

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu.

I have read the above description of the research. If I had questions, I contacted the study team and I had all of my questions answered to my satisfaction. If I would like a copy of this form, I must print it out before I click "Next". I agree to participate in this research.

By clicking "Next >>", I affirm that I have read the above information and I am at least 18 years of age or older.

Basic Introductory Questions

A2: Please state the name of your firm.

A3: Please state your title within your firm.

A8: How many years of experience do you have in design?

A9: How many years of experience do you have in construction?

A4: Indicate the types of buildings your firm is involved in constructing (multiple answers can apply).

- Educational Buildings (Excluding dormitories)
- Residential, Multifamily Residential (Including Dormitories)
- Commercial Buildings
- Industrial (Manufacturing Plants, Assembly Plants, Power Plants etc.)
- Retail
- Transportation Buildings (Airport Terminals, Bus Depots, Rail Stations, etc)
- Civic (Governmental, religious, etc)
- Athletic Facilities
- Other:

A7: In the past 5 years what types of project delivery methods has your firm participated in?

- Design-Bid-Build (Traditional Contracting Method)
- Design-Build
- Construction Management/General Contractor or Construction Management at Risk
- Design-Build-Operate-Maintain
- Design-Build-Operate-Transfer
- Multiple Prime Contracting (Owner employed several prime contractors)
- Self-Performed (Owner acting as general contractor)
- Other:

Knowledge of Design for Construction Worker Safety Concept

B1: Were you previously aware of the "Design for Construction Worker Safety" concept? (Yes/No)

B5: Does your firm participate in constructability meetings with designers, where construction worker safety issues are discussed? (Yes/No)

B5a: What types of issues are usually addressed at these meetings?

B5b: Are designers willing to accept your firm's input and implement your firm's recommendations at the constructability meetings? (please elaborate)

Opinions

C1: Please indicate your firm's level of agreement with the statements provided regarding designers (architects/engineers).

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
Designers know how construction site operations and procedures take place					
Designers have a clear understanding of what constitutes a hazard to construction workers					
Designers have adequate capacity and opportunities to be educated in construction worker safety					
Designers should be involved and participate in construction worker safety through design decisions					
The nature of construction contracting does not allow designers to participate in construction worker safety					

C2: Please indicate your firm's level of agreement with the statements provided.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
Owners know how construction site operations and procedures take place					
Owners have adequate capacity and opportunities to be educated in construction worker safety					
Owners have a clear understanding of what constitutes a hazard to construction workers					
Owners should be involved and participate in construction worker safety					
The nature of construction contracting does not allow owners to participate in construction worker safety					

C3: Please indicate your firm's level of agreement with the statements provided.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
The construction industry is a hazardous industry					
Only construction contractors are currently involved in reducing hazards to construction workers					
All construction site hazards to construction workers are taken care of by construction contractors					
Decisions made before the design of a project begins can help eliminate some construction worker hazards					
Decisions made during the design of a project can help eliminate some construction worker hazards					
Decisions made during the construction of a project can help eliminate some construction worker hazards					

C4: Please indicate your firm's level of agreement with the following statements.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
My firm would be supportive of proposed legislation for designers to start practicing DCWS					
My firm would be supportive of the DCWS concept if designers were legally protected from liability in practicing DCWS					

Obstacles and Enablers

D1: Indicate your firm's agreement with the following statements regarding obstacles for designers to practice DCWS.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
There are REGULATORY obstacles that may not allow designers to practice DCWS. (“Regulatory” refers to guidelines enforced by professional and governmental organizations)					
There are ECONOMIC obstacles that may not allow designers to practice DCWS. (“Economic" obstacles refers to costs, direct and/or indirect, and insurance costs)					
There are CONTRACTUAL obstacles that may not allow designers to practice DCWS. (“Contractual” refers to standard language used in contracts)					
There are LEGAL obstacles that may not allow designers to practice DCWS. (“Legal” refers to federal, state, and local statutes)					
There are ETHICAL obstacles that may not allow designers to practice DCWS. (“Ethical” refers to principles of conduct that are considered correct)					
There are CULTURAL obstacles that may not allow designers to practice DCWS. (“Cultural” refers to standards of construction industry practice)					

D2: Please identify some of the obstacles that your firm believes are present.

D3: Indicate your firm's agreement with the following statements regarding enablers for designers to practice DCWS.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
There are REGULATORY incentives that may enable designers to practice DCWS. (“Regulatory” refers to guidelines enforced by professional and governmental organizations)					
There are ECONOMIC incentives that may enable designers to practice DCWS. (“Economic" refers to monetary benefits, direct and/or indirect, and insurance benefits)					
There are CONTRACTUAL incentives that may enable designers to practice DCWS. (“Contractual” refers to standard language used in contracts)					
There are LEGAL incentives that may enable designers to practice DCWS. (“Legal” refers to federal, state, and local statutes)					
There are ETHICAL incentives that may enable designers to practice DCWS. (“Ethical” refers to principles of conduct that are considered correct)					
There are CULTURAL incentives that may enable designers to practice DCWS. (“Cultural” refers to standards of construction industry practice)					

D4: Please identify some of the enablers that your firm believes are in place.

D5: Please indicate any additional comments you might have regarding implementation of DCWS.

Further Contact

E1: Would you be willing to be contacted to clarify some of your responses, if the need arises? (Yes/No)

E2: Please enter your contact information. (Full name, email, address, phone number)

E3: Thank you for completing the survey.

If you have any further comments please contact one of the following:

· John Gambatese, Civil and Construction Engineering, Oregon State University, 220 Owen Hall, Corvallis, OR 97331, Tel.: (541) 737-8913, john.gambatese@oregonstate.edu

· Nicholas Tymvios, Civil and Construction Engineering, Oregon State University, 220 Owen Hall Corvallis, OR 97331, Tel.: (541) 908-6473, tymviosn@onid.orst.edu

Appendix B – Designer Survey

Designer Views on the Design for Construction Worker Safety (DCWS) Concept

(Introduction and explanation of the survey identical to contractor survey)

Basic Introductory Questions

A2: Please state the name of your firm.

A3: Please state your title within your firm.

A8: How many years of experience do you have in design?

A9: How many years of experience do you have in construction?

A7: In the past 5 years what types of project delivery methods has your firm participated in?

- Design-Bid-Build (Traditional Contracting Method)
- Design-Build
- Construction Management/General Contractor or Construction Management at Risk
- Design-Build-Operate-Maintain
- Design-Build-Operate-Transfer
- Multiple Prime Contracting
- Self-Performed (Owner acting as general contractor)
- Other:

A4: Indicate the types of buildings your organization constructs (multiple answers can apply)

- Educational Buildings (Excluding dormitories)
- Residential, Multifamily Residential (Including Dormitories)
- Commercial Buildings
- Industrial (Manufacturing Plants, Assembly Plants, Power Plants etc.)
- Retail
- Transportation Buildings (Airport Terminals, Bus Depots, Rail Stations, etc)
- Civic (Governmental, religious, etc)
- Athletic Facilities
- Other

A10: Indicate the types of building systems your firm is involved in designing:

- Architectural (Drawings and Documents)

- Foundations, Geotechnical
- Structural Framing
- Building Enclosure, Thermal Moisture Protection, Wall Systems, Openings, Finishes
- Conveying Systems and Components
- Electrical Systems and Components
- Mechanical Systems and Components
- Site Utilities, Excavations, Paving, Grading and Site Work
- Other:

Knowledge of Design for Construction Worker Safety Concept

B1: Were you previously aware of the "Design for Construction Worker Safety" concept? (Yes/No)

B2: Is your firm currently actively practicing some form of DCWS? (Yes/No)

B2a: What motivated your firm to start participating in DCWS?

B2b: Please describe your firm's effort in practicing DCWS.

B3: Does your firm currently have guidelines for reviewing design for construction workers safety? (Yes/No)

B3a: Briefly describe the guidelines that your firm has for reviewing designs for construction worker safety?

B4: Has your firm ever been asked to address issues relating to construction worker safety?

B4a: Briefly describe the types of instances and what was performed by your firm.

Opinions

C1: Please indicate your firm's level of agreement with the statements provided regarding designers (architects/engineers).

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
Designers in my firm know how construction site operations and procedures take place					
Designers in my firm have a clear understanding of what constitutes a hazard to construction workers					
Designers in my firm have adequate capacity and opportunities to be educated in construction worker safety					
Designers should be involved and participate in construction worker safety through design decisions					
The nature of construction contracting does not allow designers to participate in construction worker safety					

C2: Please indicate your firm's level of agreement with the statements provided.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
Owners know how construction site operations and procedures take place					
Owners have adequate capacity and opportunities to be educated in construction worker safety					
Owners have a clear understanding of what constitutes a hazard to construction workers					
Owners should be involved and participate in construction worker safety					
The nature of construction contracting does not allow owners to participate in construction worker safety					

C3: Please indicate your firm's level of agreement with the statements provided.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
The construction industry is a hazardous industry					
Only construction contractors are currently involved in reducing hazards to construction workers					
All construction site hazards to construction workers are taken care of by construction contractors					
Decisions made before the design of a project begins can help eliminate some construction worker hazards					
Decisions made during the design of a project can help eliminate some construction worker hazards					
Decisions made during the construction of a project can help eliminate some construction worker hazards					

C4: Please indicate your firm's level of agreement with the following statements.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
My firm would be supportive of proposed legislation for designers to start practicing DCWS					
My firm would be supportive of the DCWS concept if designers were legally protected from liability in practicing DCWS					

Obstacles and Enablers

D1: Indicate your firm's agreement with the following statements regarding obstacles for designers to practice DCWS.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
There are REGULATORY obstacles that may not allow designers to practice DCWS. ("Regulatory" refers to guidelines enforced by professional and governmental organizations)					
There are ECONOMIC obstacles that may not allow designers to practice DCWS. ("Economic" obstacles refers to costs, direct and/or indirect, and insurance costs)					
There are CONTRACTUAL obstacles that may not allow designers to practice DCWS. ("Contractual" refers to standard language used in contracts)					
There are LEGAL obstacles that may not allow designers to practice DCWS. ("Legal" refers to federal, state, and local statutes)					
There are ETHICAL obstacles that may not allow designers to practice DCWS. ("Ethical" refers to principles of conduct that are considered correct)					
There are CULTURAL obstacles that may not allow designers to practice DCWS. ("Cultural" refers to standards of construction industry practice)					

D2: Please identify some of the obstacles that your firm believes are present.

D3: Indicate your firm's agreement with the following statements regarding enablers for designers to practice DCWS.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
There are REGULATORY incentives that may enable designers to practice DCWS. (“Regulatory” refers to guidelines enforced by professional and governmental organizations)					
There are ECONOMIC incentives that may enable designers to practice DCWS. (“Economic" refers to monetary benefits, direct and/or indirect, and insurance benefits)					
There are CONTRACTUAL incentives that may enable designers to practice DCWS. (“Contractual” refers to standard language used in contracts)					
There are LEGAL incentives that may enable designers to practice DCWS. (“Legal” refers to federal, state, and local statutes)					
There are ETHICAL incentives that may enable designers to practice DCWS. (“Ethical” refers to principles of conduct that are considered correct)					
There are CULTURAL incentives that may enable designers to practice DCWS. (“Cultural” refers to standards of construction industry practice)					

D4: Please identify some of the enablers that your firm believes are in place.

D5: Please indicate any additional comments you might have regarding implementation of DCWS.

Further Contact

E1: Would you be willing to be contacted to clarify some of your responses, if the need arises? (Yes/No)

E2: Please enter your contact information. (Full name, email, address, phone number)

E3: Thank you for completing the survey.

If you have any further comments please contact one of the following:

·	John Gambatese, Civil and Construction Engineering, Oregon State University, 220 Owen Hall, Corvallis, OR 97331, Tel.: (541) 737-8913, john.gambatese@oregonstate.edu

·	Nicholas Tymvios, Civil and Construction Engineering, Oregon State University, 220 Owen Hall Corvallis, OR 97331, Tel.: (541) 908-6473, tymviosn@onid.orst.edu

Appendix C – Owner Organization Survey

Owner Organization Views on the Design for Construction Worker Safety (DCWS) Concept

(Introduction and explanation of the survey identical to contractor survey)

Basic Introductory Questions

A2: Please state the name of your organization.

A3: Please state your title within your organization.

A4: Indicate the types of buildings your organization constructs (multiple answers can apply).

- Educational Buildings (Excluding dormitories)
- Residential, Multifamily Residential (Including Dormitories)
- Commercial Buildings
- Industrial (Manufacturing Plants, Assembly Plants, Power Plants etc.)
- Retail
- Transportation Buildings (Airport Terminals, Bus Depots, Rail Stations, etc)
- Civic (Governmental, religious, etc)
- Athletic Facilities

A5: Please rank the criteria with which your organization bases Construction Contractor selection.

Please number each box in order of preference from 1 to 7

- ☐ Satisfaction with work from past project experience
- ☐ Prequalification Requirements
- ☐ Project Bid Price
- ☐ Long-term contracting agreements
- ☐ Contractor safety record
- ☐ Technical ability of the contractor
- ☐ Trust in Contractor's Personnel

A6: Please rank the criteria with which your organization bases Designer selection.

Please number each box in order of preference from 1 to 7

- ☐ Satisfaction with work from past project experience
- ☐ Prequalification Requirements
- ☐ Design Fees
- ☐ Long-term contracting agreements
- ☐ Designer's active involvement in Construction worker safety
- ☐ Technical ability of the contractor
- ☐ Trust in Contractor's Personnel

A7: In the past 5 years what types of project delivery methods has your organization used for building construction?

- Design-Bid-Build (Traditional Contracting method)
- Design-Build
- Construction Management/General Contractor or Construction Management at Risk
- Design-Build-Operate-Maintain
- Design-Build-Operate-Transfer
- Multiple Prime Contracting (Owner employed several general contractors in one project)
- Self-Performed (Owner acting as general contractor)

Knowledge of Design for Construction Worker Safety Concept

B1: Were you previously aware of the "Design for Construction Worker Safety" concept? (Yes/No)

B2: Does your organization actively participate in any aspect in construction worker safety?

B2a: What motivated your organization to start participating in construction worker safety?

B2b: How does your organization participate in construction worker safety?

B2c: Please, give a reason why your organization is not participating in construction worker safety?

B3: Does your organization currently have guidelines for reviewing designs for construction worker safety?

B3a: Briefly describe the guidelines that your organization has for reviewing designs for construction worker safety?

Opinions

C1: Please indicate your firm's level of agreement with the statements provided regarding designers (architects/engineers).

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
Designers know how construction site operations and procedures take place					
Designers have a clear understanding of what constitutes a hazard to construction workers					
Designers have adequate capacity and opportunities to be educated in construction worker safety					
Designers should be involved and participate in construction worker safety through design decisions					
The nature of construction contracting does not allow designers to participate in construction worker safety					

C2: Please indicate your organization's level of agreement with the statements provided.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
My organization knows how construction site operations and procedures take place					
Members in my organization have adequate capacity and opportunities to be educated in construction worker safety					
Members of my organization have a clear understanding of what constitutes a hazard to construction workers					
My organization should be involved and participate in construction worker safety					
The nature of construction contracting does not allow my organization to participate in construction worker safety					

C3: Please indicate your organization's level of agreement with the statements provided.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
The construction industry is a hazardous industry					
Only construction contractors are currently involved in reducing hazards to construction workers					
All construction site hazards to construction workers are taken care of by construction contractors					
Decisions made before the design of a project begins can help eliminate some construction worker hazards					
Decisions made during the design of a project can help eliminate some construction worker hazards					
Decisions made during the construction of a project can help eliminate some construction worker hazards					

C4: Please indicate your organization's level of agreement with the following statements.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
My organization would be supportive of proposed legislation for designers to start practicing DCWS					
My organization would be supportive of the DCWS concept if designers were legally protected from liability in practicing DCWS					

Obstacles and Enablers

D1: Indicate your organization's agreement with the following statements regarding obstacles for designers to practice DCWS.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
There are REGULATORY obstacles that may not allow designers to practice DCWS. (“Regulatory” refers to guidelines enforced by professional and governmental organizations)					
There are ECONOMIC obstacles that may not allow designers to practice DCWS. (“Economic" obstacles refers to costs, direct and/or indirect, and insurance costs)					
There are CONTRACTUAL obstacles that may not allow designers to practice DCWS. (“Contractual” refers to standard language used in contracts)					
There are LEGAL obstacles that may not allow designers to practice DCWS. (“Legal” refers to federal, state, and local statutes)					
There are ETHICAL obstacles that may not allow designers to practice DCWS. (“Ethical” refers to principles of conduct that are considered correct)					
There are CULTURAL obstacles that may not allow designers to practice DCWS. (“Cultural” refers to standards of construction industry practice)					

D2: Please identify some of the obstacles that your organization believes are present.

D3: Indicate your organization's agreement with the following statements regarding enablers for designers to practice DCWS.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
There are REGULATORY incentives that may enable designers to practice DCWS. (“Regulatory” refers to guidelines enforced by professional and governmental organizations)					
There are ECONOMIC incentives that may enable designers to practice DCWS. (“Economic" refers to monetary benefits, direct and/or indirect, and insurance benefits)					
There are CONTRACTUAL incentives that may enable designers to practice DCWS. (“Contractual” refers to standard language used in contracts)					
There are LEGAL incentives that may enable designers to practice DCWS. (“Legal” refers to federal, state, and local statutes)					
There are ETHICAL incentives that may enable designers to practice DCWS. (“Ethical” refers to principles of conduct that are considered correct)					
There are CULTURAL incentives that may enable designers to practice DCWS. (“Cultural” refers to standards of construction industry practice)					

D4: Please identify some of the enablers that your organization believes are in place.

D5: Please indicate any additional comments you might have regarding implementation of DCWS.

Further Contact

E1: Would you be willing to be contacted to clarify some of your responses, if the need arises? (Yes/No)

E2: Please enter your contact information. (Full name, email, address, phone number)

E3: Thank you for completing the survey.

If you have any further comments please contact one of the following:

- John Gambatese, Civil and Construction Engineering, Oregon State University, 220 Owen Hall, Corvallis, OR 97331, Tel.: (541) 737-8913, john.gambatese@oregonstate.edu

- Nicholas Tymvios, Civil and Construction Engineering, Oregon State University, 220 Owen Hall Corvallis, OR 97331, Tel.: (541) 908-6473, tymviosn@onid.orst.edu

Appendix D – Summary of Survey Results

Basic Introductory Questions

Question A4: Types of Buildings Designed/Constructed

Types of Buildings	Engineers		Architects		Owners		Contractors	
Educational Buildings	103	42.2%	121	54.8%	121	100%	150	83.8%
Res., Multifamily, dorm.	72	29.5%	156	70.6%	111	91.7%	88	49.2%
Commercial	119	48.8%	178	80.5%	22	18.2%	167	93.3%
Industrial	103	42.2%	88	39.8%	13	10.7%	133	74.3%
Retail	69	28.3%	121	54.8%	26	21.5%	131	73.2%
Transp. Buildings	83	34.0%	34	15.4%	4	3.3%	81	45.3%
Civic	108	44.3%	129	58.4%	11	9.1%	138	77.1%
Athletic Facilities	78	32.0%	68	30.8%	110	90.9%	123	68.7%

Question A5: Ranking criteria for selecting construction contractor by owners

	1st	2nd	3rd	4th	5th	6th	7th	Mean Rank
Sat. with work from past project experience	28	28	31	17	2	3	1	2.5455
Prequalification requirements	25	26	22	11	9	10	5	3.0278
Project Bid Price	50	20	13	9	13	13	2	2.6833
Long-term contracting agreements	0	3	2	6	9	12	64	6.2604
Contractor safety record	0	2	9	19	34	28	11	5.0680
Technical Ability of Contractor	13	26	23	27	10	8	1	3.2130
Trust in Contractor personnel	5	10	11	17	28	24	9	4.5481

Question A6: Ranking criteria for selecting designers by owners

	1st	2nd	3rd	4th	5th	6th	7th	Mean Rank
Sat. with work from past project experience	42	39	18	13	2	0	0	2.0702
Prequalification requirements	48	18	22	13	10	3	0	2.3684
Design Fees	2	11	18	16	31	16	9	4.4272
Long-term contracting agreements	3	4	8	4	12	28	41	5.6600
Designer's active involv. in construction safety	0	0	2	10	17	32	33	5.8936
Technical Ability of Contractor	19	28	26	21	9	7	1	2.9820
Trust in Contractor personnel	5	15	18	30	20	9	8	3.9905

Question A7: Types of Project Delivery Methods used

Project Delivery Methods Used	Engineers		Architects		Owners		Contractors	
DBB	224	91.8%	196	88.7%	103	85.1%	154	86.0%
DB	182	74.6%	147	66.5%	58	47.9%	139	77.7%
CM/GC or CM@Risk	114	46.7%	111	50.2%	85	70.2%	154	86.0%
DBOM	29	11.9%	11	5.0%	17	14.0%	22	12.3%
DBOT	15	6.1%	3	1.4%	5	4.1%	7	3.9%
Multiple Prime	38	15.6%	37	16.7%	33	27.3%	58	32.4%
Self-Performed	35	14.3%	65	29.4%	52	43.0%	47	26.3%

Question A10: Types of Building Systems firm designs

	Engineers		Architects	
Architectural (drawings & documents)	76	31.1%	216	97.7%
Foundations Geotechnical	137	56.1%	75	33.9%
Structural Framing	134	54.9%	90	40.7%
Building Enc., T/M prot., wall systems, openings, finishes	67	27.5%	157	71.0%
Conveying systems/components	39	16.0%	79	35.7%
Electrical systems/components	80	32.8%	63	28.5%
mechanical systems/components	89	36.5%	59	26.7%
Site utilities, excavations, paving, grading, site work	153	62.7%	91	41.2%

Knowledge of the Design for Construction Worker Safety Concept

Question B1: Previous Knowledge of DCWS

	Engineers		Architects		Owners		Contractors	
Yes	50	20.5%	12	5.4%	26	21.5%	29	16.2%
No	179	73.4%	191	86.4%	85	70.2%	135	75.4%
NA	15	6.1%	18	8.1%	10	8.3%	15	8.4%
	244	100%	221	100%	121	100%	179	100%

Question B2: Firm/Organization practicing some form of DCWS

	Engineers		Architects		Owners		Contractors	
Yes	47	19.3%	9	4.1%	91	75.2%		0.0%
No	134	54.9%	169	76.5%	22	18.2%		0.0%
NA	63	25.8%	43	19.5%	8	6.6%		0.0%
	244	100%	221	100%	121	100%	0	0%

Question B3: Firm/Organizations has guidelines for reviewing design for construction worker safety

	Engineers		Architects		Owners		Contractors	
Yes	24	9.8%	7	3.2%	19	15.7%		0.0%
No	178	73.0%	185	83.7%	82	67.8%		0.0%
NA	42	17.2%	29	13.1%	20	16.5%		0.0%
	244	100%	221	100%	121	100%	0	0%

Question B4: Design firm asked to address issues related to construction worker safety

	Engineers		Architects		Owners		Contractors	
Yes	76	31.1%	23	10.4%		0.0%		0.0%
No	132	54.1%	177	80.1%		0.0%		0.0%
NA	36	14.8%	21	9.5%		0.0%		0.0%
	244	100%	221	100%	0	0%	0	0%

Question B5: Firm participating in constructability meetings where construction worker safety issues are discussed

	Engineers		Architects		Owners		Contractors	
Yes		0.0%		0.0%		0.0%	84	46.9%
No		0.0%		0.0%		0.0%	84	46.9%
NA		0.0%		0.0%		0.0%	11	6.1%
	0	0%	0	0%	0	0%	179	100%

Opinions

Question C1a: Designers know how construction operations and procedures take place

	SA	A	N	D	SD	NA	Sum
Engineers	36	135	36	15	3	19	244
	14.8%	55.3%	14.8%	6.1%	1.2%		
Architects	38	111	31	20	5	16	221
	17.2%	50.2%	14.0%	9.0%	2.3%		
Owners	6	46	36	22	2	9	121
	5.0%	38.0%	29.8%	18.2%	1.7%		
Contractors	1	34	53	66	19	6	179
	0.6%	19.0%	29.6%	36.9%	10.6%		

Question C1b: Designers have clear understanding of what constitutes a hazard to construction workers

	SA	A	N	D	SD	NA	Sum
Engineers	20	96	65	39	5	19	244
	8.2%	39.3%	26.6%	16.0%	2.0%		
Architects	17	78	64	30	14	18	221
	7.7%	35.3%	29.0%	13.6%	6.3%		
Owners	7	34	39	27	5	9	121
	5.8%	28.1%	32.2%	22.3%	4.1%		
Contractors	2	19	43	83	26	6	179
	1.1%	10.6%	24.0%	46.4%	14.5%		

Question C1c: Designers have adequate capacity and opportunities to be educated in construction worker safety

	SA	A	N	D	SD	NA	Sum
Engineers	20	85	59	48	12	20	244
	8.2%	34.8%	24.2%	19.7%	4.9%		
Architects	16	42	66	54	20	23	221
	7.2%	19.0%	29.9%	24.4%	9.0%		
Owners	6	46	36	17	6	10	121
	5.0%	38.0%	29.8%	14.0%	5.0%		
Contractors	20	58	35	38	16	12	179
	11.2%	32.4%	19.6%	21.2%	8.9%		

Question C1d: Designers should be involved and participate in construction worker safety through design decisions

	SA	A	N	D	SD	NA	Sum
Engineers	31	100	49	24	19	21	244
	12.7%	41.0%	20.1%	9.8%	7.8%		
Architects	15	42	69	40	38	17	221
	6.8%	19.0%	31.2%	18.1%	17.2%		
Owners	13	42	36	16	3	11	121
	10.7%	34.7%	29.8%	13.2%	2.5%		
Contractors	46	97	18	7	3	8	179
	25.7%	54.2%	10.1%	3.9%	1.7%		

Question C1e: The nature of construction contracting does not allow designers to participate in construction worker safety

	SA	A	N	D	SD	NA	Sum
Engineers	28	73	52	55	17	19	244
	11.5%	29.9%	21.3%	22.5%	7.0%		
Architects	49	82	42	23	5	20	221
	22.2%	37.1%	19.0%	10.4%	2.3%		
Owners	7	33	30	30	11	10	121
	5.8%	27.3%	24.8%	24.8%	9.1%		
Contractors	6	19	56	64	27	7	179
	3.4%	10.6%	31.3%	35.8%	15.1%		

Question C2a: Owners know how construction site operations and procedures take place

		SA	A	N	D	SD	NA	Sum
Engineers		4	39	57	88	29	27	244
		1.6%	16.0%	23.4%	36.1%	11.9%		
Architects		6	14	43	91	49	18	221
		2.7%	6.3%	19.5%	41.2%	22.2%		
Owners		30	67	12	1	0	11	121
		24.8%	55.4%	9.9%	0.8%	0.0%		
Contractors		6	19	56	64	27	7	179
		3.4%	10.6%	31.3%	35.8%	15.1%		

Question C2b: Owners have adequate capacity and opportunities to be educated in construction worker safety

	SA	A	N	D	SD	NA	Sum
Engineers	5	61	60	68	23	27	244
	2.0%	25.0%	24.6%	27.9%	9.4%		
Architects	6	26	53	73	40	23	221
	2.7%	11.8%	24.0%	33.0%	18.1%		
Owners	24	65	14	4	1	13	121
	19.8%	53.7%	11.6%	3.3%	0.8%		
Contractors	9	69	29	39	23	10	179
	5.0%	38.5%	16.2%	21.8%	12.8%		

Question C2c: Owners have clear understanding of what constitutes a hazard to construction workers

	SA	A	N	D	SD	NA	Sum
Engineers	4	30	57	92	34	27	244
	1.6%	12.3%	23.4%	37.7%	13.9%		
Architects	3	7	40	100	51	20	221
	1.4%	3.2%	18.1%	45.2%	23.1%		
Owners	14	75	13	8	0	11	121
	11.6%	62.0%	10.7%	6.6%	0.0%		
Contractors	5	20	45	74	27	8	179
	2.8%	11.2%	25.1%	41.3%	15.1%		

Question C2d: Owners should be involved and participate in construction worker safety

	SA	A	N	D	SD	NA	Sum
Engineers	31	98	44	29	13	29	244
	12.7%	40.2%	18.0%	11.9%	5.3%		
Architects	13	47	54	42	47	18	221
	5.9%	21.3%	24.4%	19.0%	21.3%		
Owners	23	49	22	9	5	13	121
	19.0%	40.5%	18.2%	7.4%	4.1%		
Contractors	39	78	29	18	7	8	179
	21.8%	43.6%	16.2%	10.1%	3.9%		

Question C2e: The nature of construction contracting does not allow owners to participate in construction worker safety

	SA	A	N	D	SD	NA	Sum
Engineers	19	52	47	77	17	32	244
	7.8%	21.3%	19.3%	31.6%	7.0%		
Architects	45	77	40	26	8	25	221
	20.4%	34.8%	18.1%	11.8%	3.6%		
Owners	4	17	25	36	24	15	121
	3.3%	14.0%	20.7%	29.8%	19.8%		
Contractors	9	37	38	59	28	8	179
	5.0%	20.7%	21.2%	33.0%	15.6%		

Question C3a: The construction industry is a hazardous industry

	SA	A	N	D	SD	NA	Sum
Engineers	74	111	22	14	0	23	244
	30.3%	45.5%	9.0%	5.7%	0.0%		
Architects	62	117	18	6	1	17	221
	28.1%	52.9%	8.1%	2.7%	0.5%		
Owners	37	56	10	5	0	13	121
	30.6%	46.3%	8.3%	4.1%	0.0%		
Contractors	81	76	8	8	0	6	179
	45.3%	42.5%	4.5%	4.5%	0.0%		

Question C3b: Only construction contractors are currently involved in reducing hazards to construction workers

		SA	A	N	D	SD	NA	Sum
Engineers		13	65	30	103	7	26	244
		5.3%	26.6%	12.3%	42.2%	2.9%		
Architects		22	83	29	53	12	22	221
		10.0%	37.6%	13.1%	24.0%	5.4%		
Owners			19	15	63	10	14	121
		0.0%	15.7%	12.4%	52.1%	8.3%		
Contractors		12	50	23	72	16	6	179
		6.7%	27.9%	12.8%	40.2%	8.9%		

Question C3c: All construction site hazards to construction workers are taken care of by construction contractors

		SA	A	N	D	SD	NA	Sum
Engineers		13	56	29	107	11	28	244
		5.3%	23.0%	11.9%	43.9%	4.5%		
Architects		22	81	32	56	9	21	221
		10.0%	36.7%	14.5%	25.3%	4.1%		
Owners		2	35	14	50	5	15	121
		1.7%	28.9%	11.6%	41.3%	4.1%		
Contractors		20	65	24	51	12	7	179
		11.2%	36.3%	13.4%	28.5%	6.7%		

Question C3d: Decisions made before the design of a project begins can help eliminate some construction hazards

		SA	A	N	D	SD	NA	Sum
Engineers		30	137	40	9	1	27	244
		12.3%	56.1%	16.4%	3.7%	0.4%		
Architects		11	94	66	15	15	20	221
		5.0%	42.5%	29.9%	6.8%	6.8%		
Owners		9	63	31	3	2	13	121
		7.4%	52.1%	25.6%	2.5%	1.7%		
Contractors		44	101	19	5	3	7	179
		24.6%	56.4%	10.6%	2.8%	1.7%		

Question C3e: Decisions made during the design of a project can help eliminate some construction worker hazards

	SA	A	N	D	SD	NA	Sum
Engineers	31	159	21	6	1	26	244
	12.7%	65.2%	8.6%	2.5%	0.4%		
Architects	10	106	57	15	14	19	221
	4.5%	48.0%	25.8%	6.8%	6.3%		
Owners	10	70	25	2	1	13	121
	8.3%	57.9%	20.7%	1.7%	0.8%		
Contractors	51	104	12	1	3	8	179
	28.5%	58.1%	6.7%	0.6%	1.7%		

Question C3f: Decisions made during the construction of a project can help eliminate some construction worker hazards.

	SA	A	N	D	SD	NA	Sum
Engineers	90	121	6	2	0	25	244
	36.9%	49.6%	2.5%	0.8%	0.0%		
Architects	81	105	13	2	1	19	221
	36.7%	47.5%	5.9%	0.9%	0.5%		
Owners	34	63	9	2	0	13	121
	28.1%	52.1%	7.4%	1.7%	0.0%		
Contractors	81	84	4	0	3	7	179
	45.3%	46.9%	2.2%	0.0%	1.7%		

Question C4a: My firm/organization would be supportive of proposed legislation for designers to start practicing DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	6	32	70	46	47	43	244
	2.5%	13.1%	28.7%	18.9%	19.3%		
Architects	2	21	63	41	71	23	221
	0.9%	9.5%	28.5%	18.6%	32.1%		
Owners	1	13	57	18	15	17	121
	0.8%	10.7%	47.1%	14.9%	12.4%		
Contractors	19	49	62	21	16	12	179
	10.6%	27.4%	34.6%	11.7%	8.9%		

Question C4b: My firm would be supportive of the DCWS concept if designers were legally protected from liability in practicing DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	25	105	56	9	7	42	244
	10.2%	43.0%	23.0%	3.7%	2.9%		
Architects	18	76	68	11	24	24	221
	8.1%	34.4%	30.8%	5.0%	10.9%		
Owners	4	22	55	13	5	22	121
	3.3%	18.2%	45.5%	10.7%	4.1%		
Contractors	10	47	66	25	15	16	179
	5.6%	26.3%	36.9%	14.0%	8.4%		

Question D1a: There are REGULATORY obstacles that may not allow designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	11	67	79	23	2	62	244
	4.5%	27.5%	32.4%	9.4%	0.8%		
Architects	28	75	57	16	2	43	221
	12.7%	33.9%	25.8%	7.2%	0.9%		
Owners	7	30	45	8	1	30	121
	5.8%	24.8%	37.2%	6.6%	0.8%		
Contractors	5	30	69	29	5	41	179
	2.8%	16.8%	38.5%	16.2%	2.8%		

Question D1b: There are ECONOMIC obstacles that may not allow designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	41	109	37	14	0	43	244
	16.8%	44.7%	15.2%	5.7%	0.0%		
Architects	49	87	41	11	0	33	221
	22.2%	39.4%	18.6%	5.0%	0.0%		
Owners	7	45	34	8	1	26	121
	5.8%	37.2%	28.1%	6.6%	0.8%		
Contractors	10	80	40	26	2	21	179
	5.6%	44.7%	22.3%	14.5%	1.1%		

Question D1c: There are CONTRACTUAL obstacles that may not allow designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	40	113	35	12	0	44	244
	16.4%	46.3%	14.3%	4.9%	0.0%		
Architects	56	92	27	12	0	34	221
	25.3%	41.6%	12.2%	5.4%	0.0%		
Owners	12	43	31	6	2	27	121
	9.9%	35.5%	25.6%	5.0%	1.7%		
Contractors	10	63	45	33	2	26	179
	5.6%	35.2%	25.1%	18.4%	1.1%		

Question D1d: There are LEGAL obstacles that may not allow designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	49	86	45	14	0	50	244
	20.1%	35.2%	18.4%	5.7%	0.0%		
Architects	67	70	34	11	1	38	221
	30.3%	31.7%	15.4%	5.0%	0.5%		
Owners	12	33	40	8	0	28	121
	9.9%	27.3%	33.1%	6.6%	0.0%		
Contractors	13	56	52	23	4	31	179
	7.3%	31.3%	29.1%	12.8%	2.2%		

Question D1e: There are ETHICAL obstacles that may not allow designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	2	22	77	77	20	46	244
	0.8%	9.0%	31.6%	31.6%	8.2%		
Architects	17	33	67	52	12	40	221
	7.7%	14.9%	30.3%	23.5%	5.4%		
Owners	3	6	46	32	8	26	121
	2.5%	5.0%	38.0%	26.4%	6.6%		
Contractors	3	14	35	69	31	27	179
	1.7%	7.8%	19.6%	38.5%	17.3%		

Question D1f: There are CULTURAL obstacles that may not allow designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	13	76	67	37	7	44	244
	5.3%	31.1%	27.5%	15.2%	2.9%		
Architects	22	64	54	28	9	44	221
	10.0%	29.0%	24.4%	12.7%	4.1%		
Owners	5	28	42	13	5	28	121
	4.1%	23.1%	34.7%	10.7%	4.1%		
Contractors	7	47	32	52	15	26	179
	3.9%	26.3%	17.9%	29.1%	8.4%		

Question D3a: There are REGULATORY incentives that may enable designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	3	25	78	62	9	67	244
	1.2%	10.2%	32.0%	25.4%	3.7%		
Architects	1	20	70	51	26	53	221
	0.5%	9.0%	31.7%	23.1%	11.8%		
Owners	2	11	50	16	3	39	121
	1.7%	9.1%	41.3%	13.2%	2.5%		
Contractors	2	17	75	31	5	49	179
	1.1%	9.5%	41.9%	17.3%	2.8%		

Question D3b: There are ECONOMIC incentives that may enable designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	7	36	67	58	15	61	244
	2.9%	14.8%	27.5%	23.8%	6.1%		
Architects	1	29	53	63	26	49	221
	0.5%	13.1%	24.0%	28.5%	11.8%		
Owners	1	12	42	25	3	38	121
	0.8%	9.9%	34.7%	20.7%	2.5%		
Contractors	5	32	57	37	5	43	179
	2.8%	17.9%	31.8%	20.7%	2.8%		

Question D3c: There are CONTRACTUAL incentives that may enable designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	5	39	63	59	16	62	244
	2.0%	16.0%	25.8%	24.2%	6.6%		
Architects	0	29	56	49	36	51	221
	0.0%	13.1%	25.3%	22.2%	16.3%		
Owners	1	13	47	19	2	39	121
	0.8%	10.7%	38.8%	15.7%	1.7%		
Contractors	5	38	51	34	8	43	179
	2.8%	21.2%	28.5%	19.0%	4.5%		

Question D3d: There are LEGAL incentives that may enable designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	5	36	62	47	26	68	244
	2.0%	14.8%	25.4%	19.3%	10.7%		
Architects	2	32	49	50	35	53	221
	0.9%	14.5%	22.2%	22.6%	15.8%		
Owners	1	13	46	19	3	39	121
	0.8%	10.7%	38.0%	15.7%	2.5%		
Contractors	6	31	57	32	10	43	179
	3.4%	17.3%	31.8%	17.9%	5.6%		

Question D3e: There are ETHICAL incentives that may enable designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	5	65	88	20	3	63	244
	2.0%	26.6%	36.1%	8.2%	1.2%		
Architects	4	57	74	24	12	50	221
	1.8%	25.8%	33.5%	10.9%	5.4%		
Owners	2	29	42	12	0	36	121
	1.7%	24.0%	34.7%	9.9%	0.0%		
Contractors	17	49	52	11	6	44	179
	9.5%	27.4%	29.1%	6.1%	3.4%		

Question D3f: There are CULTURAL incentives that may enable designers to practice DCWS

	SA	A	N	D	SD	NA	Sum
Engineers	1	33	93	45	6	66	244
	0.4%	13.5%	38.1%	18.4%	2.5%		
Architects	0	33	79	32	25	52	221
	0.0%	14.9%	35.7%	14.5%	11.3%		
Owners	0	13	47	19	2	40	121
	0.0%	10.7%	38.8%	15.7%	1.7%		
Contractors	7	29	71	24	5	43	179
	3.9%	16.2%	39.7%	13.4%	2.8%		

Appendix E – Delphi Survey – Round 1

Intro: Thank you once again for serving on the Delphi panel for this research. Your participation is greatly appreciated! The purpose of this introductory survey is to:

1) Objectively confirm your status as an expert in the field of construction safety or risk management based on your academic and professional experience and achievements. Please remember that both industry and academic experience are highly valuable.

2) Begin the 1st round of the Delphi process, by objectively choosing a course of action for the possible implementation of Design for Construction Worker Safety (DCWS) by the US construction industry.

Please answer all of the following questions to the best of your ability. This survey is intended to be completed in less than 30 minutes.

Please complete this survey by July 1st.

Personal Information

The following questions are intended to confirm your position as an expert. Once validated, the Delphi responses will be anonymous and all Delphi Panel members will be treated equally.

P1: Personal Information

Please enter your name:	
Please enter your current employer/organization:	
Please enter your current position:	
Please enter your city/state:	
Please enter your country:	

P2: Please indicate the degrees that you have earned from accredited institutions of higher learning (Major and area of concentration):

	Degree	Major / Field of concentration
☐	None	
☐	Associates	
☐	Bachelors	
☐	Masters	
☐	Doctorate	

P3: Please enter the extent of your professional experience in each of the following roles (approximate number of years):

	Position	Number of Years of experience
☐	Laborer	
☐	Foreman	
☐	Construction Work Site Superintendent	
☐	Safety and Health Management	
☐	Risk Management	
☐	Upper management (General Contractor, Construction Manager, or Subcontractor)	
☐	Design Engineer (EIT and PE)	
☐	Architect	
☐	Other (Please specify)	

P4: Please indicate your professional licensure/certification:

Check any that apply

	Licensure/Certification	Comments
☐	Professional Engineer (NSPE or other)	
☐	Structural Engineer (NCSEA or other)	
☐	Certified Safety Professional	
☐	Certified Industrial Hygienists	
☐	Associate Risk Manager	
☐	Licensed Architect (AIA)	
☐	Contractor Certifications (CPC or other)	
☐	Other (Please Specify)	

P5: Please list any safety, health or risk management committees of which you are or have been a member (ASCE Site safety committee, ASSE construction Safety), and indicate if you have been a chair in that committee

P6: If you believe that there is an element of your academic or professional experience that helps to qualify you as an expert that cannot be classified in a previous category, please list and briefly describe it.

Opinions

*** Very Important - Please Read***

The following questions refer to the possible adoption of the concept of Design for Construction Worker Safety (DCWS) by the construction industry in the US. The term DCWS can also be found in literature as Prevention through Design (PtD) and as Safety in Design (SiD).

To clarify the definition of DCWS, the following bullet items explain what it is and what it is not:

DCWS is:

- Explicitly considering the safety of construction workers in the design of a project.
- Being conscious of and valuing the safety of construction workers when performing design tasks.
- Making design decisions based in part on how the project's inherent risk to construction workers may be affected.
- Including worker safety considerations in the constructability review process

DCWS is not:

- Having designers take a role in construction safety DURING construction.
- An endorsement of future legislation mandating that designers design for construction

safety.

- An endorsement of the principle that designers can or should be held partially responsible for construction accidents.
- Implying that the vast majority of U.S. design professionals are currently equipped to design for construction safety.

O1: Should DCWS be implemented widely in the US construction industry? (Please explain your answer)

	Please choose one of the following:	**Please enter your comment here:**
☐	Yes, to the full extent	
☐	Yes, with some limitations	
☐	No, it is not a concept that should be implemented	
☐	No answer	

O2: How should DCWS be implemented in the US construction industry? (Please explain your answer)

	Please choose one of the following:	**Please enter your comment here:**
☐	DCWS should be implemented voluntarily by construction industry participants	
☐	DCWS should be implemented through certifications per project much like LEED	
☐	DCWS should be mandatory through legislation	
☐	DCWS should not be implemented	
☐	No answer	

O3: Where should people interested in DCWS concentrate their efforts to make DCWS acceptable to the construction industry?

	Licensure/Certification	**Comments**
☐	Business case: To increase acceptance and interest in DCWS there is a need for the development of a "Business case" model, where investment in DCWS generates a reasonable return in the form of profit, reduction in losses, and cost avoidance.	
☐	Education: To increase acceptance and interest in DCWS there is a need for increased education of practicing design professionals, owners, contractors, as well as university students enrolled in Design, Engineering, Architecture and Construction programs.	
☐	Legislation: The implementation of DCWS in the US should be achieved by the use of legislation at the Federal or State level.	
☐	Industry standards: The implementation of DCWS in the US should be achieved by the development of an industry standard much like quality standards such as ISO 9001 for quality management.	
☐	Other 1. (Please describe the effort)	
☐	Other 2. (Please describe the effort)	
☐	Other 3. (Please describe the effort)	

Influence

I1: Please rate the level of influence that each of the following groups has on generating interest in DCWS in the US construction industry?

I1b: Please explain your rating and reasoning for the influence of each group

Group	0 = The least Influence, 10 = The greater influence	Explain Answer
Contractors	0 1 2 3 4 5 6 7 8 9 10	
Owners	0 1 2 3 4 5 6 7 8 9 10	
Designers (Engineers)	0 1 2 3 4 5 6 7 8 9 10	
Designers (Architects)	0 1 2 3 4 5 6 7 8 9 10	
Politicians – Legislators	0 1 2 3 4 5 6 7 8 9 10	
Insurance Companies	0 1 2 3 4 5 6 7 8 9 10	
Trade Organizations	0 1 2 3 4 5 6 7 8 9 10	
Labor Organizations	0 1 2 3 4 5 6 7 8 9 10	
Educators	0 1 2 3 4 5 6 7 8 9 10	

O4: The Business Case

You selected the "Business Case" as a possible area to concentrate efforts.

The "Business Case" analysis is a type of cost analysis performed from a business's perspective. In this case the analysis would investigate the possible reasonable return after a business invests in DCWS. Reasonable returns can be: profit, reduction in losses, and cost avoidance.

Please indicate the extent to which each construction industry participant group should be targeted in order to generate interest in DCWS using the "Business Case"

Group	1 = should not be targeted 10 = should definitely be targeted	Explain Answer
Contractors	0 1 2 3 4 5 6 7 8 9 10	
Owners	0 1 2 3 4 5 6 7 8 9 10	
Designers (Engineers)	0 1 2 3 4 5 6 7 8 9 10	
Designers (Architects)	0 1 2 3 4 5 6 7 8 9 10	
Politicians – Legislators	0 1 2 3 4 5 6 7 8 9 10	
Insurance Companies	0 1 2 3 4 5 6 7 8 9 10	
Trade Organizations	0 1 2 3 4 5 6 7 8 9 10	
Labor Organizations	0 1 2 3 4 5 6 7 8 9 10	
Educators	0 1 2 3 4 5 6 7 8 9 10	

O5: You selected "Education" as a possible area to concentrate efforts.

To generate interest in DCWS, the various construction industry participant groups would need to be educated through various methods. This can be through continuing education credits, seminars, inclusion of DCWS into academic coursework, etc.

Please indicate the extent to which each construction industry participant group should be targeted in order to generate interest in DCWS using "Education"

Group	1 = should not be targeted 10 = should definitely be targeted	Explain Answer
Contractors	0 1 2 3 4 5 6 7 8 9 10	
Owners	0 1 2 3 4 5 6 7 8 9 10	
Designers (Engineers)	0 1 2 3 4 5 6 7 8 9 10	
Designers (Architects)	0 1 2 3 4 5 6 7 8 9 10	
Politicians – Legislators	0 1 2 3 4 5 6 7 8 9 10	
Insurance Companies	0 1 2 3 4 5 6 7 8 9 10	
Trade Organizations	0 1 2 3 4 5 6 7 8 9 10	
Labor Organizations	0 1 2 3 4 5 6 7 8 9 10	
Educators	0 1 2 3 4 5 6 7 8 9 10	

O6: You selected "Legislation" as a possible area to concentrate efforts.

DCWS may be enforced in the US using legislation at the Federal or State level, that promotes or requires its use.

Please indicate the extent to which each construction industry participant group should be targeted in order to promote the creation of DCWS legislation.

Group	1 = should not be targeted 10 = should definitely be targeted	Explain Answer
Contractors	● 0 ● 1 ● 2 ● 3 ● 4 ● 5 ● 6 ● 7 ● 8 ● 9 ● 10	
Owners	● 0 ● 1 ● 2 ● 3 ● 4 ● 5 ● 6 ● 7 ● 8 ● 9 ● 10	
Designers (Engineers)	● 0 ● 1 ● 2 ● 3 ● 4 ● 5 ● 6 ● 7 ● 8 ● 9 ● 10	
Designers (Architects)	● 0 ● 1 ● 2 ● 3 ● 4 ● 5 ● 6 ● 7 ● 8 ● 9 ● 10	
Politicians – Legislators	● 0 ● 1 ● 2 ● 3 ● 4 ● 5 ● 6 ● 7 ● 8 ● 9 ● 10	
Insurance Companies	● 0 ● 1 ● 2 ● 3 ● 4 ● 5 ● 6 ● 7 ● 8 ● 9 ● 10	
Trade Organizations	● 0 ● 1 ● 2 ● 3 ● 4 ● 5 ● 6 ● 7 ● 8 ● 9 ● 10	
Labor Organizations	● 0 ● 1 ● 2 ● 3 ● 4 ● 5 ● 6 ● 7 ● 8 ● 9 ● 10	
Educators	● 0 ● 1 ● 2 ● 3 ● 4 ● 5 ● 6 ● 7 ● 8 ● 9 ● 10	

O7: You selected "Industry Standards" as a possible area to concentrate efforts.

Much like the ISO 9001 standard for quality, an industry standard for the implementation of DCWS in the US construction industry can be created to ensure and promote DCWS.

Please indicate the extent to which each construction industry participant group should be targeted in order to generate interest in DCWS using "Industry Standards".

Group	1 = should not be targeted 10 = should definitely be targeted	Explain Answer
Contractors	0 1 2 3 4 5 6 7 8 9 10	
Owners	0 1 2 3 4 5 6 7 8 9 10	
Designers (Engineers)	0 1 2 3 4 5 6 7 8 9 10	
Designers (Architects)	0 1 2 3 4 5 6 7 8 9 10	
Politicians – Legislators	0 1 2 3 4 5 6 7 8 9 10	
Insurance Companies	0 1 2 3 4 5 6 7 8 9 10	
Trade Organizations	0 1 2 3 4 5 6 7 8 9 10	
Labor Organizations	0 1 2 3 4 5 6 7 8 9 10	
Educators	0 1 2 3 4 5 6 7 8 9 10	

O8a, 09a, 10a: You chose a method that was not listed (Other 1 or Other2 or Other 3). Please describe the effort the best way you can.

O8, 09, 10: For the effort you chose (Other 1 or Other 2 or Other3), which construction industry participant group should be targeted in order to generate interest in DCWS?

Group	1 = should not be targeted 10 = should definitely be targeted	Explain Answer
Contractors	0 1 2 3 4 5 6 7 8 9 10	
Owners	0 1 2 3 4 5 6 7 8 9 10	
Designers (Engineers)	0 1 2 3 4 5 6 7 8 9 10	
Designers (Architects)	0 1 2 3 4 5 6 7 8 9 10	
Politicians – Legislators	0 1 2 3 4 5 6 7 8 9 10	
Insurance Companies	0 1 2 3 4 5 6 7 8 9 10	
Trade Organizations	0 1 2 3 4 5 6 7 8 9 10	
Labor Organizations	0 1 2 3 4 5 6 7 8 9 10	
Educators	0 1 2 3 4 5 6 7 8 9 10	

Addtitional Comments

Additional 1: If you have any additional comments regarding DCWS or the survey questions, please provide them below:

E3: Thank you for taking the time to fill out the questions for the first round of the Delphi process. The second round of Delphi process will begin in August. If you have any questions about this survey or about the research project in general, please do not hesitate to contact me or my advisor John Gambatese at:

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Appendix F – Delphi Survey – Round 2

DCWS Implementation Framework

Delphi Survey – Round 2

Thank you for completing the first round of the Delphi survey. You have been qualified as an expert based upon the strict guidelines suggested in literature and several restrictions set for this study.

This Round 2 survey is intended to be completed in approximately 30-35 minutes. When you have finished answering all of the questions, please email your response, in Word format, to tymviosn@onid.orst.edu .

After all Delphi participants have completed the Round 2 survey, the results will be reported to you in the form of simple statistics (e.g. median response and range). You will then be given the opportunity to change your response.

INSTRUCTIONS

Please answer all of the following questions to the best of your ability. Fields that require a response have been highlighted in yellow. Please indicate your response by placing an 'X' in the appropriate boxes.

Question 1:

Where should people interested in design for construction worker safety (DCWS) concentrate their efforts to make DCWS acceptable to the construction industry? (Please explain your answer)

Your responses to the above question in Round 1 were: a, b, and d.

If you would like to change your answer, mark with an 'X' the appropriate fields, otherwise your answer from Round 1 will be considered.

Possible responses	% of Round 1 responses	**Your Round 2 Response (Please mark with "X")**
a. Business case: To increase acceptance and interest in DCWS there is a need for the development of a "Business case" model, where investment in DCWS generates a reasonable return in the form of profit, reduction in losses, and cost avoidance.		
b. Education: To increase acceptance and interest in DCWS there is a need for increased education of practicing design professionals, owners, contractors, as well as university students enrolled in Design, Engineering, Architecture and Construction programs.		
c. Legislation: The implementation of DCWS in the US should be achieved by the use of legislation at the Federal or State level.		
d. Industry standards: The implementation of DCWS in the US should be achieved by the development of an industry standard much like quality standards such as ISO 9001 for quality management.		

Instructions – Question 2:

For each influence rating you will see two values: your response from the Round 1 survey (indicated with a highlighted box), and the group median from the Round 1 survey indicated with a capital 'M'. Please take one of the following three actions for each group:

1. **Accept the group median response by leaving the field completely unchanged.**
2. **Maintain your original response by placing an 'X' in the highlighted field*.**
3. **Indicate a new response by placing an 'X' in the appropriate field*.**

*** If your response is more than two units above or below the group median, please provide a reason for your outlying response in the field provided.**

Question 2

Please rate the level of influence that each of the following groups has on generating interest in DCWS in the US construction industry?

	Level of influence for DCWS: 1 = The least influence, 10 = The most influence									
Group	1	2	3	4	5	6	7	8	9	10
Contractors								M		
Owners										M
Designers (Engineers)								M		
Designers (Architects)							M			
Politicians - Legislators			M							
Insurance Companies								M		
Trade Organizations							M			
Labor Organizations						M				
Educators						M				
Reason(s) for outlying response(s):										

Instructions – Questions 3-5:

For each target efforts rating you will see two values: your response from the Round 1 survey (indicated with a highlighted box), and the group median from the Round 1 survey indicated with a capital M. In groups where there are two "M" values per row, the median was in the middle of the two values. For example, if both 7 and 8 are marked with "M", the median value was 7.5. Please take one of the following three actions for each group:

1. **Accept the group median response by leaving the field completely unchanged.**
2. **Maintain your original response by placing an 'X' in the highlighted field*.**
3. **Indicate a new response by placing an 'X' in the appropriate field*.**

*** If your response is more than two units above or below the group median, please provide a reason for your outlying response in the field provided.**

Question 3:

Business Case:

You selected the "Business Case" as a possible area to concentrate efforts.

The "Business Case" analysis is a type of cost analysis performed from a business's perspective. In this case the analysis would investigate the possible reasonable return after a business invests in DCWS. Reasonable returns can be: profit, reduction in losses, and cost avoidance.

Please indicate the extent to which each construction industry participant group should be targeted in order to generate interest in DCWS using the "Business Case".

	Target efforts for Business Case: 1 = should not be targeted, 10 = should definitely be targeted									
Group	1	2	3	4	5	6	7	8	9	10
Contractors										M
Owners										M
Designers (Engineers)							M			
Designers (Architects)								M		
Politicians - Legislators		M								
Insurance Companies								M		
Trade Organizations							M			
Labor Organizations						M				
Educators						M				
Reason(s) for outlying response(s):										

Question 4:

Education:

You selected "Education" as a possible area to concentrate efforts.

To generate interest in DCWS, the various construction industry participant groups would need to be educated through various methods. This can be through continuing education credits, seminars, inclusion of DCWS into academic coursework, etc.

Please indicate the extent to which each construction industry participant group should be targeted in order to generate interest in DCWS using "Education".

	Target efforts for Education: 1 = should not be targeted, 10 = should definitely be targeted									
Group	1	2	3	4	5	6	7	8	9	10
Contractors										M
Owners										M
Designers (Engineers)									M	
Designers (Architects)									M	
Politicians - Legislators	M	M								
Insurance Companies								M	M	
Trade Organizations								M		
Labor Organizations							M			
Educators									M	M
Reason(s) for outlying response(s):										

Question 5:

Industry Standards:

You selected "Industry Standards" as a possible area to concentrate efforts.

Much like the ISO 9001 standard for quality, an industry standard for the implementation of DCWS in the US construction industry can be created to ensure and promote DCWS.

Please indicate the extent to which each construction industry participant group should be targeted in order to generate interest in DCWS using "Industry Standards".

	Target efforts for Industry Standards: 1 = should not be targeted, 10 = should definitely be targeted									
Group	1	2	3	4	5	6	7	8	9	10
Contractors									M	M
Owners										M
Designers (Engineers)									M	
Designers (Architects)									M	
Politicians - Legislators			M							
Insurance Companies									M	
Trade Organizations								M	M	
Labor Organizations								M		
Educators								M		
Reason(s) for outlying response(s):										

Instructions - Question 6:

Out of the four methods for generating interest for DCWS you did not select "LEGISLATION**". If you would like to change** your answer and include Legislation as a method for generating interest, please fill out the table below and provide comments about the involvement of each group in generating that interest for DCWS through legislation.

Legislation:

DCWS may be enforced in the US using legislation at the Federal or State level that promotes or requires its use.
Please indicate the extent to which each construction industry participant group should be targeted in order to promote the creation of DCWS legislation.

	Target efforts for Legislation: 1 = should not be targeted, 10 = should definitely be targeted									
Group	1	2	3	4	5	6	7	8	9	10
Contractors										
Owners										
Designers (Engineers)										
Designers (Architects)										
Politicians - Legislators										
Insurance Companies										
Trade Organizations										
Labor Organizations										
Educators										

Group	Comments on rating value
Contractors	
Owners	
Designers (Engineers)	
Designers (Architects)	
Politicians - Legislators	
Insurance Companies	
Trade Organizations	
Labor Organizations	
Educators	

Instruction - Question 7:
Business Case Costs and Benefits:

The majority of the participants in this Delphi Panel stated that the preferred method for concentrating efforts on DCWS should be the "Business Case".

In the tables below, please list costs and benefit items for practicing DCWS for each of the four biggest stakeholders in the US construction industry: Owners, Designers (Architects), Designers (Engineers) and Contractors. (Include as many items as you can. Do not limit your answers to six if you feel more should be included)

Costs and benefits can be monetary as well as intangible.

Monetary costs are additional costs to the construction industry stakeholder for practicing DCWS, such as increased insurance fees, design fees, construction costs, etc.

Monetary benefits are benefits to the construction industry stakeholder for practicing DCWS, such as decreased construction costs, savings due to innovations, etc.

Non-monetary costs/benefits are items that do not have a monetary value but can have an effect to the operations of the construction industry stakeholder who practices DCWS. Such costs/benefits could be increased market share, decreased competitiveness, etc.

Please complete the following tables from the point of view of designers (Engineers)

Designers (Engineers)

Monetary Costs	Monetary Benefits
For example: Increased design costs 1. 2. 3. 4. 5. 6.	For example: Reduced design services during construction 1. 2. 3. 4. 5. 6.
Comments on Monetary Costs for **Engineers**:	Comments on Monetary Benefits for **Engineers:**

Designers (Engineers)

Non-Monetary Costs	**Non-Monetary Benefits**
For example: Reduced competitiveness 1. 2. 3. 4. 5. 6.	For example: Reputation improvement 1. 2. 3. 4. 5. 6.
Comments on Non-Monetary Costs for **Engineers**:	Comments on Non-Monetary Benefits for **Engineers**:

Please complete the following tables from the point of view of designers (Architects)

Designers (Architects)

Monetary Costs	Monetary Benefits
For example: Increased design costs 1. 2. 3. 4. 5. 6.	For example: Reduced design services during construction 1. 2. 3. 4. 5. 6.
Comments on Monetary Costs for **Architects**:	Comments on Monetary Benefits for **Architects:**

Designers (Architects)

Non-Monetary Costs	Non-Monetary Benefits
For example: Reduced competitiveness 1. 2. 3. 4. 5. 6.	For example: Reputation improvement 1. 2. 3. 4. 5. 6.
Comments on Non-Monetary Costs for **Architects**:	Comments on Non-Monetary Benefits for **Architects**:

Please complete the following tables from the point of view of construction contractors

Contractors

Monetary Costs	Monetary Benefits
For example: Increased construction costs 1. 2. 3. 4. 5. 6.	For example: Construction costs savings 1. 2. 3. 4. 5. 6.
Comments on Monetary Costs for **Contractors**:	Comments on Monetary Benefits for **Contractors:**

Contractors

Non-Monetary Costs	Non-Monetary Benefits
For example: Reduced competitiveness 1. 2. 3. 4. 5. 6.	For example: Reputation improvement 1. 2. 3. 4. 5. 6.
Comments on Non-Monetary Costs for **Contractors**:	Comments on Non-Monetary Benefits for **Contractors**:

Please complete the following tables from the point of view of construction facility owners

Owners

Monetary Costs	Monetary Benefits
For example: Increased construction costs 1. 2. 3. 4. 5. 6.	For example: Construction costs savings 1. 2. 3. 4. 5. 6.
Comments on Monetary Costs for **Owners**:	Comments on Monetary Benefits for **Owners**:

Owners

Non-Monetary Costs	Non-Monetary Benefits
For example: Reduced competitiveness 1. 2. 3. 4. 5. 6.	For example: Reputation improvement 1. 2. 3. 4. 5. 6.
Comments on Non-Monetary Costs for **Owners**:	Comments on Non-Monetary Benefits for **Owners**:

Thank you for completing the survey. Please email the MS Word file to: tymviosn@onid.orst.edu

Appendix G – Delphi Survey – Round 3

Intro: Thank you once again for serving on the Delphi panel for this research. Your participation is greatly appreciated! The purpose of this survey is to:

1. Present the results of the 1st and 2nd rounds to the panel
2. Confirm the list of Costs and Benefits that were identified in Round 2
3. Identify if these Cost/Benefits are project specific or if the Costs/Benefits can be applied to future projects

Please answer all of the following questions to the best of your ability. This survey is intended to be completed in less than 30 minutes.

Please complete this survey by December 15.

Personal Information

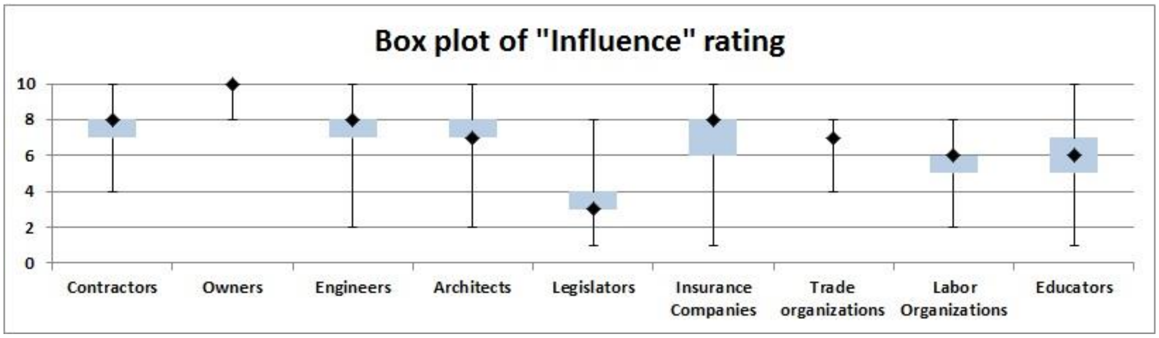
The following page will ask you for your name. This is the only piece of personal information that we will be asking you to provide.

P1: Please enter your name:

Results from Rounds 1 and 2

R1-Influence: In rounds 1 and 2 you were asked to give a rating for the INFLUENCE each group has on generating interest in DCWS is the US construction industry.

The following Box Plot depicts the results of that question from all Delphi panel members. The diamond markers represent the median response. The blue boxes represent the 25th and the 75th percentiles of the responses.

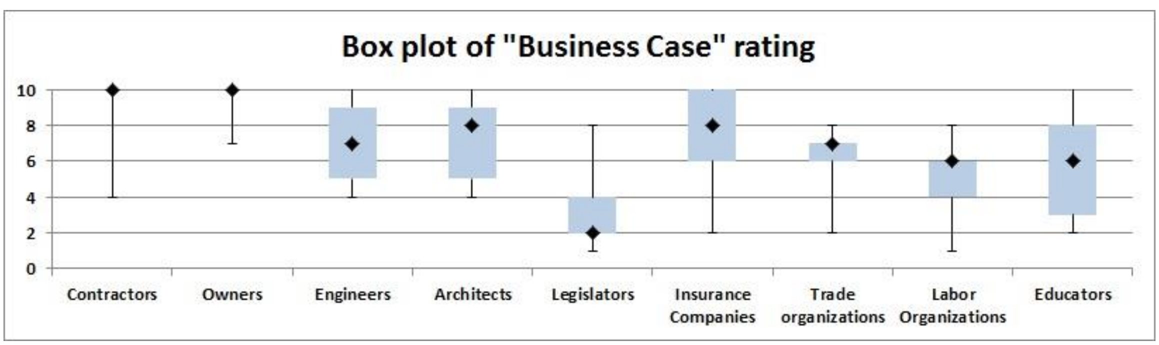


A table of the above data is shown below:

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	8	10	8	7	3	8	7	6	6
Min	4	8	2	2	1	1	4	2	1
Max	10	10	10	10	8	10	8	8	10

R2-Business Case: In rounds 1 and 2 you were asked to give a rating for the extent each construction industry participant group should be targeted in order to generate interest in DCWS using the BUSINESS CASE.

The following Box Plot depicts the results of that question for all Delphi panel members. The diamond markers represent the median response. The blue boxes represent the 25th and the 75th percentiles of the responses.

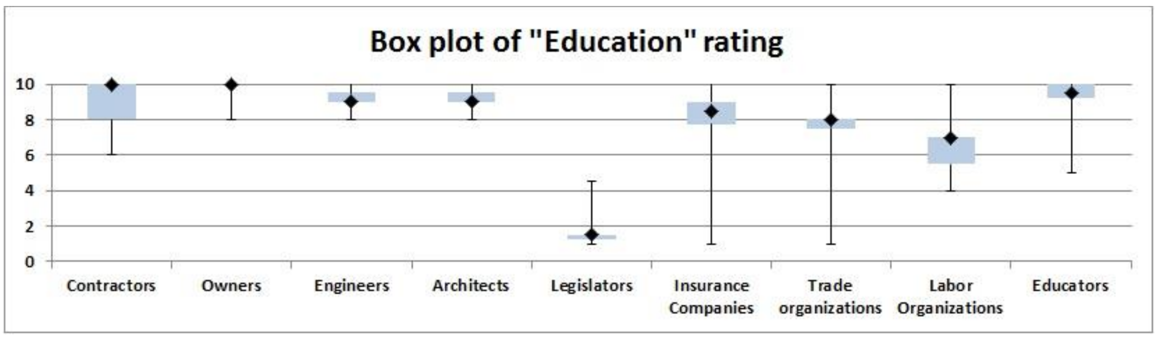


A table of the above data is shown below:

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	10	10	7	8	2	8	7	6	6
Min	4	7	4	4	1	2	2	1	2
Max	10	10	10	10	7	10	10	10	10

R3-Education: In rounds 1 and 2 you were asked to give a rating for the extent each construction industry participant group should be targeted in order to generate interest in DCWS using EDUCATION.

The following Box Plot depicts the results of that question for all Delphi panel members. The diamond markers represent the median response. The blue boxes represent the 25th and 75th percentiles of the responses.

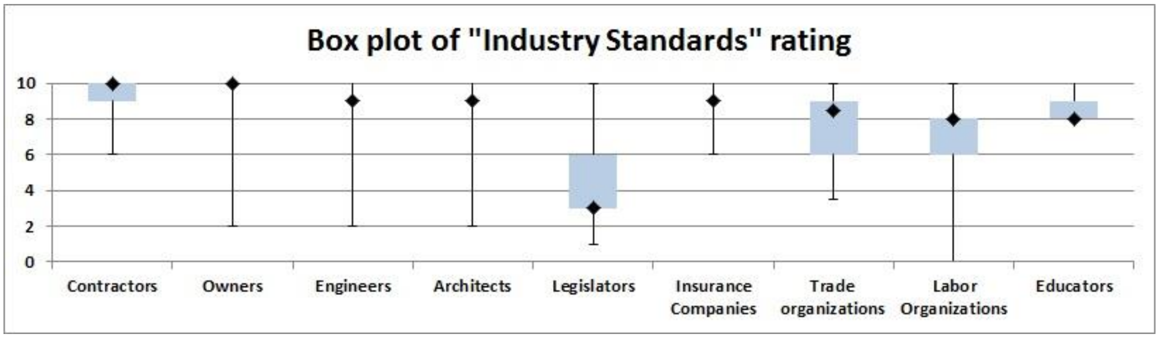


A table of the above data is shown below:

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	10	10	9	9	2	9	8	7	10
Min	6	8	8	8	1	1	1	4	5
Max	10	10	10	10	5	10	9	9	10

R4-Industry Standard: In rounds 1 and 2 you were asked to give a rating for the extent each construction industry participant group should be targeted in order to generate interest in DCWS using INDUSTRY STANDARDS.

The following Box Plot depicts the results of that question for all Delphi panel members. The diamond markers represent the median response. The blue boxes represent the 25th and 75th percentiles of the responses.



A table of the above data is shown below:

Group	Contractors	Owners	Engineers	Architects	Legislators	Ins. Comp.	Trade Org.	Labor Org.	Educators
Median	10	10	9	9	3	9	9	8	8
Min	7	2	2	2	1	6	6	2	8
Max	10	10	10	10	10	10	10	10	10

Costs and Benefits

The following sections include costs or benefits related to a possible implementation of DCWS. Please identify whether each item is a cost or benefit that could be applied to a single project, or could be allocated across several projects.

Costs and Benefits

CB Design: The following items include costs and benefits related to DESIGN. Please identify whether each item, cost or benefit, would be applied to a single project or allocated across several projects.

	Cost/Benefit applicable to only one project	Cost/Benefit allocated over several projects
Additional costs (excluding time) to design DCWS solutions.		
Cost of additional time to design DCWS solutions.		
Cost of coordination between Owner/Designers/Contractors.		
Cost of coordination among designers working in a particular firm		

CB Personnel: The following items include costs and benefits related to PERSONNEL. Please identify whether each item, cost or benefit, would be applied to a single project or allocated across several projects.

	Cost/Benefit applicable to only one project	Cost/Benefit allocated over several projects
Cost of hiring of additional employees to implement DCWS by DESIGNERS.		
Cost of hiring external personnel to facilitate implementation of DCWS by DESIGNERS.		
Cost of training of existing employees in office and on-site for DESIGNERS.		
Cost of hiring of additional employees to implement DCWS by OWNERS.		
Cost of hiring external personnel to facilitate implementation of DCWS by OWNERS.		
Cost of training of existing employees in office and on-site for OWNERS.		
Cost of hiring of additional employees to implement DCWS by CONTRACTORS.		
Cost of hiring external personnel to facilitate implementation of DCWS by CONTRACTORS.		
Cost of training of existing employees in office and on-site for CONTRACTORS.		
Possible reduction of cost from training and replacing injured workers.		
Increased morale for construction crews and plant workers.		
Retention of employees.		
Attraction of higher caliber employees		

CB Constr.: The following items include costs and benefits related to CONSTRUCTION. Please identify whether each item, cost or benefit, would be applied to a single project or allocated across several projects.

	Cost/Benefit applicable to only one project	Cost/Benefit allocated over several projects
Coordination costs for CONTRACTORS relating DCWS.		
Increase/Decrease of construction costs related to DCWS solutions.		
Cost of submitting and managing RFI by CONTRACTORS.		
Cost of responding to RFI by DESIGNERS and OWNERS.		
Possible reduction of RFI requests.		
Possible reduction of Change Orders.		
On-site presence requirements (meetings, supervision, etc.) by OWNERS.		
On-site presence requirements (meetings, supervision, etc.) by DESIGNERS.		
Cost/Benefit from possible increase/decrease of field labor by CONTRACTORS.		
Cost/Benefit from the reduction/increase of safety equipment needs.		
Possible reduction of missed work by CONSTRUCTION CREWS from injuries.		
Cost/Benefit from possible increase/decrease of construction schedule.		
Better/Worse understanding of designs by CONTRACTORS.		
Improved/Worsen Constructability.		

CB Management: The following items include costs and benefits related to MANAGEMENT. Please identify whether each item, cost or benefit, would be applied to a single project or allocated across several projects.

	Cost/Benefit applicable to only one project	Cost/Benefit allocated over several projects
Cost of managing a DCWS plan.		
Cost of setting up a quality assurance program.		
Cost of additional quality assurance requirements.		
Labor and cost for tracking metrics to assemble case histories for DCWS solutions.		
Cost of time and energy spent in chganging the momentum of the current owner/designer/contractor relationship model to one that would be more open to DCWS.		
Possibility for increased conflict among project participants.		
Increase/Decrease in understanding of construction site operations and processes.		

CB Post Construction: The following items include costs and benefits related to POST CONSTRUCTION. Please identify whether each item, cost or benefit, would be applied to a single project or allocated across several projects.

	Cost/Benefit applicable to only one project	Cost/Benefit allocated over several projects
Possible reduced/increased maintenance/operation costs.		
Possible increase/decrease life cycle of capital assets.		
Potential for a better/worse quality project.		
Possible increase/decrease in sustainability of final capital assets.		

CB Market: The following items include costs and benefits related to MARKETABILITY. Please identify whether each item, cost or benefit, would be applied to a single project or allocated across several projects.

	Cost/Benefit applicable to only one project	Cost/Benefit allocated over several projects
Possible reduction/increase in Marketability (for Designers).		
Possible reduction/increase in Marketability (for Contractors).		
Potential for repeat business (for Designers).		
Potential for repeat business (for Contractors).		
Potential for attraction of more mature contractors and workers.		
Market specialization advantage.		
Reputation improvement/Improved image to the public.		
Potential for decrease/increase in competitiveness (for Designers).		
Potential for decrease/increase in competitiveness (for Contractors).		
Ethical and Moral Benefits/Costs.		
Opportunities for innovation in construction methods and design solutions.		

CD Contracts: The following items include costs and benefits related to CONSTRUCTION DOCUMENTS. Please identify whether each item, cost or benefit, would be applied to a single project or allocated across several projects.

	Cost/Benefit applicable to only one project	Cost/Benefit allocated over several projects
Improved quality of construction documents.		
Cost of making modifications to contract/construction documents.		
Increased/Decreased complexity in the process of bidding/awarding/managing contracts.		
Harder/Easier to assign responsibility to project issues.		
Increase/Decrease in need to rework contracts with subcontractors.		

CB INS: The following items include costs and benefits related to INSURANCE and LITIGATION. Please identify whether each item, cost or benefit, would be applied to a single project or allocated across several projects.

	Cost/Benefit applicable to only one project	Cost/Benefit allocated over several projects
Cost of obtaining liability insurance (Error and Omissions) for designers.		
Possible reduction of insurance costs (Errors and Omissions) for designers.		
Possible reduction in OWNER furnished insurance costs.		
Potential for reduction in Worker's Compensation.		
Potential for reduction in EMR (Experience Modification Rate)		
Possible Increase/Decrease in liability for Designers.		
Possible Increase/Decrease in liability for Owners.		

Additional Comments

Additional 1: **Please list any items that you believe should be included in a Business Case Model for DCWS, and were not mentioned in the previous questions.**

Additional 2: If you have any additional comments regarding DCWS or the survey questions, please provide them below:

E3: Thank you for taking the time to fill out the questions for the third round of the Delphi process. If you have any questions about this survey or about the research project in general, please do not hesitate to contact me or my advisor John Gambatese at:

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Appendix H – Identified Costs and Benefits

Engineer Costs & Benefits

Monetary Costs

H. Costs to design
    a. Cost associated with the design (Excluding time and training)
    b. Cost of time to incorporate DCWS in the design
    c. Additional internal meetings required to discuss DCWS issues with design
I. Cost associated with hiring new employees that would be used to implement DCWS
    a. Hiring of an external specialist
J. Cost for coordinating with all other parties (Owner, Architect, Contractor, Subcontractors)
    a. Coordination costs (These should be differentiated from costs that are normally associated with the coordination of the project These costs should not be all contributed to DCWS)
    b. Additional on-site requirements for meetings only associated with DCWS
K. Cost associated with training
    a. Cost to train employees for DCWS in the office
        i. Time
        ii. Other costs excluding time
    b. Cost to train office employees on-site
        i. Time
        ii. Other Costs excluding time
L. Cost associated with implementing the DCWS plan.
    a. Management of DCWS plan
    b. Cost of additional Quality Assurance
    c. Setting up a continuous improvement system for DCWS
M. Cost associated with changes in contract documents
    a. Contract change costs/construction documents
N. Costs associated with insurance/litigation/risk
    a. Possible litigation costs
    b. Costs to liability insurance (E&O)

Monetary Benefits

D. Benefits associated with insurance
    a. Possible decreases in insurance costs (E&O)
E. Benefits from reduced post design involvement
    b. Reduced RFI requests
    c. Reduced Change Orders
F. Reduced potential for litigation

Non-monetary Costs

B. Increased Liability

Non-monetary Benefits

J. Market Specialization advantage(Niche Market)
K. Marketing advantage
L. Market differentiation
M. Reputation improvement
N. Improved relationships with industry participants (owners, contractors)
O. Ethical/Moral benefits
P. Potential for repeat business
Q. Gained knowledge from understanding how things are build and construction safety knowledge
R. Improved Quality of construction documents

Architect Costs & Benefits

Monetary Costs

A. <u>Costs to design</u>
    c. Cost associated with the design (Excluding time and training)
    d. Cost of time to incorporate DCWS in the design
    e. Additional internal meetings required to discuss DCWS issues with design
B. Cost associated with <u>hiring new employees</u> that would be used to implement DCWS
    a. Hiring of an external specialist
C. Cost for <u>coordinating with all other parties</u> (Owner, Architect, Contractor, Subcontractors)
    a. Coordination costs (These should be differentiated from costs that are normally associated with the coordination of the project These costs should not be all contributed to DCWS)
    b. Additional on-site requirements for meetings only associated with DCWS
D. Cost associated with <u>training</u>
    a. Cost to train employees for DCWS <u>in the office</u>
        i. Time
        ii. Other costs excluding time
    b. Cost to train office employees <u>on-site</u>
        i. Time
        ii. Other Costs excluding time
E. Cost associated with <u>implementing the DCWS plan</u>.
    a. Management of DCWS plan
    b. Cost of additional Quality Assurance
    c. Setting up a continuous improvement system for DCWS
F. Cost associated with <u>changes in contract documents</u>
    a. Contract change costs/construction documents

G. Costs associated with insurance/litigation/risk
    a. Possible litigation costs
    b. Costs to liability insurance (E&O)

Monetary Benefits

A. Benefits associated with insurance
    d. Possible decreases in insurance costs (E&O)
B. Benefits from reduced post design involvement
    a. Reduced RFI requests
    b. Reduced Change Orders
C. Reduced Potential for litigation

Non-monetary Costs

B. Increased Liability

Non-monetary Costs

A. Market Specialization advantage(Niche Market)
B. Marketing advantage
C. Market differentiation
D. Reputation improvement
E. Improved relationships with industry participants (owners, contractors)
F. Ethical/Moral benefits
G. Potential for repeat business
H. Gained knowledge from understanding how things are build and construction safety knowledge
I. Improved Quality of construction documents

Owner Costs & Benefits

Monetary Costs

A. Project Costs
    a. Labor & Cost tracking metrics to assemble case history
    b. Increased design cost (designer fee)
B. Cost associated with hiring new employees that would be used to implement DCWS
    a. Hiring of an external specialist (increased staff for owner)
C. Training Costs

   a. Training costs for Owner employees

D. Time Requirements
   a. Time required for meetings & coordination
   b. Time required for site visits and reviews
   c. Increased design time
   d. Effects of construction time
E. Construction
   a. Increased construction costs
   b. Capital Costs increases
F. RFI – Change Order
   a. Potential for increased amount of RFI requests

Monetary Benefits

A. Insurance Costs
   a. Owners furnished insurance cost reduced
   b. Potential for reduced workers compensation
B. Construction Costs
   a. Potential for reduced construction costs
   b. Reduced maintenance/operation costs
C. Construction Schedule
   a. Potential for reduced schedule for construction
D. Organization
   a. Savings for better organized worksite
E. Project Life Cycle
   a. Increased life cycle of capital assets
F. Quality
   a. Potential for a better quality project
G. RFI- Change orders
   a. Potential for reduced amount of RFI
H. Litigations
   a. Potential for fewer litigations

Non-monetary Costs

A. Personal time and energy spent changing the momentum of the current owner / designer / contractor relationship model to one that would be more open to DCWS
B. Reduced competitiveness
   a. Less contractors bidding for jobs
   b. Marketability reduced
C. Liability discrepancies

   a. Might inherit some liability via designers? Who owns the drawings and the design
   b. Blurs line between design and build, may be harder to assign responsibility for project issues

D. Increased complexity of contracts
   a. The process of bidding/awarding/managing contracts will grow in complexity

Non-monetary Benefits

A. Safety
   a. Savings from improved safety
   b. Improved productivity from healthy workers
   c. Reduced number of workers on sites
B. Efficiency
   a. Improved overall efficiency
   b. Reduced construction schedule
   c. Easy of facility operations with safety in mind
C. Image – Competitiveness
   a. Improved image to the general public
D. Sustainability
   a. Improved sustainability of final capital asset
E. Workforce
   a. Recruitment of a higher quality workforce
   b. Better staff retention
   c. Attraction of more mature contractors & workers
F. Increased morale for construction crews and plant workers
G. Relationships
   a. Improved relationships with contractors and designers

Contractor Costs & Benefits

Monetary Costs

A. Construction costs
   a. Potential for increased construction costs (equipment & materials)
B. Design costs (in cases of Design-Build)
   a. Potential for increased design costs
C. Cost of hiring new employees
   a. Requirement of staff specialized in DCWS
D. Cost of increased initial involvement
   a. Meeting time costs to discuss DCWS during design
   b. Increased coordination with owner and designer

    c. Cost of reviewing initial designs
E. Possibility for increased project schedule
F. Possibility for increased change orders
G. Increased cost for coordination
H. Increased liability risk
I. Education & Training
    a. Education of employees
    b. Internal QA department education to perform audits of DCWS
    c. Employee awareness
J. Possible impact on schedule

Monetary Benefits

A. Insurance
    a. Decreased insurance costs
    b. Savings in Workers compensations
    c. Reduced EMR
B. Schedule
    a. Potential for a decreased schedule
    b. Improved constructability
C. Productivity
    a. Potential for increased productivity
    b. Improvements due to better planning
D. Labor
    a. Reduction of field labor
    b. Skilled personnel making economically wise decisions
    c. Reduced cost for training and replacing workers
E. Benefits from reduced post design involvement
    a. Reduced RFI requests
    b. Reduced Change Orders
F. Savings in maintenance costs
G. Safety
    a. Safety equipment savings
    b. Reduced missed work from injuries
    c. Lower injury rate

Non-monetary costs

A. Reduced competitiveness
B. Possibility for increased conflict between project participants
C. There is a need to rework scope and contract issues with subcontractors

Non-monetary benefits

A. Improved relationships
    a. Potential for repeat business
    b. Possibility for a niche market
    c. Marketing opportunities
    d. Increase competitive advantage
    e. Improved reputation
    f. Ethical/Moral benefits
    g. Increased morale
    h. Better relationships with owner/designers
    i. Better understand designs through improved communication
B. Labor
    a. Retention of employees
    b. Attract high-caliber new hires

Appendix I – Benefit Cost Model

Instructions

The instructions for the spreadsheet users are shown here:

DCWS Benefit/Cost analysis for Owners

Instructions:

This Benefit/Costs analysis tool allows construction facility owners to make a decision for the implantation of a DCWs solution in their proposed projects.

The owners can compare a DCWS option against traditional construction and design solutions. In that case, the second option "OPTION B" should be labeled as a traditional solution. The owners can also compare two different DCWS solutions by changing the second option to "DCWS solution B"

The decision spreadsheet allows owners to consider costs/benefits through a decision score card. Items considered in the scorecard include cost of design and construction, as well as issues regarding personnel, owner time commitments, various project issues, safety, litigation/insurance, post construction and marketability.

The owners are asked to input values in cells marked in GREEN only. In the Design & Construction costs cells, the owners are asked to enter the values of the cost estimates for the two solutions. In the other categories, the owners are asked to rate each line item according to its impact and importance for each particular solution. The impact score is on a scale of -3 to 3. If the line item is not affected by the option, the owners are asked to leave the impact value as neutral "0".

The "Importance Factor" asks users to rate how significant is the group of line items in terms of making a decision for each particular option. The importance factor is on a 1-5 scale, where a value of 1 has the least amount of importance and a value of 5 has the highest value of importance.

Results:

After the user enters the values, an option score is calculated. The owner should choose the option with the highest score.

Line Item Definitions

Personnel

Need for Owner Personnel Training

If an option requires training investment then the impact is below zero. If the option requires less training than the baseline model, then the impact value is greater than zero.

Need of hiring additional personnel

If an option requires the hiring of additional personnel then the impact is below zero. If the option requires fewer personnel than the baseline model, then the impact value is greater than zero.

Quality of recruited workforce

If an option attract a better quality workforce, then the impact score is greater than zero. If the workforce attracted is of lower quality, then the impact value is lower than zero

Staff retention

If the option encourages staff retention during the time of the project, then the impact value is greater than zero. If the option does not encourage staff retention, then the impact value is lower than zero

Owner Time Commitments

Owner Commitments for meetings and coordination

If the owners time commitments are increased then the value is below zero. If the commitments are reduced, then the value is greater than zero

Owner commitments for site visit

If the owner commitments for site visits are increased, then the value id below zero. If the commitments are reduced, then the value is greater.

Owner time for drawing and specs reviews

If the owner commitments for reviews are increased, then the value is below zero, otherwise greater than zero

Construction/Design Time

Design time

If the design time is increased, then the impact value is lower than zero, otherwise it is greater than zero

Construction time

If the construction time is increased, then the impact value is lower than zero. Otherwise it is greater than zero.

Project Issues

Number of RFI requests

If the RFI requests are expected to be more, then the impact value is below zero. If the RFI requests are expected to be fewer, then the impact value is greater than zero

Complexity of bidding contract

If the complexity of bidding a contract is increased, then the impact value is lower than zero. If the complexity is decreased, then the impact value is greater than zero

Complexity of awarding contract

If the complexity of awarding a contract is increased, then the impact value is lower than zero. If the complexity is decreased, then the impact value is greater than zero

Complexity of managing construction contract

If the complexity of managing the contract is increased, then the impact value is lower than zero. If the complexity is decreased, then the impact value is greater than zero

Maturity of contractors and workers

If the contractors and workers are expected to be more mature, then the impact value is greater than zero. Otherwise it is lower than zero

Worksite productivity

If the productivity of the workers is expected to be increased, then the value is greater than zero. Otherwise below zero

Relationships between Designers and Contractors

If the relationships between the contractors and designers are expected to be improved, then the impact value is greater than zero. Otherwise lower than zero.

Worksite organization

If the organization of the worksite is expected to be improved, then the impact value is greater than zero. Otherwise lower than zero.

Safety

Overall Construction Safety

If safety is improved due to the presence of the DCWS solution over the baseline, then the impact score should be greater than zero. Otherwise, lower than zero

Number of workers on site

If the number of workers needed onsite is increased, then the impact vale is lower than zero. Otherwise the value is greater than zero

Costs/Savings from safety concerns

If there are expected to be savings from eliminating safety concerns, then the impact value is greater than zero. Otherwise if safety concerns are increased, then the impact value is lower than zero.

Litigation/Insurance

Potential for litigation

If there is an increased potential for litigation, then the impact value is lower than zero. Otherwise the impact value is greater than zero

Potential for Workers' compensation

If there is an increased potential for workers' compensation, then the impact value is lower than zero. Otherwise the impact value is greater than zero

Owner furnished insurance costs

If there is a potential for increased rates for owner furnished insurance costs, then the impact value is lower than zero. Otherwise the impact value is greater than zero

Owner inherent liability via designers (Increase/Decrease)

If there is a potential for increased inherent liability from designers, then the impact value is *lower than zero. Otherwise the impact value is greater than zero*

Blurs of lines between "Design" and "Build"

If the option would blur the line between Design and Build, then the impact value is lower than zero. Otherwise the value is greater than zero

Post construction

Sustainability of final capital assets (Improved/Worsened)

If there is an increased sense of sustainability of the capital assets, then the impact value is greater than zero. Otherwise the value is lower than zero

Overall potential of project quality (Better/Worse)

If there is an increased potential for improvements in project quality, then the impact value is greater than zero. Otherwise the value is lower than zero

Life cycle of capital assets (Increase/Decrease)

If the life cycle of the capital assets improved, then the impact value is greater than zero. Otherwise the value is lower than zero

Maintenance/operation costs

If future maintenance costs are expected to be reduced, then the impact value is greater than zero. Otherwise the value is lower than zero.

Ease of facility operations with safety in mind

If facility operations are expected to be operated safely then the impact score is greater than zero, otherwise the score is lower than zero.

Marketability

Morale of construction Crews

If the morale of the construction crews is expected to be improved, then the impact score is greater than zero. Otherwise it is lower than zero.

Owner image to general public

If the owner's image to the general public is expected to be favorable, then the impact value is greater than zero. Otherwise the value is lower than zero.

Number of bidding contractors (Increase/Decrease)

If the number of bidding contractors is expected to be increased, then the impact value is greater than zero. Otherwise the impact value is lower than zero.